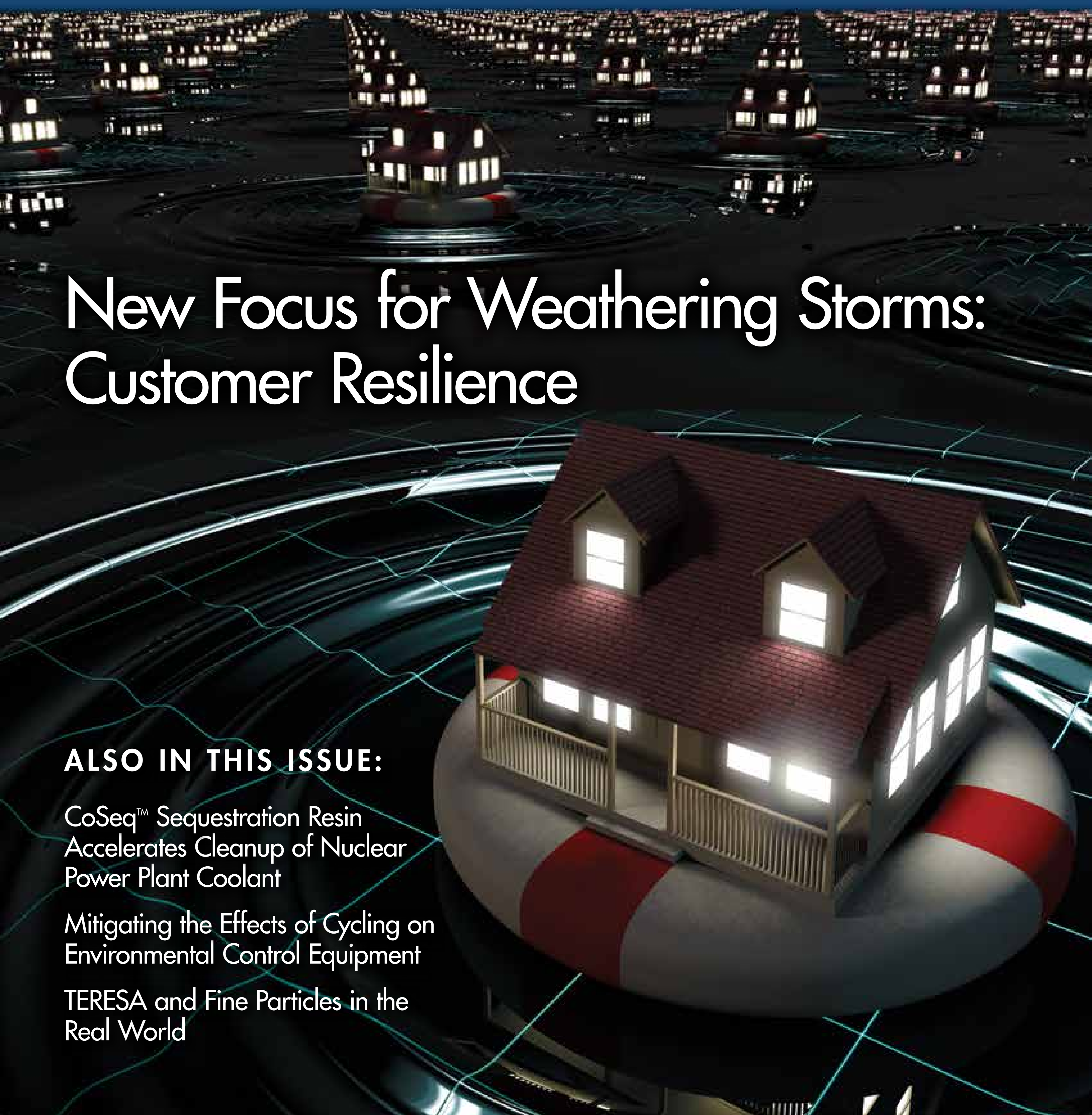
SPRING 2013

EPRI JOURNAL

ELECTRIC POWER RESEARCH INSTITUTE



New Focus for Weathering Storms: Customer Resilience

ELECTRIC POWER RESEARCH INSTITUTE

The Electric Power Research Institute, Inc. (EPRI, www.epri.com) conducts research and development relating to the generation, delivery and use of electricity for the benefit of the public. An independent, nonprofit organization, EPRI brings together its scientists and engineers as well as experts from academia and industry to help address challenges in electricity, including reliability, efficiency, affordability, health, safety and the environment. EPRI also provides technology, policy and economic analyses to drive long-range research and development planning, and supports research in emerging technologies. EPRI's members represent approximately 90 percent of the electricity generated and delivered in the United States, and international participation extends to more than 30 countries. EPRI's principal offices and laboratories are located in Palo Alto, Calif.; Charlotte, N.C.; Knoxville, Tenn.; and Lenox, Mass.

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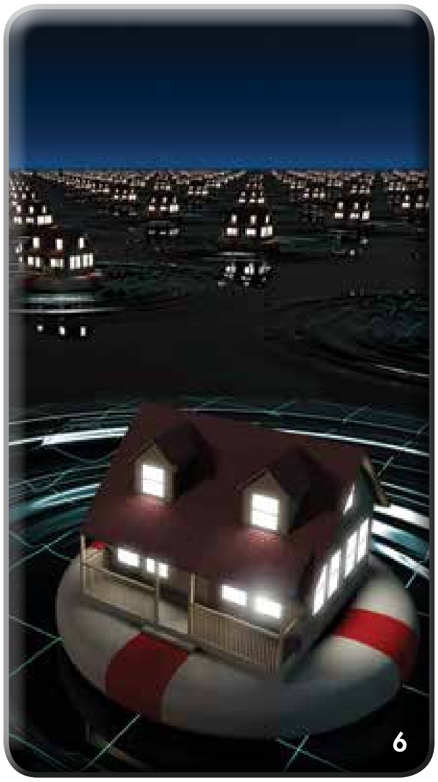
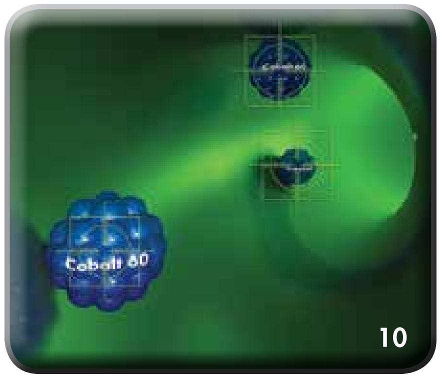
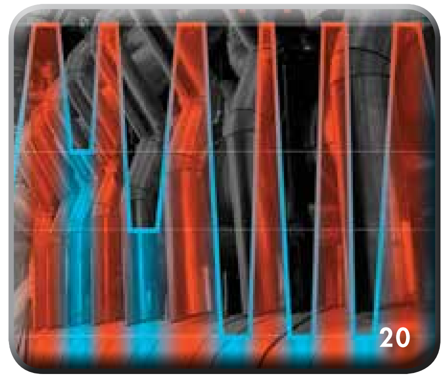






VIEWPOINT

FEATURES

DEPARTMENTS

VIEWPOINT

by Mike Howard, President and CEO, EPRI

Insights from Scenario Planning and the R&D Portfolio: Moving Toward a Flexible, Resilient, Connected Power System

Recently, EPRI used in-depth scenario planning to "stress test" its research and development (R&D) portfolio in order to see how it is aligning with and responding to major drivers and uncertainties in the electricity sector. We identified three key factors that will significantly influence the electricity sector: demand for electricity, price of natural gas, and environmental and energy policy. Insights from our scenario planning and Prism 2.0 analysis point to three important characteristics of the evolving power system—one that is more flexible, resilient, and connected.

Flexible

Utilities will rely increasingly on flexibility in power generation and delivery over an interconnected power system. The extent of this depends on how policy drives greater reliance on variable renewable generation; how the price of natural gas continues to favor gas-fired generation; and how economics drives changes in generation, energy storage, and distributed generation using photovoltaics, microturbines, and central heat and power facilities. As a result, utilities can expect to:

- Rely less on traditional approaches for operating base-load generation and rely more on cycling generation assets and operating them at lower outputs.
- Rely more on distributed supplies, energy storage, and demand response.
- Deploy a new infrastructure to integrate and provide for the two-way communication and two-way flow of electricity that will characterize this more flexible, dynamic system.

The expanded functionality will extend from the customers' premises to the distribution, transmission, and generating systems and to regional independent system operators. Utilities will be called on to manage many streams and points of data, but they in turn will be able to call on a full portfolio of supply, demand, and system operating resources.

Resilient

Given recent events ranging from Hurricane Sandy to Fukushima, we should not be surprised if public uncertainty and a sense of vulnerability grow regarding the power generation and delivery system. As we become more digitally dependent, we also become less tolerant of interruptions to life's necessities (which now include cell phone service in addition to electricity). Our sense of vulnerability is affected also by man-made outages and cyber security incursions.

EPRI is focusing its R&D in several areas:

Hardening the system can prevent or reduce damage through design standards, construction, maintenance and inspection, and recovery practices. Areas of focus include vegetation management, select undergrounding of T&D facilities, redesigning or reinforcing overhead lines and poles, hydrophobic coatings, cyber security measures, and dynamic circuit operation. Materials in fossil steam plants must be designed to withstand the greater stresses of cycling, and nuclear plants are looking to fuel designs that are more resistant to melting and provide operators more time to take action during an accident.

Recovery requires prompt damage assessment and repair and effective restoration management tools. R&D efforts in T&D include airborne damage assessment; outage management systems; geographical information systems embedded in asset management systems; field force visualization tools; and recovery transformers. In nuclear plants, investigations are focusing on the strategic placement of safety-related support equipment to improve accident management.

Survivability entails using plug-in electric vehicles as a power source; enabling photovoltaic systems to operate as a standby source; and enabling urgent service to cell phones, traffic lights, hospitals, and prisons. Read more about survivability in this issue's cover story.

Connected

Relying on both wired and wireless connectivity, each U.S. residence now has, on average, five networked devices. The average person views a mobile device 150 times per day. Today's house is not just a home, it is a "home area network," providing tablet users a seamless experience and content stored in the Cloud.

But this also brings opportunities to utilities, including:

- Aggregating demand response services and value-added services in building security and energy;
- Utility-retail partnerships offering consumers appliance monitoring and energy-efficiency programs; and
- Sensors that can gather and deliver data from throughout the power system to enhance life-cycle management.

At EPRI, we see an opportunity for multi-faceted R&D that encompasses such diverse areas as sensors, data analytics, control systems, visualization technology, and behavioral sciences. Utilities will rely on better connections with each customer and with individual components in their power plants and delivery systems. As those connections grow to become powerful, integrated networks, we can imagine a system that is radically different from today's. To transform to this integrated system, we need to ensure the "interoperability" of communication technology across the electricity enterprise, seamlessly linking its own systems and those of its diverse customers and suppliers.

As researchers, we are entering a fascinating period of rapid change and progress in the development and operation of power systems. Even as we continue to apply in-depth scenario planning, we know that not all electricity providers will be affected in the same way. But through broad-based collaboration among the electricity sector and its stakeholders, we can continue to identify and execute priority R&D initiatives that will create a power system that is more flexible, resilient, and connected.

Michael W. Howard
President and Chief Executive Officer

SHAPING THE FUTURE

Innovative approaches to upcoming challenges

Adapting M-Cycle Technology for Power Plant Cooling

Evaporative cooling, used by the majority of U.S. thermal electric power plants, is most efficient in very dry climates, with a large difference between dry-bulb temperature and wet-bulb temperature (which reflects the effect of humidity). In humid regions, where dry- and wet-bulb temperatures are closer, the air is less likely to accept more moisture, making evaporative cooling less efficient. EPRI is collaborating with the Gas Technology Institute (GTI) and its partners to develop a new evaporative cooling system for power plants called the Advanced Dew Point Cooling Tower, which promises to substantially increase cooling efficiency.

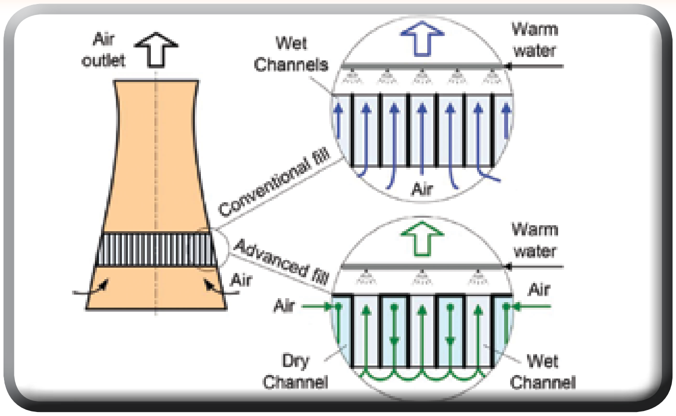
This approach is based on M-Cycle™ technology, a patented evaporative cooling method that allows cooling water to be brought below the ambient wet-bulb temperature—the current limit for conventional systems. This can enable a lower steam-condensation temperature, reducing backpressure to the final, low-pressure turbine and resulting in higher power production with substantially lower water and energy consumption.

Wet and Dry Channels

In conventional cooling towers, hot water from the turbines is sprayed through an array of open evaporation channels, and ambient air is introduced below, traveling up through the channels to accept heat from the water and carry it out through the top of the cooling tower as the water vapor is released. The channels contain a fill medium, such as thin sheets of PVC, to increase the surface area and time of contact between the water and air, improving heat transfer.

The M-Cycle design adds dry channels, sealed at the top, between the wet channels, and the ambient air is introduced at the tops of these dry channels rather than from below the array. The air travels down the length of the dry channels before entering and moving up through the wet channels. The dry channels allow the incoming ambient air to be precooled to about the dew point before passing into the adjacent wet channels, where more heat is removed. The precooled air enables evaporation at a much lower temperature, resulting in a cooled-water temperature close to the dew point, significantly below the ambient air wet-bulb temperature.

Theoretically, water could be cooled to around 55°F (13°C) rather than the 75°F (24°C) typical of conventional cooling towers, improving power plant efficiency. In addition, GTI estimates that the lower cooled-water temperatures and decreased evaporative losses relative to conventional cooling towers could reduce cooling water and makeup water use by 15%–20%, with further improvement of the technology potentially eliminating evaporative losses.



Advanced M-Cycle technology (bottom) adds dry channels to precool the ambient air before it flows through wet cooling channels, where additional heat is removed. The precooled air enables evaporation at a much lower temperature than with conventional systems (top).

According to GTI, reducing water use by 10% would save $1,150,000 per year in a typical 500-megawatt (MW) power plant.

The M-Cycle technology has been successfully commercialized for industrial and commercial air conditioning and has shown promise in experimental evaluations for distillation and desalination operations. Preliminary analytical study has evaluated the technology for power plant cooling towers—an effort being expanded by the EPRI/GTI collaboration.

Next Steps

EPRI's Technology Innovation program is funding the assessment of the Advanced Dew Point Cooling Tower concept and will provide expertise in evaluating the technology's overall feasibility, as well as guidance for practical technology development.

In the next steps, GTI will research the literature and patents to identify all codes and standards relevant to the advanced tower design for a 500-MW coal-fired power plant and will work with EPRI to define the design requirements. Drawing on the results of a brief feasibility study, the researchers will develop an advanced fill concept for the cooling tower, to be followed by laboratory tests and system/component design. Models derived from the concept design schematics will identify appropriate ranges of operating parameters, and a cost model will compare the economics of the new fill system with those of current cooling tower systems. EPRI will provide key data on power plant operation and mass and energy balance to assist GTI in integrating the new cooling concept with existing plants.

For more information, contact Jessica Shi, jshi@epri.com, 650.855.8516.

From Wheat Straw to Coal Slurry—Laser-Based On-Line Fuel Monitoring Can Provide Important Information in Real Time

Commercial systems for on-line monitoring of coal composition at the power plant site are relatively new to the industry, applied largely to verify fuel quality specifications or to optimize blends for environmental compliance. Useful as they are for direct coal firing, such systems are likely to be even more important for emerging coal gasification and biomass-fired plants, where fuel quality and variability can be problematic in more fundamental ways. Currently, no real-time fuel monitoring systems are commercially available for coal gasification or biomass generation processes, but EPRI is looking at an innovative laser-based system for monitoring fuel composition, optimizing process efficiency, and avoiding operational and maintenance problems.

Reading Fuel Characteristics in Real Time

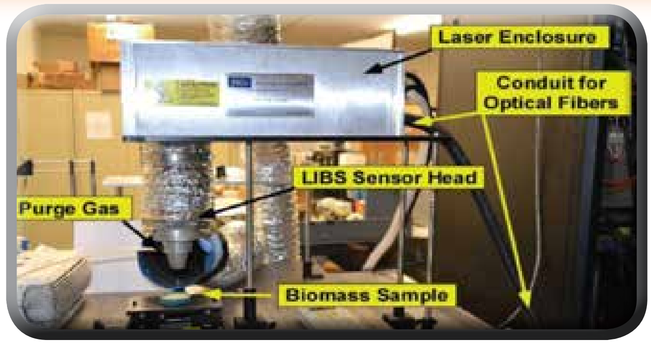
In 2010, EPRI initiated proof-of-concept testing of laser-induced breakdown spectroscopy (LIBS) for fuel characterization and process control in gasification applications. The technology is nearing commercial deployment in pulverized-coal steam plants, but has not been investigated for use with gasifier feedstocks and solid biomass fuels.

Packaged in a compact equipment setup, LIBS's pulsed laser vaporizes a very small portion of the fuel feed and atomizes it into a light-emitting plasma; a grating spectrometer analyzes the light output to identify the elements and species present and calculates their concentrations. Artificial intelligence models based on neural networks are then used to relate the spectrometer readings to key fuel characteristics, allowing fuel mixes to be adjusted predictively for good process control.

LIBS technology offers high sensitivity and rapid response, generating accurate, immediate, and comprehensive fuel characterization data. When combined with analytical tools and predictive models, it could allow real-time calculation of fuel heating value, moisture content, ash fusion temperature, slagging and fouling potential, and other parameters. Plant operators could use these data to optimize conversion efficiency and mitigate problems attributable to fuel composition. At biomass cofiring plants, accurate, real-time measurement of the biogenic fuel fraction would facilitate compliance with renewable portfolio standards.

Testing and Validation

EPRI's early laboratory experiments demonstrated accurate determination of fuel composition for diverse gasifier feedstocks, and initial predictive models based on a combination of 13 parameters were proved valid for correlating LIBS spectra with viscosity temperature and with ash content. Further tests supported the development of measurement capabilities and neural network models for predicting key slagging and fouling indicators for gasifier coal–water slurries using bituminous coal; lignite; petroleum coke; and nine biomass feedstocks: forest residue, land-clearing residue, willow trees, torrefied wood, sawdust, switchgrass, corn stover, rice hulls, and wheat straw. The LIBS/artificial intelligence was able to determine accurately the mineral composition in the fuel samples.



Experiments highlight the potential of laser-induced breakdown spectroscopy (LIBS) for monitoring fuel composition, improving process efficiency, and identifying incipient maintenance problems.

Heading for Commercialization

EPRI also is assisting demonstration of full-scale LIBS systems and analytical tools calibrated for on-line pulverized-coal measurement at AES's J. M. Stuart Station and FirstEnergy's Bruce Mansfield Station. Data are applied to inform fuel blending in real time. Commercial deployment of the technology at pulverized-coal plants is expected this year.

In the meantime, laboratory work is proceeding to validate the technology under pressurized coal–water-slurry feed conditions prior to demonstration in experimental and operational slagging gasifiers. For biomass, measurement and modeling studies are addressing the diverse feedstocks, the variable nature of individual fuels, and the prediction of ash fusion temperature and other operational parameters for coal-biomass blends. Findings will guide validation, scale-up testing, and demonstration for cofiring and biomass-only plants. Field demonstration of LIBS technology for gasification and biomass plants is being carried out through EPRI's CoalFleet for Tomorrow® program, and commercial applications are anticipated for 2015.

For more information, contact Jose Marasigan, jmarasigan@epri.com, 650.855.8739.

New Focus for Weathering Storms: Customer Resilience

THE STORY IN BRIEF

New research on storm recovery focuses not only on grid resilience and service restoration strategies but also on improved customer communication and the use of distributed resources for interim customer support.

Hurricane Irene in 2011, Superstorm Sandy in 2012, and the thousand-mile front that sent 20 tornados ripping through six southeastern states in early 2013 are no longer viewed as isolated freak events, but rather as part of an emerging pattern of larger and more frequent storms. This realization is the driving force behind utilities' efforts to broaden their approach to grid resilience. Resilience of the power system has traditionally focused on prevention and restoration—that is, on hardening the power delivery system and improving the tools and techniques that operators and utility crews use to restore service. But with mounting damage and potentially longer outages, the resilience of customers is also commanding attention. Customer resilience calls for maintaining some level of basic service, e.g., communications, refrigeration, and computing, in the event of a complete loss of power from the grid. Utility responses and possible solutions range from helping customers use assets, such as rooftop photovoltaic (PV) systems or even electric vehicles, to supporting the development and utilization of microgrids.

"The importance of grid resilience has never been greater," said Mark McGranaghan, EPRI's vice president for Power Delivery and Utilization. "Con Edison, for example, intends to invest $1.5 billion over the next five years to improve its ability to survive major storm events. The evidence is there. It's not just Sandy. It's the fact that for whatever reason, the number of these events has grown, and their inevitability is pretty much accepted." Data from the North American Electric Reliability Corporation(NERC) support the assertion that the number of major weather-related disturbances in the United States increased dramatically between 1992 and 2009. New York governor Andrew Cuomo recently remarked that he dealt with six such major events in his first 18 months in office, in contrast with his father, who dealt with only three during his 12-year tenure.

"The main thing to understand about our challenge is that grid resilience is expensive," said McGranaghan. "So we need to look carefully and comprehensively at the whole spectrum of possible investments. We know we can't make the system completely immune to the impacts of weather, no matter how much we spend. Customer support for critical services has to be part of the overall economic evaluation."

Changes in Customer Expectations

How can utilities help customers meet their most critical needs during outages? Historically, many customers such as hospitals, banks, and data centers assumed responsibility for resilience, relying on generators or uninterruptible power supplies and, occasionally, alternative distribution feeds. Other customers simply waited it out. However, the 24/7 web of connectivity afforded by digital devices has led to rising and more demanding expectations. Service interruptions and slowdowns in service are less acceptable now and tend to foster customers' anxiety and dissatisfaction. It is no longer enough to meet the standards set by regulatory agencies for restoration. Customers want faster restoration and greater engagement in the process, preferably in the form of continuous, interactive communication before, during, and after the event.

On average, U.S. electricity consumers can expect to lose power for more than 100 minutes annually from power outages. While this long-term average may be inching up, tolerance is declining, and utilities are reaching out. Commonwealth Edison is among a growing number of utilities that are enhancing their outage reporting and customer communication activities.

In McGranaghan's view, now is an opportune time for utilities to reassess customer support, including, but not limited to, distributed power to support essential services, such as traffic lights, hospitals, prison security, and mobile communications. Cell phone service has become critical in maintaining customer connectivity and providing a means to coordinate emergency services and restoration activities.

"Cell phone towers themselves survive these storms, but they eventually lose power when battery back up is depleted said McGranaghan. "Addressing this problem calls for better coordination between utilities and communication companies—and possibly the government—to figure out how to keep cell phone towers powered and operational during and following storms." In emergencies, communications may be even more important than power, and utilities recognize that they will likely have to include towers as a special focus. Devices for charging cell phones from car batteries and solar panels might also be a useful investment for helping to maintaining customer connectivity.

One intriguing innovation to aid in power recovery, called the Field Force Data Visualization Tool, shows the potential of new technology to bridge fieldwork and customer connectivity. With this technology, a field crew with a smart phone or tablet computer can point the device at a transformer that has failed or a pole that has been downed by a tree and have it automatically link with the utility's geographic information system, asset management system, and outage management system. A circuit diagram appears, along with relevant information on the asset, assisting the field crew and operators by providing information to enhance situational awareness and decision making.

"In the future, we could take this one step further, putting the same field visualization technology into the hands of the customer," said McGranaghan. "They could use a cell phone app to photograph a tree branch on a power line, for example, and send it to the utility, along with a geographic tag and a time stamp. With this crowdsourcing of damage data, the customer becomes a vital part of the utility crew working to restore the system. This has huge potential to expand the information available, to reveal the dimensions of the outage, and to prioritize repair efforts. Of course, we need to be careful. As customers become empowered as part of the restoration team, utilities will need to provide feedback so that they don't feel their efforts are in vain. The communications must be interactive—a part of the connectivity people have come to expect in their daily affairs."

Innovations in Disaggregated Supply

Customer resilience will increasingly be built on innovations in distributed generation and storage that extend beyond the traditional backup diesel generator and short-term uninterruptible power supply. For large-scale facilities, microgrids employing fast-starting gas turbines or fuel cells could offer clean and efficient standby operation. For residential customers, electric vehicles and rooftop PV coupled with storage offer a back-up alternative.

Plug-in electric vehicles, both all-electric and hybrid, could be used to supply energy to a home during an outage. Hybrid electric vehicles also could operate as gasoline-fueled generators to provide additional standby power. Some automakers are already introducing the concept. Nissan Motor Company offers a system that enables the Nissan Leaf that connects with a residential distribution panel and supply residences with electricity from its lithium ion batteries. The batteries can provide up to 24 kilowatt-hours of electricity, sufficient to power some household critical needs for a few days.

"Including electric vehicles in the range of customer options is definitely something we are excited about," said McGranaghan, "but we don't want to ignore the fact that there is a limited amount of storage and life in that battery. If you are out for five days, it is not going to be the thing that keeps you going."

Increasingly, consumers are installing rooftop PV systems to augment grid-supplied electricity. Usually limited by roof area and sized to meet an economically viable portion of the building's electrical needs, these systems normally cannot supply 100% of a residence's typical demand, nor do the systems, as currently configured, allow for independent operation as an independent microgrid to supply part of a residence's needs. But EPRI assessments have identified inverter and concept designs that could convert PV systems into self-sufficient technologies, without batteries. Significant work is required on safety and interconnections with customer panels to manage loads while in backup operation and to make sure that the utility service is disconnected.

Standalone PV systems with batteries are common for remote off-grid applications. They are significantly more complicated and more expensive than grid-connected PV. However, with improvements in technology and increases in storm-related outages, systems that operate on and off grid may be considered. With a proper transfer switch, perhaps communicating with the utility, such a system could provide backup power to residences or to a community.

"There's significant potential to make these PV systems work in an island mode," said McGranaghan. "If it could be done without storage—since storage is very expensive—it would be a nice bonus for people who have PV."

Also, PV systems are proving surprisingly rugged. "They seem to survive hail storms and high winds," said McGranaghan. "We've found that if the roof survives, the PV survives. In this last storm, Public Service Electric and Gas Company had PV systems on poles all over the state of New Jersey, and they came through fine. They didn't detach from power poles, even while trees were falling down all around them."

When it comes to storage, most R&D is focused on batteries. "There are drivers and incentives everywhere to bring down the cost of battery technology. The U.S., Japanese, and Korean governments, among others, are funding this work. It also seems like every major company and university in the world is looking at battery technology. The incentives in the consumer electronics area alone are huge," said McGranaghan, "and we intend to follow these developments very closely."

Evolution Toward the Microgrid

The microgrid is a natural evolution of distributed resources serving a defined customer load and geographic area, such as a college campus. They are particularly attractive in remote areas where conventional power systems are not available—or are not sufficiently reliable—or where conventional power systems are constrained in meeting demand. EPRI expects a growing number of end users may want to operate in tandem with the normal power delivery system and to disconnect and operate independently in the event of a bulk supply failure or emergency.

Potentially, individual residential customers could operate a microgrid if they were equipped with storage and backup generation. In practice, however, microgrids make more sense today at the facility level—on a campus or military base or at a hospital. "A lot of these facilities already have backup generation—something that can be used more frequently than a diesel generator, such as a fuel cell, a gas turbine, or even renewable resources combined with storage," said McGranaghan.

He pointed out that microgrids in general, and renewables combined with storage in particular, have become a priority in the military. "The military has requirements that are absolutely critical, such as the ability to disconnect in case of a reliability problem or a security breach. Military bases will be among the places where microgrids will be applied first. As the technology evolves and costs come down, microgrids will start to serve university campuses, research parks, hospitals, data centers, shopping malls, and the like; all these places can justify the cost because of their absolute reliability needs."

In terms of aggregating residential customers into a microgrid, there are lots of issues to be worked out—safety and ownership questions, and legal issues associated with who can sell power.

Technically, issues of hierarchical control must be resolved. In a dual configuration, not only must the generators all work together to control voltage, frequency, and other parameters, they must do so in an environment in which the microgrid can periodically reshape itself to deal with changing loads, configurations, and generator conditions. Achieving this flexibility will require the highest level of communication among generation devices and an adaptive grid command-and-control setup.

EPRI's Role

McGranaghan sees three key roles for EPRI in helping utilities prepare their customers for improved resilience. First, can provide utilities with a comprehensive inventory and assessment of technical innovations. Second, can support development of technology to make the customer side more resilient "for example, by figuring out how to take advantage of things the customer might already have, such as PV; we want to help build the electric service panels that provide for convenient, safe switchover so they can be used duringthese events. Also, we'll be investigatingexpansion of energy storage's role as costs come down."

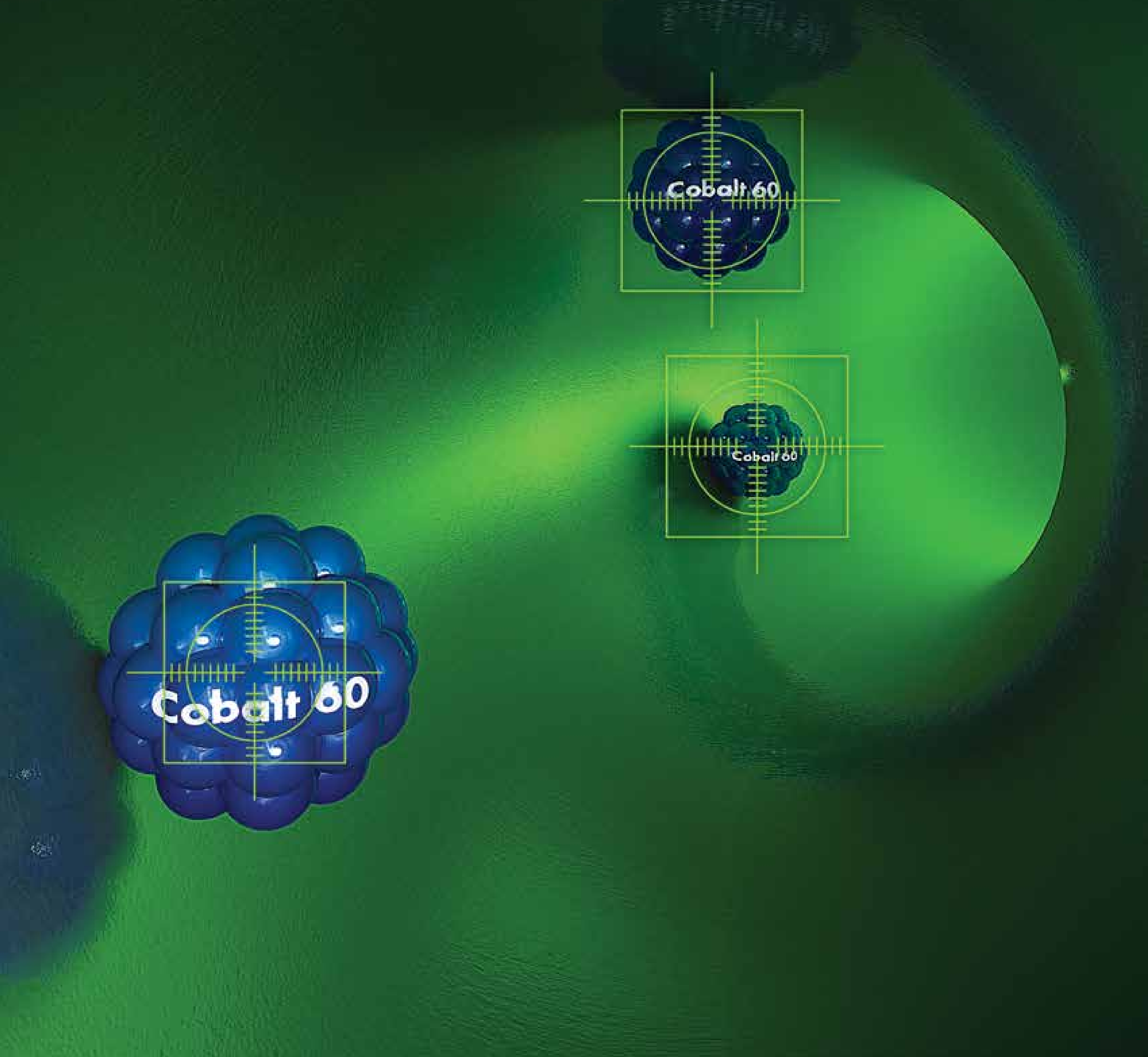
Third, the Institute can focus on the longer-term and more substantial work needed to advance the microgrid. "EPRI can have an important role in developing the technologies needed, such as controls and guidelines for safety and integration. They must work and interface properly with the utility system, and this will require demonstrations to show that we can make the technology work seamlessly."

Tablet computers and smart phones will enable real-time, interconnected capabilities for field operations and disaster response.

These innovations recognize that customer resilience is no longer the sole responsibility of the customer. Utilities see the benefit of having overall grid-resilience planning grow to encompass critical customer support functions. Hardening cell phone service, integrating customer assets—from PV to electric vehicles—and expanding the use of microgrids will be key to improving the customer's resilience to outages.

This article was written by Brent Barker. Background information was provided by Mark McGranaghan, mmcgranaghan@epri.com, 865.218.8029.

CoSeq™ Sequestration Resin Accelerates Cleanup of Nuclear Power Plant Coolant



To ensure worker safety during nuclear plant outages, access to the reactor containment building is delayed until processing equipment can reduce radiation to acceptable levels. Reducing this delay by a day could avoid as much as $1 million in replacement power costs. Innovative work being conducted by EPRI may soon provide a solution enhancing the removal of cobalt-60 from plant water streams.

THE STORY IN BRIEF

EPRI's CoSeq™ resin technology uses a novel sequestration chemistry to significantly increase the amount of cobalt that can be removed from water streams at nuclear power plants. That can possibly mean improved worker safety, reduced radiation exposure, and lower electricity costs due to shorter maintenance outages.

Cobalt-59 and nickel-58 are found naturally in nuclear power facilities in a variety of alloys that contain chromium, manganese, nickel, iron, and cobalt. With the corrosion of certain plant components, such as valves, piping, and reactor parts, the cobalt and nickel are released into the nuclear reactor's water streams and deposited in the fuel core. There they are exposed to radiation and are converted to the isotopes cobalt-60 and cobalt-58, which are the major contributors to outage occupational radiation exposure in both boiling water reactors (BWRs) and pressurized water reactors (PWRs).

Radioactive cobalt-60 and cobalt-58 are circulated from the fuel core surfaces through the reactor water to various parts of the containment area. Because of the gamma rays that accompany radioactive decay of cobalt-60 and cobalt-58, radiation in the containment area must be brought to predetermined levels by reactor water cleanup systems before workers are allowed to enter plant containment and begin outage activities, such as fuel moves and inspections. The more quickly those levels are brought down, the sooner work in the containment area can begin and the sooner the plant can return to service. Shorter outages can reduce worker exposure and potentially save millions of dollars in replacement electricity costs.

Traditionally, the ion-exchange process has been used in nuclear plants to remove corrosion products and radioactive isotopes from the plants' cooling water and to eliminate soluble chemical components that contribute to corrosion. In BWR plants, for instance, ion exchange is used to treat makeup water, returned condensate, water in the spent fuel pool, reactor coolant, and radioactive waste (radwaste).

Today's ion-exchange resins are specialized polymer-based materials that attract ionic species using charged binding sites. Cobalt ions compete for the same exchange sites with zinc, iron, and other ionic species that are present at significantly higher concentrations but are less harmful from a radiation perspective. The ions are "exchangeable," however, meaning the attractions that take place can also be reversed. Over short periods, existing ion-exchange resins are 90%–99% effective in briefly controlling ionic corrosion products after being put into service, but their capacity to attract ions is quickly diminished. As a result, fresh resin must be used on a regular basis, and residual contaminants in the water that cannot be removed contribute to site radioactivity levels and occupational exposures. Ion-exchange applications may take several days to reduce corrosion product concentrations to safe levels, so applications must be scheduled several days in advance of outages to ensure that contaminant levels are low enough to permit outage activities.

New Technology: Cobalt Sequestration Resin

EPRI began studying the possibility of sequestration, rather than ion exchange, toward the end of 2009 through its Technology Innovation Program. Since then, EPRI researchers helped develop a resin that can sequester radioactive cobalt species. This new resin, which can be applied in powdered form to conventional demineralizer filters, captures and locks cobalt species through both physical and electronic interactions, avoiding the unwanted reversal of exchange that can occur with ion-exchange systems. Designed for use in reactor water cleanup systems, this new resin to reduce critical path downtime, replacement power costs, and site activity levels during outages by accelerating uptake of corrosion products responsible for most radiation exposure at plants. Dubbed CoSeq™, the resin preferentially targets elemental and activated cobalt.

A systematic progression of laboratory and field studies was necessary to test different resin formulations and to scale up production. "These tests help ensure, first and foremost, that we will do no harm when we introduce new cleanup technologies into a nuclear plant," said project manager Susan Garcia. "We are working with complex chemistries that involve difficult reactions, and we don't want to have a negative impact in any way—for instance, by introducing any impurities into the water."

No new equipment is needed for testing the CoSeq™ resin, since it can be used in existing water treatment systems. The resin can be used throughout a nuclear plant's operating cycle, as well as during plant outages.

Exelon Generation, in an effort to take dose reduction to the next level, hosted testing and development of this novel technology at its LaSalle County and Peach Bottom generating stations. The first tests involved plant reactor water and fuel pool water at LaSalle, where benchtop tests showed that CoSeq™ outperformed the site's current resins for cobalt removal. EPRI then increased production of the powdered CoSeq™ resin to provide enough for a plant demonstration in BWR reactor water cleanup systems. The resin was tested for physical properties important for a filter demineralizer demonstration, such as ease of removal from the system after use, impacts on differential pressure, and settling behavior.

Testing with plant water in actual plant treatment systems is necessary to prove that these resins outperform traditional ion-exchange resins. "The original benchtop studies were critical to our work, but we couldn't be absolutely sure of this resin's capabilities until we actually went into the plant itself," Garcia said. "We rely heavily on the industry to try new technologies, and the utilities that have stepped up to do this have been instrumental in the success of the project."

BWR in-plant demonstrations began in April 2012 at Exelon's LaSalle 1. The CoSeq™ powdered resin operated for 36 days with high removal efficiencies and no negative impacts on plant operation. The comparison test bed, which used LaSalle's normal resins, had to be backwashed twice during the 36-day test period because of high conductivity associated with a mechanical issue.

In a subsequent demonstration later in 2012, the CoSeq™ resin again outperformed the standard resin when tested side by side during and after an on-line chemical application that is known to be associated with higher cobalt-60 levels in the reactor water.

Last fall, powdered CoSeq™ resin was evaluated in a side-by-side demonstration during a plant shutdown at Exelon's Peach Bottom 2 BWR. The testing took place during a period when cobalt-60 levels were elevated, requiring added outage time for cleanup. Again, CoSeq™ outperformed the standard resin for efficient removal. Additional BWR demonstrations and side-by-side tests followed in February 2013 during a shutdown at Exelon's LaSalle 2.

"We were very pleased to be chosen to conduct the CoSeq™ pilot testing at LaSalle and Peach Bottom," said Peter Orphanos, Exelon's vice president for fleet support. "We are currently pursuing an aggressive dose-reduction initiative that involves improvements in processes, shielding technology, worker behavior, and source term reduction. We believe resin optimization is a strategy that can make a big difference in reducing source term and improving worker safety."

Effective Results

The original goals for the new resin were as follows:

- Increase cobalt removal using existing plant water cleanup systems.
- Reduce outage time and replacement power costs required for water cleanup.
- Decrease worker exposure and waste management costs while supporting safe and economical long-term operations.

In-plant tests conducted so far have confirmed the laboratory results: A single CoSeq™ active resin site does the work of at least two ion-exchange sites while improving cobalt uptake rates and increasing overall effectiveness.

CoSeq™ provides faster, higher-capacity uptake of those corrosion products responsible for most of the radiation dose in BWR applications. As a "plug-in" treatment solution for existing and new nuclear plants, this sequestration resin promises at least a threefold increase in longer-term uptake for key cobalt species, as well as higher overall removal capacity. Applying these resins in primary coolant treatment systems could reduce the time delay before the reactor vessel can be opened during outages (potentially by as much as 24 to 48 hours), leading to replacement power savings of $500,000 to $1 million per day.

Most important, whether the plant is operating or in an outage, this technology can decrease worker radiation exposure, extend resin lifetime, and help control radioactive waste production and associated management and disposal costs.

The CoSeq™ resin can be used with conventional water cleanup systems.

Photograph courtesy of Korea Hydro & Nuclear Power | Kori Nuclear Power Plant

Based on the successful laboratory and plant testing, EPRI began exploring mechanisms for making the resin commercially available to the industry. In April, EPRI licensed the technology to a commercial resin vendor, who will then supply the material to nuclear power plants. Production of commercial-scale batches may begin this Fall.

"Typical ion exchange resins are not designed to go after cobalt specifically," Exelon's Orphanos pointed out. "CoSeq™ is the first resin developed with cobalt removal as the primary focus. We are very excited about the potential to commercialize this new technology, which will clearly help Exelon and the industry reduce exposure of our workforce."

The Studies Continue: Additional Uses for CoSeq™

At most BWR plants, water streams pass through demineralizer filters, which can be coated with a powdered form of the CoSeq™ resin. In PWR plants, some BWR plants, and radwaste treatment systems, the streams to be decontaminated are passed through deep-bed demineralizers—large containers that hold hundreds of kilograms of resin beads stacked like loose marbles. These applications will require a bead form of the CoSeq™ resin, which EPRI is also pursuing.

CoSeq™ bead-type resins have been generated successfully at bench scale with a variety of substrates, and several utilities have volunteered their PWR plants as demonstration sites. Radwaste testing is scheduled for this spring at a plant owned by Korea Hydro & Nuclear Power. The four-column testing of various resins will include evaluation of colloidal cobalt removal, as well as removal from multiple waste streams. Radwaste testing is also in progress at NextEra Energy's Seabrook Station. Macroporous and gel-form bead resins with and without a sequestration ligand will be screened with the radwaste water.

Another use for powdered CoSeq™ resin is in submersible filter applications. Submersible filters are used during outages to quickly clean up a plant's cooling water. If successful, the technology could be tailored to specific needs, such as cavity cleanup and fuel pool cleanup. Already, powdered CoSeq™ has been embedded in a submersible filter, and a combination of filter and submerged deep-bed demineralizer could constitute a viable test configuration as well. Demonstrations at a plant slated for an outage this fall will help quantify the value and use of submersible units.

EPRI will continue to study sequestration of other elements to determine whether this technology could be used with other radioisotopes and in other applications. Applying sequestration chemistry for lead, mercury, or antimony removal at fossil plants, for example, could enhance water treatment options across the electric power industry.

This article was written by Debra Murphy. Background information was provided by Susan Garcia, sgarcia@epri.com, 650.855.2239; Daniel Wells, dwells@epri.com, 650.855.8630; and Keith Fruzzetti, kfruzzet@epri.com, 650.855.2211.

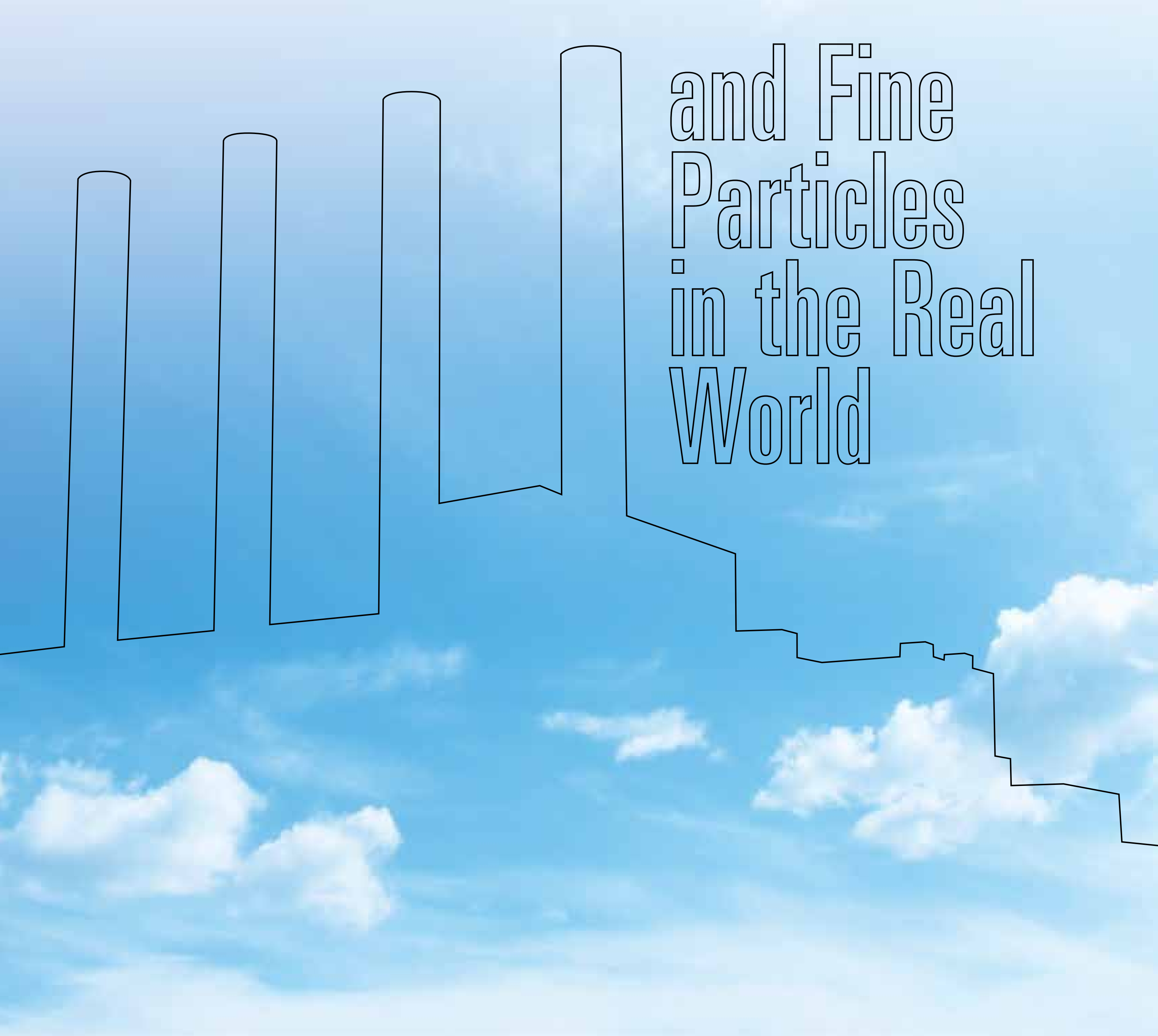
Susan Garcia is a senior project manager specializing in BWR chemistry, with particular focus on optimized chemistry treatment, mitigation and monitoring of stress corrosion cracking, fuel performance, and dose reduction. Before joining EPRI in 1999, she was a technical project manager at GE Nuclear Energy. Garcia has a B.S. in nuclear chemistry from San Jose State University.

Daniel Wells is a senior project manager specializing in corrosion mitigation and chemistry regimes as they relate to radiation fields and activity transport. Before joining EPRI in 2010, he worked as a project engineer at Radiological Solutions, Inc., and earlier at ExxonMobile Process Research. Wells received a B.S. in chemical engineering from Auburn University and a Ph.D. in chemistry from Northwestern University.

Keith Fruzzetti is a technical executive in the Nuclear Fuels and Chemistry Division, focusing on optimizing chemistry for corrosion mitigation, fuel performance, and radiation management. Before joining EPRI in 2001, he worked at NWT Corporation as a senior consultant involved in PWR primary and secondary water chemistry issues. Fruzzetti received a B.S. in chemical engineering from San Jose University and and M.S. and Ph.D. degrees in the same field from the University of California, Davis.

TERESA

and Fine Particles in the Real World



Understanding the health effects of fine particulate matter is crucial for the utility industry and regulators. Policy makers have continued to tighten air quality standards over the years, a trend likely to continue. To meet these standards, operators of pollution sources, such as coal-fired power plants, have undertaken significant retrofits to control emissions. Research that can provide realistic assessments of the pollutants associated with power plant emissions will help shape policy discussions and decisions on power generation in the future.

How does one determine the health effects of coal-fired power plant emissions? Historically, studies have used simple surrogates of plant emissions, such as fly ash or sulfate, which yielded results that were far from comprehensive or conclusive. A more realistic method is to capture actual emissions and test them in the laboratory under conditions that closely resemble real-life exposures. This is the approach that EPRI took in 2002, when it launched its Toxicological Evaluation of Realistic Emissions of Source Aerosols (TERESA) study.

TERESA is the first and only study to recreate scenarios that mimic the formation of fine particulate matter downwind of flue gas releases and to test its toxicity. EPRI researchers, in collaboration with investigators at the Harvard School of Public Health, designed the multiyear project with innovative approaches that made the realistic assessment possible, from the methods used to "age" the emissions to the use of a mobile toxicological laboratory at study sites. The results demonstrate the value of this rigorous approach, supporting the conclusions of earlier studies with far greater realism and specificity.

TERESA mobile laboratories

THE STORY IN BRIEF

A groundbreaking study of the health effects of fine particles derived from power plant emissions yielded more definitive results and substantially advanced the course of future realistic laboratory research through its innovative design and methodology.

"The TERESA study was methodologically unique and met an important need for scientific information about coal-fired power plants," said Annette Rohr, a senior project manager for air quality and health at EPRI. "Previous studies did not provide definitive answers regarding the health effects of these power plant emissions. TERESA was a big step forward in helping increase our understanding of this issue."

The collaboration with the Harvard School of Public Health was funded primarily by EPRI members, with additional funding from the U.S. Department of Energy's National Energy Technology Laboratory and the State of Wisconsin. The researchers published eight papers in a special issue of the scientific journal *Inhalation Toxicology* (Vol. 23, No. S2) in 2011.

Project Scope

The project's goal was to determine if and how particulate matter 2.5 microns and smaller from coal-fired power plants could affect human health under different circumstances. The Study aimed to evaluate the toxicity of primary emissions released directly by the plant and secondary particles that form downwind as sulfur dioxide gas oxidizes to form sulfate particles. It also incorporated other atmospheric components, such as ammonia and secondary organic aerosol, to create different mixes of particles that more accurately reflect real-life conditions. Researchers compared the results from the power plant emission exposures with the results from similar experiments that used concentrated ambient particles from Boston, Massachusetts.

Need for a New Approach

Previous toxicology research on fine particles from coal-fired power plants generally relied on simplistic approaches using coal fly ash, which represents only primary particulate matter. This material is already effectively controlled by equipment such as electrostatic precipitators, and as a result, its emission in the United States is very low. Earlier studies typically involved very high doses of fly ash and non-physiological methods of exposure, which did not reflect the real-life environment. In some cases, experiments used emissions from pilot-scale combustors, which typically lack emissions controls and operate under conditions different from those at full-scale plants.

Other research had focused solely on the secondary particles that form from sulfur dioxide emissions. Those experiments typically evaluated the health effects of sulfate, or sometimes sulfuric acid, although the latter is usually at least partly neutralized by atmospheric ammonia. Overall, these studies lacked information on the health impacts of the combination of primary and secondary particles, along with other materials that typically exist in the atmosphere.

Epidemiological studies have evaluated health impacts related to power plant emissions by using "factor analysis" to group different pollutants into so-called "source factors" according to how their concentrations vary and then statistically linking

TERESA Methods Employed in Tunnel Study

TERESA's research design and mobile laboratory setup were replicated to study vehicular emissions in the U.S. Northeast. The U.S. Environmental Protection Agency funded a Harvard School of Public Health study to examine particles extracted from a highway tunnel containing tailpipe emissions and other, lesser-studied particles, such as those derived from brake and tire wear, road dust, and evaporating fuel. As in the coal emissions study, researchers simulated various atmospheric scenarios by using ozone and other additives.

Vehicular emissions differ significantly in composition from coal-fired power plant emissions. The former contain much more organic material emitted as primary particles and gases, leading to the formation of secondary organic material upon oxidation in the atmosphere. Vehicular emissions also contain metals such as copper and zinc as traffic-related or road dust components.

The emissions were drawn from a tunnel ventilation exhaust stack and run through the photochemical chamber to convert the exhaust—the primary emissions—into compounds that usually form after exhaust is exposed to the sun and air. The chamber used 180 40-watt fluorescent lamps to simulate sun exposure.

Researchers were successful in forming secondary particles in the photochemical chamber. They observed that some of the fine particles caused breathing pattern changes in the exposed rats, although these changes tended to be mild. They also recorded statistically significant changes in the rats' blood pressure, which increased and stayed at a higher level during the weeks of exposure.

"Significant changes in blood pressure are demonstrated here as a result of exposure from modest, yet stable concentrations of pollutants," concluded one of the resulting research papers, published online in the journal *Air Quality, Atmosphere & Health* in June 2012.

them to health outcomes in a specified population. Limitations arise because the same component—such as organic carbon—often comes from several different sources. Moreover, the composition of source factors varies from study to study, making precise comparisons difficult. While epidemiological studies contribute key information to the overall research into links between plant emissions and health, only controlled laboratory studies can definitively show cause and effect.

The Methodology

Researchers designed TERESA to collect actual emissions at operating coal-fired power plants, expose laboratory rats to the emissions in various forms, and evaluate the effects of inhaling the particles.

Three plants were chosen to represent the types of coal burned and the diverse environmental control technologies used by utilities across the country: a plant in the upper Midwest burning subbituminous coal and equipped with an electrostatic precipitator; a plant in the Southeast burning low- to medium-sulfur eastern bituminous coal and equipped with an electrostatic precipitator and selective catalytic reduction equipment for nitrogen oxide control; and a plant in the Midwest burning medium- to high-sulfur eastern bituminous coal and equipped with an electrostatic precipitator, selective catalytic reduction equipment, and a scrubber to remove sulfur dioxide.

Collected flue gases were "aged" to simulate the oxidation that normally occurs in the atmosphere in the days or weeks after emissions leave the plant. Aging was accomplished in three steps. First, sulfur dioxide was transformed into sulfate or sulfuric acid particles. Second, the particles were neutralized with ammonia. Third, the particles were mixed with secondary organic aerosol, which is often present in the atmosphere and can become associated with secondary sulfate particles as well as primary particles. This aerosol forms from both biogenic (naturally occurring) and anthropogenic (man-made) volatile organic compounds as they themselves oxidize.

In an on-site laboratory, researchers mixed the flue gas directly extracted from the stack with ozone and ultraviolet light and/or ammonia and/or secondary organic aerosol. The secondary organic aerosol used in these experiments came from alpha-pinene, a volatile organic compound largely derived from vegetation. In an important step, a "denuder" removed many of the gases present in the flue gas before delivering the particles to the animals. By removing the gases, which can cause health effects themselves, researchers ensured that any effects observed were the result of particulate matter only. After preparing different mixtures of flue gas and additives, researchers exposed the test animals to these particle types:

- Primary particles
- Secondary (oxidized) particles
- Oxidized particles mixed with secondary organic aerosol
- Oxidized and neutralized particles mixed with secondary organic aerosol

Researchers used two mobile laboratories to carry out experiments at the power plants. One was a bus fitted with photochemical chambers, denuders, and extensive equipment to measure the levels of different pollutants in the mixtures. The second was a trailer custom-built as a toxicological laboratory, housing the test animals.

The researchers exposed rats to emissions created from the simulated atmospheric conditions and looked for changes in the rats' pulmonary and cardiovascular health. They recorded the rats' breathing patterns, looked for pulmonary inflammation, and evaluated oxidative stress in heart and lung tissue. A control group of rats breathed filtered air.

"Compromised" rats recovering from induced heart attacks were used in a subset of experiments. Because previous studies had reported that humans with cardiac conditions were more susceptible to effects of ambient particulate matter, TERESA investigated whether exposure to primary and secondary particles specifically from power plants would produce the same effect. In these experiments, researchers outfitted the rats with implanted telemeters to measure heart rate variability and other responses during exposure.

Project Results

TERESA's ambitious approach required researchers to overcome several technical challenges. Among these were development of a flue gas sampling technology, an aging chamber small enough to fit into a field laboratory, a denuder system to remove gases without changing the particles' characteristics, and a mobile toxicology laboratory.

Complex data sets required intensive data analyses. The results showed some biological effects in the exposed rats that were not seen in the control animals, and these effects were statistically significant for some exposures at a subset of the power plants studied. Overall, results showed that the rats developed only mild responses after being exposed to different types of fine particles under different atmospheric conditions.

It was difficult to determine conclusively the individual particle components most associated with responses. Researchers did observe more pronounced changes in the health of rats that inhaled secondary organic aerosol. Neither neutral nor acidic sulfate appeared to play a large role in the biological effects, which supports the findings of many previously published studies that indicated that coal fly ash or sulfate tends to cause health effects only at relatively high concentrations. The study also showed that, in light of different results at the three power plants, particulate emissions appear to be heterogeneous, varying with the specific coal types burned and the different emissions controls used. The research also showed that the toxicity of the power plant emissions in the TERESA scenarios was the same as or lower than the toxicity of the concentrated ambient particles from Boston.

While EPRI has no near-term plans to expand on the TERESA project, the research model it created can be applied to the study of a variety of emission sources, from residential fireplaces to power plants using fuels other than coal, Rohr said. In fact, as a separately funded part of TERESA, Harvard School of Public Health researchers used the same experimental design and infrastructure to investigate the toxicity of vehicle emissions from a roadway tunnel in the northeastern United States (see page 16).

"TERESA has substantially increased our understanding of the health effects of coal-fired power plant emissions," said Rohr. "The study was innovative and ambitious and filled an important knowledge gap. Future toxicological research should strive to recreate realistic conditions in much the same manner."

This article was written by Ucilia Wang. Background information was provided by Annette Rohr, arohr@epri.com, 425.298.4374.

Annette Rohr is senior project manager in EPRI's Air Quality program area. She conducts research on the health effects of air pollution, including particulate matter and gaseous co-pollutants. Before joining EPRI in 2001, she was an environmental scientist at Dames & Moore, where she conducted human health and ecological risk assessments. Rohr serves on the editorial board of the journals *Indoor Air* and *Journal of Clinical Toxicology*. She received a B.S. degree in microbiology and an M.S. in environmental engineering from the University of British Columbia in Vancouver and an Sc.D. in environmental health from Harvard University.

R&D Quick Hits

What Happened in Vegas . . .

EPRI researchers joined more than 150,000 people at the International Consumer Electronics Show in Las Vegas, Nevada, to scout technologies and developments relevant to the electricity sector. Some highlights:

- The focal point for the home area network (HAN) is shifting to the smart phone or tablet, delivering a seamless user experience with content stored in the Cloud.
- All types of consumer electronics have the capacity for wireless interconnectivity (predominantly Wi-Fi).
- Smart phones and tablets have the potential to function as mobile energy-use displays.
- Large established industries such as HVAC, security, cable, and home improvement retailers are driving lower-cost, retail, do-it-yourself systems for managing security, appliances, and household electronics.
- Manufacturers are embedding multiple wired and wireless communication protocols, or "protocol agnostic" communications capabilities, in their products.

For example, Lowe's is driving toward a convergence of home communications and controls, working with Cisco to develop a combination Wi-Fi + Z-Wave + ZigBee router with built-in energy-optimization strategies. For utility demand response and efficiency programs, there is the opportunity to partner with established retailers such as Lowe's, Ingersoll Rand, and GE. Vendors are developing application programming interfaces for third parties to access in-home devices through the Cloud. For more insights into these trends and developments in consumer electronics, appliances, lighting, and other areas, download *Highlights of the 2013 International Consumer Electronics Show* (go to www.epri.com and enter Product ID 3002000202 in the Search field).

Driving a Stake Through the Heart of 'Vampire Loads'?

EPRI "innovation scouting" is looking at something called the self-sustained synchronous rectifier (SSSR), which has the potential to reduce by 75% the energy consumed by computers, printers, and other electronic devices when they are idle. For more information, go to www.epri.com and enter Product ID 1026775 in the Search field.

Not for Finding Nemo

Researchers with EPRI and the Massachusetts Institute of Technology have demonstrated the feasibility of a mini-robot submarine to inspect components in nuclear reactor pressure vessels and spent fuel pools. Underwater testing is looking at a payload that will allow real-time navigation, visual inspection, and the capturing of high-resolution data to support nondestructive evaluation. The somewhat egg-shaped robot has no appendages and can do a number of maneuvers. A fully functioning mini-robot sub is scheduled for in-plant testing in 2014. A brief video of the prototype is available on YouTube at www.youtube.com/watch?v=HPV6aX4XqIw

Video source: Massachusetts Institute of Technology

Slurry with the Coal on Top

EPRI is leading research to investigate the feasibility and cost of using captured carbon dioxide (CO_2) as a liquid in a slurry of low-rank coal to feed an integrated gasification–combined-cycle (IGCC) plant. Past research indicates that such a slurry has the potential to significantly reduce the cost and increase the efficiency of IGCC power plants with carbon capture and storage (CCS). Compared with water, liquid CO_2 takes less energy to vaporize and has the potential to significantly improve the performance of a slurry-fed gasifier.

The project is briefly described in a recent EPRI report, *Coalfleet Integrated Gasification Combined Cycle Research and Development Roadmap: 2011 Update* (go to www.epri.com and enter Product ID 1022035 in the Search field).

Old Man River, He Just Keeps Powerin' Along

EPRI's mapping and assessment of hydrokinetic resources in 71,398 river segments in the continental United States estimates that 119.9 terawatt-hours (TWh) of electricity, 3% of the nation's annual electricity use, is technically recoverable.

Big Daddy

Not surprisingly, the "Father of Waters," the Mississippi River, accounts for 62.5 TWh, or 52% of the total. Add Alaska (17.1%), the Pacific Northwest (9.2%), and the Ohio region (5.7%), and you have accounted for more than 80% of the technically recoverable hydrokinetic resources. For more information, go to www.epri.com and enter Product ID 1026880 in the Search field.

Hydrologic Region	Technically Recoverable Annual Energy (TWh/yr)	Portion of Total Technically Recoverable Resource (%)
New England	0.2	0.2
Mid Atlantic	1.0	0.8
South Atlantic Gulf	1.2	1.0
Great Lakes	0.01	0.2
Ohio	6.9	5.7
Tennessee	1.0	0.9
Sauris Red-Rainy	0.03	0.03
Upper Mississippi	5.1	4.2
Lower Mississippi	57.4	47.9
Texas Gulf	0.05	0.04
Arkansas Red	1.3	1.0
Lower Missouri	5.6	4.7
Upper Missouri	2.8	2.3
Rio Grande	0.3	0.2
Lower Colorado	3.9	3.2
Upper Colorado	1.1	0.9
Great Basin	0	0
California	0.7	0.6
Pacific Northwest	11.0	9.2
Alaska	20.5	17.1
Total	**119.9**	

The Internal Combustion Engine and the Grid

The EPRI 2012 Technical Assessment Guide (TAG®) provides an overview of cost and performance estimates for a broad cross-section of generation and environmental control technologies, including the internal combustion engine.

The following are some key trends reported in the latest TAG®:

- In 1993, natural gas–fired units accounted for about 5% of the worldwide market for units of 1–30MW. From 2000 through 2011, that figure averaged above 10%.
- Most natural gas engines are modified diesel-fired engines; they produce only 60%–80% of the power output of their diesel-fired counterparts, with correspondingly higher unit capital costs. But because they burn cleaner fuel, the gas-fired engines benefit from prolonged component life and lower maintenance costs.

- In about 2000, driven by countries with marginal grid reliability, the market began to trend toward multiunit baseload power plants with larger (>5 MW) internal combustion engine generators.
- In the United States, a growing number of natural gas–fired reciprocating-engine power plants have been built to provide grid stability and to back up wind generation. Many of these plants use 5-MW- to 16-MW-engine generators, with total plant capacities ranging from 75 MW to 200 MW.

For an abstract of the 2012 TAG, go to www.epri.com and enter Product ID 1024063 in the Search field.

Some Like It Hotter

A U.S. national R&D program is showing results in developing materials for advanced ultra-supercritical (A-USC) boilers and steam turbines. A superheater test loop manufactured with several A-USC materials is operating at temperatures up to 760°C (1400°F) in a commercial coal-fired power plant, and the first ingot of Haynes 282, a new A-USC alloy, is being subjected to microstructural analysis.

EPRI is providing technical direction and coordination of the U.S. Department of Energy/Ohio Coal Development program, a multiyear government/industry consortium identifying, evaluating, and qualifying boiler steam turbine materials that will enable turbine throttle steam conditions of 760°C (1400°F)/35 MPa (5000 psi).

Ten years into the project, the goal now seems achievable. No "fatal flaws" have been identified that would prevent successful application of the identified materials. Details of the past and current research are available in a recent EPRI report, *Progress Report on A-USC Technology Development* (go to www.epri.com and enter Product ID 1023868 in the Search field).

Mitigating the Effects of Cycling on Environmental Control Equipment

THE STORY IN BRIEF

Increased cycling of baseload coal-fired plants is challenging the capability of environmental control systems to operate flexibly while meeting tougher emission limits. Current research is seeking ways for these systems to adjust to new modes of operation.

Over the past decade, U.S. coal-fired generation has been forced to increasingly switch from high-capacity-factor baseload operation to various modes of flexible operation, including load following and low-load operation. This rise in flexible operation is reflected in U.S. Energy Information Agency statistics on average monthly kilowatt-hour coal generation, which show a 40% increase in the variation in monthly coal-fired generation since 2008.

The main driver: lower natural gas prices, which can make gas-fired plants a lower-cost option with dispatch priority. Also, because the recession in some cases reduced demand in the industrial sector, which exhibits less seasonal fluctuation than the residential and commercial sectors, overall demand variation has increased. In some regions, the burgeoning deployment of renewable generation, with its "must take" dispatch designation, forces coal plants to provide load-balancing services.

As new duty cycles cause baseload plants to operate closer to, or beyond, nominal design limits, potential detrimental impacts may be experienced throughout a plant, including thermal fatigue damage in boiler headers, corrosion in waterwalls and turbine blades, and creep fatigue in tubing and piping.

A key challenge is the effect of plant cycling on environmental control equipment, including selective catalytic reduction (SCR) systems for control of nitrogen oxides (NOx), flue gas desulfurization (FGD) systems for removal of sulfur dioxide (SO_2), and other systems for reducing emissions of particulate matter and mercury.

"The effects depend on the type of control system and the mode of operation," said Tony Facchiano, EPRI senior program manager for environmental controls. "With load following, the issue is responsiveness, including a control system's ability to change its processes quickly to match changes in load. Low-load operation, which results in lower SCR inlet temperatures, can affect the process chemistry, which is designed for plant operation within a specific temperature range. What's new about this issue in recent years is the frequency and level of cycling required and the tighter restrictions on emissions. These systems now have to be much more flexible than was anticipated when they were first put into play."

To address these challenges, EPRI research is analyzing the impacts of plant operations on emission control systems and is developing guidelines and best practices for cost-effectively meeting compliance requirements under flexible operation.

SCR Systems at Low Load

The SCR systems deployed in 260 U.S. coal-fired units are significant in the cycling debate. Usually they are a prime limiting factor in a unit's low-load operation. The systems reduce NOx emissions by injecting ammonia into the flue gas stream as the gases pass through a catalyst chamber.

"Flue gas temperatures must be at or above a minimum operating temperature defined by the catalyst vendor to achieve required levels of NOx reduction and avoid ammonia slip, which is ammonia passing through unreacted," said Richard Himes, EPRI project manager for post-combustion NOx control. "The temperature limit is designed to avoid deposition of ammonium bisulfate $(NH_4)HSO_4$, a sticky, corrosive liquid that forms at lower flue gas temperatures and can deactivate the catalyst by filling the catalyst pores."

Units forced to operate at low load can maintain flue gas temperatures above the minimum if the plant design includes a flue gas or waterside economizer bypass. This solution, however, requires capital investment and imposes a thermal efficiency penalty.

Another option is to suspend reagent injection during low-load operation, but this forgoes NOx removal, which may not be allowable under governing emission mandates.As a result, units burning high-sulfur coal with SCR systems and without an economizer bypass need to find other methods for safely operating SCR systems below the minimum operating temperature.

A recent EPRI bench-scale laboratory study sought to determine the maximum time allowed at low load before SCR performance is compromised. Results suggest that overnight operation (8–12 hours) with a new catalyst at low load below the ammonium bisulfate dew point does not jeopardize SCR performance. However, operation under these conditions for more than 24 hours can deactivate the catalyst to the degree that it no longer maintains requisite NOx reduction and may allow ammonia slip. As the catalyst deactivates, there is a decrease in the window of time over which the system can operate below the dew point while maintaining target NOx reduction performance.

"How utilities use this information will differ," said Himes. "Both SCR performance under low load and the decisions that need to be made are highly utility and site specific, depending on unit size and type, fleet mix, emission mandates, catalyst performance guarantees, and other factors."

Application at TVA

An example of how this issue affects utility generation on a fleetwide basis may be seen with the Tennessee Valley Authority (TVA). In recent years, TVA's fleet demand profiles have begun to exhibit more-pronounced daily peak and minimum load swings. Plant turndown—operation at reduced capacity—has presented a challenge with TVA's current asset mix. Nuclear units do not turn down, and hydro and large supercritical units have limited turndown capability. Thus, smaller-capacity units have been required to turn down to lower loads than in the past. Units with SCR equipment have sometimes been unable to turn down because they need to maintain minimum operating temperature for continuous SCR operation. This has required units to be cycled off to meet the lower minimum loads, resulting in significant costs for plant shutdowns and startups.

Using the results of EPRI's SCR lab study and EPRI load-cycling technology guides, TVA determined that the units with SCR equipment could operate at inlet temperatures lower than those prescribed in existing operational procedures. The new lower-temperature operating regimes were designed to include appropriate recovery times during which to evaporate ammonium bisulfate at higher operating temperatures in order to avoid permanent deposition and catalyst damage.

This procedural change permitted 11 units to operate at a lower minimum load, which improved TVA turndown by approximately 1,500 megawatts (MW). "TVA was thus able to meet required generation for minimum load periods without forcing smaller units to cycle off," said Mellissa Cook, TVA's generation engineering environmental systems manager. "Sites that may not have had a chance to run if they could not meet the minimum load now are competitive." This resulted in significant savings in startup costs without affecting the reliability of the cycled units.

As a follow-up to the lab study, EPRI and TVA initiated a field trial to verify SCR operating capabilities at reduced load. The study is being conducted at TVA's Cumberland Unit 1, a 1,300-MW coal-fired, once-through supercritical unit. Tests performed at full load and current minimum load (700 MW) will assess the rate of loss of catalyst activity incurred in meeting NOx reduction targets, the maximum time allowed at low-load operation before SCR performance is compromised, the rate of recovery of catalyst activity upon unit ramping to full load, and the impact of catalyst aging. EPRI plans to conduct additional SCR field studies at other plants.

The Cumberland study will encompass the entire plant, with the aim of improving its turndown capability and determining safe maximum-load ramp rates by monitoring and evaluating data on plant systems other than SCR equipment, including the boiler and turbine. This is one of several operational flexibility field demonstration studies that EPRI is conducting at U.S. plants (see page 23).

Other Environmental Control Systems Under Load Following

EPRI is also initiating research to explore the effects of cycling on other environmental control systems. Preliminary chemical studies indicate that cycling unit load without making operating adjustments in FGD process controls will significantly impact FGD chemistry. Reducing load causes a high oxygen-to-sulfur ratio in the flue gas, which can raise the oxygen reduction potential in the slurry. Results can include a shift of mercury to the liquid phase potential, raising re-emissions of elemental mercury; a shift of selenium from selenite to selenate, which requires more difficult wastewater treatment; and a change in manganese constituents, potentially causing scale formation in reaction tanks and crevice corrosion of Alloy 2205 vessels.

Research sponsored by EPRI will develop procedures to evaluate cycling impacts on FGD chemistry, provide guidance on water-balance issues, identify operational and design improvements to minimize cycling impacts, and conduct case studies to document effects and mitigation strategies.

Another EPRI project this year will study how plant operations, including cycling, startup, and shutdown, may affect strategies to reduce emissions of mercury, fine particulate matter, and hydrochloric acid in compliance with the U.S. EPA's Mercury and Air Toxics Standards. The study will be based on field data from selected sites.

This article was written by Jonas Weisel. Background information was provided by Tony Facchiano, afacchia@epri.com, 650.855.2494, and Richard Himes, rhimes@epri.com, 949.766.8470.

Tony Facchiano is a senior program manager for environmental controls in EPRI's Generation Sector. He manages research on boiler performance, postcombustion NOx control, and integrated environmental controls. Before coming to EPRI in 1993, he worked at Coen Company, Bechtel Power Corporation, and Exxon Research and Engineering Company. Facchiano holds B.S. and M.S. degrees in mechanical engineering from Manhattan College.

Richard Himes is a senior project manager in EPRI's environmental controls program area. Before joining EPRI in 1999, he worked at Carnot Technical Services, Fossil Energy Research Corporation, the Los Angeles Department of Water and Power, and KVB. Himes holds an M.S. degree in mechanical engineering from the University of California, Irvine, and an M.B.A. from the University of Southern California.

EPRI Initiatives on Plant Operational Flexibility

For several years, EPRI's Generation Sector initiative on flexible operation has identified research needs related to flexible operation and has coordinated research on damage mitigation strategies for fossil plant equipment that includes boilers, turbines, balance-of-plant equipment, and emission control systems. From 2011 to 2013, EPRI completed or planned more than 50 projects, spread over 13 programs. More than half of these address issues related to the boiler or the heat recovery steam generator or address material property assessment, heat rate, or coal/gas combustion.

In one EPRI study, researchers identified system modifications that recover plant efficiency lost to continuous cycling operation. These include equipment and operating procedures for improving heat rate under cycling operating conditions. EPRI also developed cycle-chemistry guidelines for all transient operations and shutdowns, including procedures and advice for cycling, shutdown, startup, and layup for most utility boilers and feedwater treatments.

In 2011, EPRI launched a project called Operational Flexibility Implementation: Case Studies. The project is based on successful European fossil plant experience with flexible operations over the past two decades, which showed that operational trials offer the most cost-effective strategy to improve unit flexibility and reduce impacts on plant equipment. These trials explore unit operations and improved controls rather than component design as the first step in a hierarchy of actions. Experience has shown that improved knowledge of the impacts of operator actions on component temperature transients can help to optimize procedures for startup, ramping, and turndown.

The EPRI project works directly with plant operators that have specific goals related to unit turndown, reduced startup time, or improved ramp rate.

The research focus is on reducing thermal transients experienced by components in the steam generating and turbine systems of coal and combined-cycle plants. A series of operational trials is performed, each followed by detailed assessment of observed changes in the process data relative to these goals. Industry subject-matter experts work with the EPRI project team as well as the plant staff to develop improved procedures and make recommendations for low-cost modifications to improve flexible operation. These operational trials can be enhanced by adding instrumentation to components such as the boiler or heat recovery steam generator to reveal damaging temperature transients caused by improper draining and quenching.

To date, four case studies are complete or in progress. In one case study, utility management sought to reduce the hot-restart time of their combined-cycle units in order to remain competitive in the power marketplace. Previously, the subject units had experienced damaging amounts of water induction when pressurized hot restarts were attempted. Using a holistic approach, the EPRI project team not only focused on resolving the water-induction mechanisms within the steam generator and piping but also carefully examined the gas paths, gas turbines, and steam turbines for possible strategies to reduce startup times and mitigate the formation of condensate in the steam generator and associated piping during startup. By developing concise startup procedures and recommending several key equipment and control modifications, the EPRI project was able to reduce hot-restart times by 60%, from 2.5 hours to just under 1 hour.

More information can be found in *Demonstration Development Project: Plant Operational Flexibility—Alignment of Generation Sector Research* (1024639) and *Operational Flexibility Implementation: Case Study #1* (1026588).

FIRST PERSON *with Glenn Pritchard*

BIG DATA

Looks Like Big Opportunity to PECO

Glenn Pritchard, principal engineer with PECO, an Exelon Company, has helped build the ever-growing volume of data that utilities are using to manage their systems. As the technology lead for PECO's smart grid/smart meter initiatives, he has more than a decade's experience guiding the deployment of advanced meters and related infrastructure. With his engineering and operations experience, he offers an evenhanded perspective on the challenges and opportunities presented by a smarter grid and its growing data streams. In contrast to the "data tsunami" that some predict, Pritchard sees that "surf's up" for improved reliability and service.

EJ: What's the "big idea" when it comes to "big data" and utilities?

Pritchard: The utility industry is embracing IT [information technology] in ever-growing ways. Things like the smart grid enable us to move from a manual, labor-intensive system and processes that were built in the twentieth century to a high-performing, remotely managed, self-aware system with distributed intelligence.

EJ: You have extensive experience at PECO with advanced metering infrastructure [AMI]. Do you consider this a vanguard technology of big data?

Pritchard: The concept of big data is an interesting notion, especially for utilities. The smart grid definitely enables more data, but I don't know if it's big data. Let me explain. At PECO, we have been automated with an automatic meter reading [AMR] system since 2000. So for the past 13 years, we've been receiving daily meter reads—24 to 30 reads per month, rather than 1 read per month—for 2.2 million electric and gas meters each day. But now, as we get into the AMI space, we're increasing this to 24 to 96 readings per day, or 770-plus per month. And we're also enabling communications to a number of other distribution system endpoints as well. This is in contrast to our substations, where we are currently receiving readings every 2 seconds on each SCADA [supervisory control and data acquisition] endpoint. This translates into a significant amount of data per device. However, the overall population of endpoints is limited, unlike with an AMI system. The smart grid is definitely an increase in scale, but it's not the data tsunami that it was once thought to be.

EJ: So you don't feel like you're staring at a huge, incoming wave of data? It looks manageable and appropriately scoped for the systems and the work you want to do?

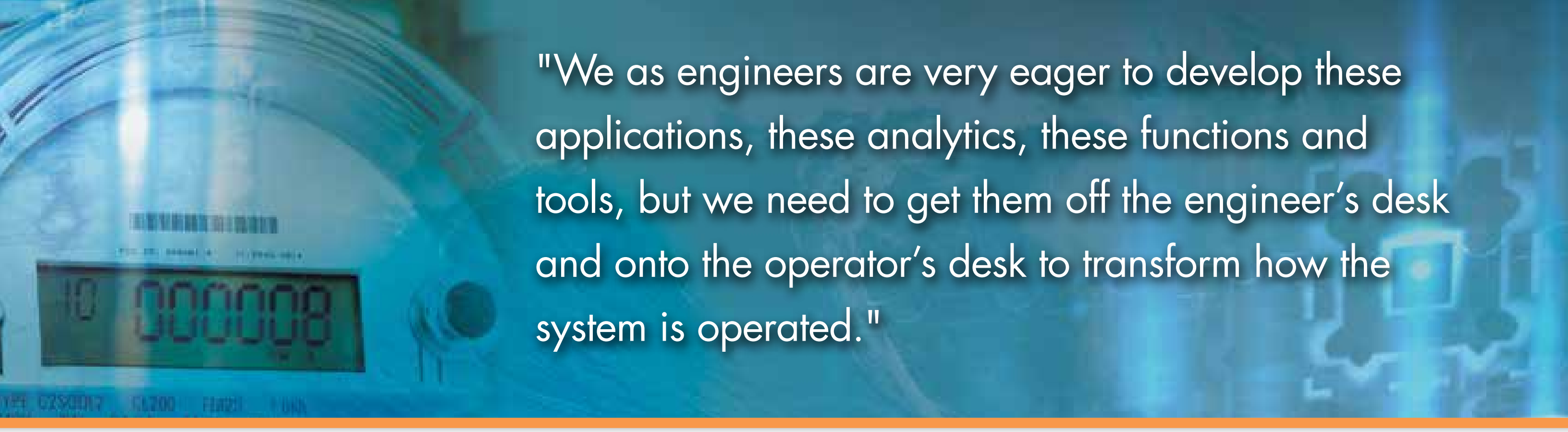
Pritchard: Yes. To use a cliché, surf's up, and in a very positive way. Utilities can really get insight into how their distribution grid is working—essentially monitoring endpoints at every delivery point on the distribution grid. We can now go beyond traditional meter data, such as consumption, energy demand, or power factor, and move to voltage and other engineering parameters. It is now possible to build models of the distribution grid by simply aggregating data from each customer that shares a transformer. You can model how that transformer is performing, then combine the results from several transformers to understand how a feeder or spur is performing. By continuing this process and following the circuit connectivity model, you can model the entire feeder and, ultimately, detect line loss as you look at what is delivered at the substation compared with what was delivered to the customer. This leads to a complete view of how the distribution grid is operating.

> "PECO believes that we reduced our outage restoration times by as much as three days by having increased awareness of what was truly out of service and what was restored, and then being able to send the right crew to those jobs the first time."

EJ: So how would you describe the challenge in taking such data and turning it into useful information?

Pritchard: While there are lots of opportunities to use and develop analytics, I don't hear a lot of talk in the industry yet about change management. We as engineers are very eager to develop these applications, these analytics, these functions and tools, but we need to get them off the engineer's desk and onto the operator's desk to transform how the system is operated—that may be the biggest challenge ahead of us. We need to go beyond development to ensure that the solutions are firmly in place with the operating groups. Otherwise, the effort will fail in the long run.

EJ: In a workshop EPRI hosted recently with utility CIOs, some expressed concern with how you integrate IT and OT—information technology and the



"We as engineers are very eager to develop these applications, these analytics, these functions and tools, but we need to get them off the engineer's desk and onto the operator's desk to transform how the system is operated."

information technology people along with operating technologies and the operations people.

Pritchard: In many ways, the IT versus OT discussion begins to highlight different project management philosophies and operating practices from inside plant versus outside plant. I think the challenge escalates when you're building applications for non-engineers—end users want a polished product for operations where they don't need to be an expert in engineering to use the application. We must be sensitive to this.

EJ: So how do you best focus on data from those two camps?

Pritchard: You need to recognize the different and unique uses of the data. On the customer side, a lot of data relates to billing, marketing, customer information, rates, demand response, and even revenue protection. For engineers, you have a different focus when you talk about analytics. There's pattern recognition, trending, and predictive analytics; there's comparative analytics, where you're taking divergent data sets and combining them to find new information. At PECO, analytics on the customer side are more established from our experience with AMR, but the engineering side has lots of opportunity for new research and new ideas. Each can still learn from the other.

EJ: What do you see as the priorities on the customer side versus the distribution side?

Pritchard: On PECO's customer side, a priority for more than 10 years has been increasing efficiency and optimizing the meter-to-cash process, including areas such as revenue protection and delivering high read rates. One of the most significant changes with AMI is the introduction of interval data. This is having a greater impact on the engineering side of the business. In this case, the engineers are able to generate actual load shapes for distribution system devices. This is unlike the traditional processes, where utilities needed to take a standard load curve and apply it each day and then do a true-up at the end of the month with the one monthly meter reading. As hourly readings are introduced, you have the actual load shape based on measured usage, which gives you a more accurate model. The uncertainty is eliminated as unknowns are removed and replaced by actual measurements.

EJ: So the same data can be applied to operational modeling or demand response, then ultimately as part of a feedback loop to the customer?

"Performing analysis in near real time, as it's happening, and making key decisions can be quite valuable. It does not matter whether this is on the customer side or the T&D side, benefits abound."

Pritchard: Definitely, to the customer and to the utility, yes. It actually opens up markets and programs that had previously been reserved for the largest customers, so now third-party retailers can begin to cater their programs that get right down to individual customers like you and me.

EJ: When you look at the creation and flow of data, do you see particular opportunities in data generation, processing, or storage?

Pritchard: Yes. Data typically is generated and then transferred over some sort of network into the utility, it's stored in a database, and then analysis or batch processing can occur. I challenge us to do that analysis in real time as the data are delivered. Performing analysis in near real time, as it's happening, and making key decisions can be quite valuable. It does not matter whether this is on the customer side or the T&D side, benefits abound.

EJ: Where are PECO's focus and priorities?

Pritchard: I think our biggest opportunity is with distribution operations. Our first priority as we transfer from an AMR system to an AMI system is to perform at the same level and provide the same benefits. We can't afford to take a step backward with the new system. For example, we have received tremendous benefit from integrating the meter-reading system with our outage management system. These benefits include reliability improvements, more accurate CAIDI [customer average interruption duration index] and SAIFI [system average interruption frequency index], and even operational costs.

From Hurricane Isabel in 2003 to Hurricane Irene in 2011 and last year's Hurricane Sandy, we've seen very significant benefits with these tools. I can say with great confidence that PECO believes that we reduced our outage restoration times by as much as three days by having increased awareness of what was truly out of service and what was restored, and then being able to send the right crew to those jobs the first time. During Hurricane Sandy alone, we documented over 6,100 jobs that we either would have dispatched needlessly, where the lights were already on, or would have dispatched incorrectly, by sending a crew with the wrong skill set the first time. This relates to significant cost savings.

EJ: And on the T&D side?

Pritchard: We are looking at how transformers are operating and even doing some initial analysis on line losses—things that we may not have been acutely aware of previously. We're building tools that will help correct any inaccuracies in the connectivity model that defines the relationship between customers and their transformer; having accurate information on this relationship is fundamental to any meter-based solution.

One of my particular responsibilities is developing solutions and running pilots that leverage smart grid and AMI resources. The purpose of the effort is to demonstrate the potential of such applications. If there is merit in a particular solution, I then ensure that business cases and formal project plans are created and submitted for approval.

EJ: What about the customer's hardware and the proliferation of tablets, smart phones, and apps?

Pritchard: Demand for such applications is obviously increasing, but I see a corresponding dwindling of demand for in-home devices. I think the market is moving to iPads, PDAs, and similar devices. We're addressing the need for customer data through soft solutions, including web presentation and even things like the Green Button. [The Green Button is part of a national initiative to provide energy consumers timely online access to their own energy data with the click of a single button.] The question is, how much will customers take advantage of that functionality?

And so right now, maybe the focus of the smart grid should be where the utility has more direct control and influence, such as power delivery and improved reliability. Another important goal should be educating customers on their demand and consumption patterns so they can recognize when they're using energy, particularly at peak and expensive times. Customer curiosity and demand will drive future "killer" apps for the customer, but until those markets are defined and operating regularly, there will be continual change as new products come and go.

EJ: How do you rank data security among your challenges right now?

Pritchard: It's important and constantly evolving. We want to make sure that proper controls are in place to protect our customers, with specific emphasis on privacy and customer needs, but we need to be able to use this data to continue to deliver the high-quality product they expect.

EJ: How are you progressing with AMI deployment?

Pritchard: We've fully deployed our communication network, we have just over 400,000 new meters deployed today [mid-March 2013], and we are rapidly moving to the full deployment of 1.8 million electric meters. As the technology gets in place, the benefits take hold. In many cases, these benefits require deployment in large, orchestrated, contiguous blocks rather than a shotgun approach. This is particularly true in the case of automated outage management.

> "I want not only devices that I can talk to but devices that I can rely on to act intelligently and reliably. This is a fundamental trait of a truly smart grid."

Another benefit we saw related to the recent storms was the concept of resilience, specifically related to the communication network that we installed to support the smart grid. During Hurricane Sandy, we lost nearly a third of the communication nodes due to extended power outages and depleted battery reserve supplies. But we lost communications to only 2% of the meters. Building redundancy into the network means it can take a very significant blow but keep on running at a very high level. This is our goal.

EJ: So it might be helpful to pair the concept of big benefits with big data? In wrapping up, is there anything about data and grid operations you'd like to point out?

Pritchard: I think in many ways utilities are looking forward to getting these systems in place. When asked what defines a smart meter or smart device, I think most people would say "bi-directional communications." Personally, I think it goes much further than that—to having a device that can change its role, change its responsibilities or its operational attributes on the fly, much like a personal computer. A smart meter must be a device that can be adapted to new applications and roles. I want not only devices that I can talk to but devices that I can rely on to act intelligently and reliably. This is a fundamental trait of a truly smart grid.

Mercury's Fingerprints: Tracing Emissions to the Source

Mercury is emitted to the atmosphere from natural sources such as oceans and volcanoes, as well as from anthropogenic sources such as coal-combustion plants, cement factories, and mining operations. Once released, mercury can remain in the atmosphere for years, traveling long distances and becoming broadly distributed around the globe. In addition, mercury is fairly reactive and tends to change form in the atmosphere, with elemental mercury—Hg(0)—oxidizing to Hg(II), and Hg(II) reducing to Hg(0) according to its height in the atmosphere, the amount of sunlight present, and other physical and chemical conditions. This complex biogeochemical cycling, the mixing of emissions from multiple sources, and mercury's relatively low concentrations in the environment make it difficult to tie specific release locations (sources) to final deposition locations (receptor sites) and complicate the issue of where and how to control emissions for the most effective results.

EPRI is developing a promising new approach that uses ratios of seven stable, naturally occurring mercury isotopes to "fingerprint" mercury from a source, such as a coal-fired power plant, and then identify that mercury by its unique fingerprint at a receptor site, such as a lake that hosts sport fishing. This capability will help policymakers and other stakeholders better trace the complicated transport and fate of mercury in the environment and match global mercury sources with local mercury receptors. This new approach is explained in a recent environment brief (1024678) describing the physical and chemical processes that shape the behavior of mercury isotopes and make them useful as mercury tracers.

Fingerprints and Fractionation

Isotopic signatures are based on fractionation—the relative enrichment or depletion of specific, stable isotopes from their natural background occurrences via physical and chemical processes that preferentially distinguish among the isotopes. Mass-dependent fractionation occurs during oxidation and reduction transformations, biological cycling, and volatilization of mercury and can be used to increase our understanding of the processes that control Hg distribution and bioaccumulation. For example, lighter isotopes are more readily volatilized from surface-deposited mercury simply because they have lower mass and weaker bonds than heavier isotopes. Mass-independent fractionation (MIF)—anomalous deviation from the standard mass-dependent ratios—is the key feature in the mercury fingerprint. While the exact mechanisms of MIF are not well understood, they are thought to involve quantum effects at the nuclear scale.

Studies carried out in atmospheric, terrestrial, and aquatic environments have attempted to distinguish mercury sources and the relative role of cycling processes in the isotopic mix of mercury at particular locations. In one experiment, scientists studied mercury isotope fractionation in fish samples from New England lakes. The MIF signature indicated that fractionation had occurred in the upper parts of the home waterways at depths to which sunlight readily penetrates, implying that bioaccumulation of mercury through the complex food web of plankton, microfauna, and macrofauna did not further alter the MIF characteristics. These findings help explain which processes occur in the bioaccumulation of mercury in the food web and at what rates.

Connecting the Dots

EPRI research using mercury stable-isotope fractionation focuses on two areas: source differentiation and process identification. Current research along the Gulf of Mexico is looking at the isotopic ratios of different mercury species in atmospheric aerosols and rainfall samples. To characterize mercury dynamics in the overlying atmosphere, researchers are collecting samples in western Florida near a coal plant subject to a range of precipitation.

The research is investigating whether mercury isotope fractionation can indicate the depth of atmospheric mixing and whether mercury oxidants originate primarily in the upper troposphere, which is the global background pool, or in the marine boundary layer, which contains local and regional emissions. In one recent finding, distinct differences in mercury's isotopic composition in atmospheric samples imply that long-range transport of mercury is an important contributor to deposition in Florida. Though data analyses are ongoing, results to date show that natural processes, such as redox chemistry, as well as meteorology and long-range transport, drive mercury's atmospheric composition and deposition.

For more information, contact Arnout ter Schure, aterschu@epri.com, 650.855.2281.

Robot in the Works for Repairing Spent Fuel Liners

The used fuel from nuclear reactors is stored in spent fuel pools—concrete pools lined with sheets of stainless steel that are welded together and anchored to the walls and base slab. Pool liner integrity is particularly important because the water contains radioactive nuclides such as tritium and strontium-90. Leaks can affect the integrity of the concrete and reinforcing bars and, if not contained, can taint groundwater running under the site. EPRI and EDF have worked together on a number of approaches to handling this potential problem and are currently developing a robotic repair process that could reduce worker exposure and give long-lasting leak protection.

First Approaches

Early work focused on locating and assessing the severity of leaks. EDF developed a crack inspection method that uses a probe to induce a current locally into a suspect weld, thereby generating an electric field. Analysis of the electric field's characteristics yields information on the depth and length of a defect. A follow-up project developed a silicone patch and a manually operated apparatus for its application.

While effective when correctly employed, these technologies have some operational limitations: the inspection tool is unable to detect defects smaller than 80 mils mm in length, and the silicone repair apparatus must be set up and operated by a diver in the pool and later retrieved, requiring a second dive.

Application by Robot

To avoid such restrictions, EDF is working on a more versatile patching approach: a metal-coated polymer repair strip that can be applied over extended surfaces by a specially designed robot.

The robot can carry a 14-meter (46-foot) roll of repair tape, allowing it to cover a continuous welded seam from the bottom of the pool to the top. This eliminates the need to pinpoint individual flaws at different points along the seam. The repair strip is about 4 mm (0.16 in.) thick and 50 mm (2 in.) wide and is designed to provide effective repair for butt, lap, and plug welds, both horizontal and vertical. The goal is a repair that can be accomplished entirely by robot and that will last at least 10 years.

A successful repair robot needs to be reliable in a spent fuel pool's physical and nuclear environment: bottom pressure of 2.4 bar (35 psi), boric acid concentration of 2,400 parts per million, water temperature of 20°C–25°C (68°F–77°F), and radioactive dose rate of 200 gray per hour. Physical obstacles must also be taken into account, including ladders, posts, wires, and cables.

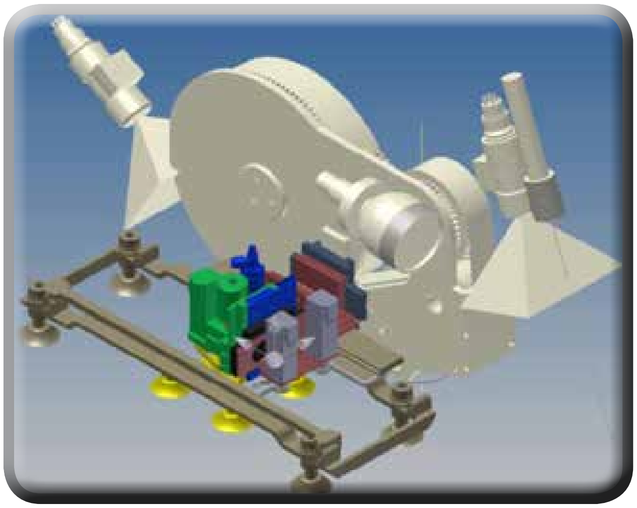
The robot must be able to achieve and maintain contact with the wall by means of suction cups incorporated in the tool's travel assembly. Front- and rear-facing cameras allow remote operators to monitor tape application and adjust the device's trajectory. Laser pointers assist with device alignment and help the operator estimate distances.

Although the robot is being designed to carry out some programmed routines automatically via a computerized controller, it can also be operated manually, with the computer offering assistance with fine-control alignment correction. The robot is expected to move at 0.5–2 meters per minute (1.6–6.6 feet per minute) during strip application. Operators can abort the procedure by pushing a button, which inflates a buoyancy balloon that floats the device quickly to the surface.

Continuing Work

As part of the integrated robot design, a prototype tape dispenser is being refined to address technical and practical challenges. Lap welds are of particular concern because the higher surface on one side of the weld can cause tape stretching and alignment problems. Such issues are being investigated in bench-scale tests to evaluate the effectiveness of repair strip application, optimal suction cup size and positioning, repair strip cutting-blade design, and control wire management.

For more information, contact Greg Frederick, gfrederi@epri.com, 704.595.2571.



General design of a robot able to apply a repair strip

EPRI Refines the Search for Radiation-Resistant Materials

As nuclear plant owners seek to extend reactor operation beyond original design lifetimes, limiting the degradation of structural components becomes especially important. Irradiation can lead to void swelling, stress corrosion cracking, and reduced fracture toughness in austenitic alloys, especially in components and fasteners near the reactor core. While nuclear plants have successfully managed materials aging to date, higher irradiation levels accumulated over extended operating lifetimes could accelerate degradation.

To reduce these concerns, EPRI is exploring the development and use of advanced, radiation-resistant materials that are optimized for in-core use. Such new alloys—employed in the near term for replacement components and incorporated over the longer term as standard materials in next-generation plants—will allow utilities to operate reactors with greater efficiency and reliability and reduce maintenance, inspection, and repair costs.

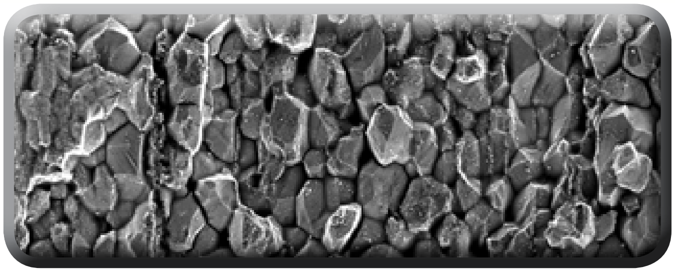
The research program has two primary objectives: by 2021, to develop and test a degradation-resistant alloy that lies within current commercial alloy specifications; and by 2024, to develop and test two or three advanced alloys with superior degradation resistance. This two-pronged approach will ensure that a code-qualified, damage-resistant material is available for use by vendors and utilities near term and will allow extensive testing on new advanced materials to ensure superior performance to very high doses.

Narrowing the Field

The wide range of candidate alloys includes both low-strength materials (Alloy 690 and Zr-2.5Nb, for example), which would be suitable for normal structural applications such as core shrouds and baffle plates, and high-strength materials (Alloys 625 and 725) for use in applications such as bolting.

Extensive testing and characterization of candidate materials will yield data on physical constants, thermal properties, mechanical properties (such as fatigue strength and fracture toughness), metallography, corrosion resistance (including hydrogen embrittlement and environmentally assisted fatigue), irradiation properties (such as swelling and stress relaxation), and ease of processing and fabrication.

Because it is impractical to generate all of this information for all candidate materials, EPRI—working with the U.S. Department of Energy(DOE)—has narrowed the field of choices through a process based on a range of attributes for the candidate materials under both unirradiated and irradiated conditions. These attributes include strength, fracture resistance, resistance to stress corrosion cracking, cost, and fabricability. The selection process is described in a critical issues report (1026482) coauthored by EPRI and DOE. The report has been widely reviewed by international experts on radiation damage.



Specimens of irradiated stainless steel tested in high-temperature water show signs of cracking at grain boundaries.

The report provides a detailed review of the irradiation behavior of the various classes of materials that are being considered as possible candidates for advanced radiation-resistant materials in light water reactor (LWR) internals applications. These classes include austenitic stainless steels, ferritic/martensitic stainless steels, oxide dispersion–strengthened ferritic/martensitic alloys, nickel alloys, innovative materials such as multilayer composites and ultrafine-grain materials, and refractory alloys.

The report does the following:

- Describes the strengths and weaknesses of each material with regard to its use in LWR internals applications.
- Identifies knowledge gaps; ranks promising candidate alloys.
- Provides an overall roadmap for the material's development.

The proposed work will be done through an international collaborative program that will include EPRI and DOE.

Project Timeline

Time and resource constraints limit the testing of all promising alloys in actual reactor conditions, so much of the testing and screening will be carried out by means of proton and heavy ion irradiations, followed by laboratory tests. Only materials that perform well in these more rapid, less expensive tests will be tested under actual reactor conditions.

Interim results documenting the microstructural, mechanical, and stress corrosion cracking studies of proton-irradiated alloys will be available late in 2015, with a final report in 2017. Early results of the neutron-irradiation studies are expected by the end of 2019, followed by irradiation to high neutron doses in fast reactors and possibly in actual LWRs.

For more information, contact Raj Pathania, rpathani@epri.com, 650.855.8762.

Water Research Center Investigates Tools and Technologies

A new water research facility under collaborative development by Georgia Power (a subsidiary of Southern Company), EPRI, and the Southern Research Institute will be a major focal point for research on water management tools and treatment technologies in power plants, the first of its kind. The Water Research Center (WRC) at Plant Bowen, near Cartersville, Georgia, will host collaborative research supported by a dozen additional power companies.

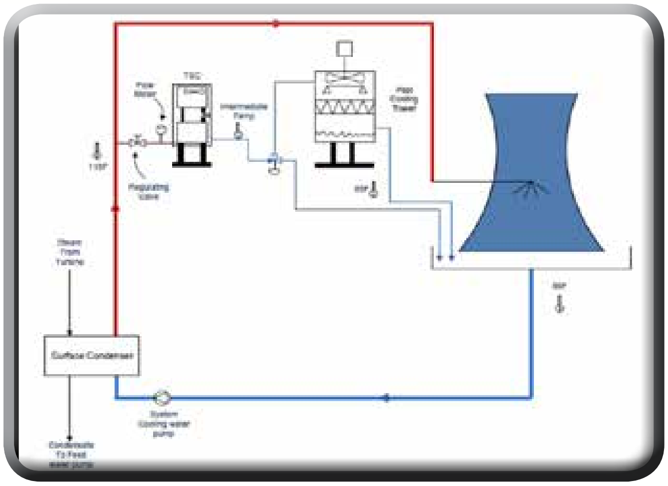
The center will provide electric generating companies, research organizations (including EPRI), and vendors with access to pilot-scale infrastructure, treatable water, monitoring and analysis facilities, and specialist staff for conducting plant-based water research studies in the field. Users will be able to bring a technology or process to the WRC—a chemical additive, membrane, or biological medium, for example, or even a skid- or trailer-mounted pilot unit. The Southern Research Institute, as the facility operator, will install the process, run the tests, make the measurements, and document the findings.

Testing for Best Practices

Research conducted at the WRC will provide insights into best practices for sustainable water management and meeting wastewater restrictions. Specifically, the center will evaluate technologies for reducing water consumption and improving wastewater treatment. Research will examine advanced cooling-water technologies, biological and inorganic wastewater treatments, zero liquid discharge systems, solid landfill water management approaches, and water conservation technologies (including moisture recovery from flue gas). Pilot units are currently being tested, and the on-site analytical lab is fully equipped. Infrastructure for wastewater treatment (physical/chemical and biological) is expected to be ready for use by summer, and flue gas supply-and-return ductwork is being installed for flue gas–driven thermal evaporation and for post–flue gas desulfurization moisture recovery for operation by mid-summer.

First Project—Thermosyphon Cooler

Various technologies are candidates for performance testing. The first cooling-water project will evaluate a thermosyphon cooler (TSC) developed by Johnson Controls. The technology transfers a portion of a plant's heat load to the environment without evaporative water loss by using an air-cooled refrigerant that cools water before it enters the cooling tower. The TSC cooler unit itself employs a dry heat rejection technology that uses natural convection to circulate a refrigerant between a shell-and-tube evaporator and an air-cooled condenser. Heat is transferred from the hot power plant condenser return water



Configuration of the thermosyphon cooler and pilot cooling tower at Plant Bowen

through tube walls to a refrigerant boiling in the evaporator. The resulting vapor refrigerant then flows up by natural convection to an air-cooled condenser.

In the air-cooled condenser, heat is transferred to ambient air drawn by fans over coils through which the refrigerant flows. The refrigerant condenses and flows by gravity back to the evaporator to repeat the process. Because evaporation and condensation are both constant-temperature processes, this configuration brings the temperature of the condenser return water closer to the ambient air temperature than in a conventional air-cooled condenser.

The TSC requires energy only to operate the fans that move ambient air over the condenser. No refrigerant pumping is required, because the refrigerant is transported from the evaporator to the condenser by the difference in vapor pressure between the evaporator and the condenser.

The TSC can be installed upstream of a conventional cooling tower to reduce the amount of water that must be evaporated. Some plants may be able to use the TSC in lieu of a conventional cooling tower.

A pilot unit has been installed on a side stream of cooling water from the Bowen Unit 4 cooling tower and in series with a small pilot mechanical-draft cooling tower for 12 months of testing. The WRC tests will determine how much water can be saved by operating a TSC in series with a conventional wet cooling tower. Researchers will also calculate the energy penalty incurred and determine the most effective means for scaling up the TSC.

For more information, contact George Offen, goffen@epri.com, 650.855.8942, or Richard Breckenridge, rbreckenridge@epri.com, 704.595.2792.

Understanding—and Accounting for—the Value of Ecosystems

Natural ecosystems provide important benefits for society and business, including clean water, biological species diversity, and flood regulation.

Societies derive many essential goods from natural ecosystems, including crops, timber, and pharmaceutical products. For the electric power industry, ecosystems provide services that are important in several ways. Some services, such as supplying cooling water, are directly related to the process of power generation. Others, such as erosion control or wastewater treatment by wetlands, can reduce the cost of operations and environmental compliance.

The power industry holds lands that host these services. As ecosystem protection becomes a greater global priority and preservation policies become increasingly regulated, the management of a company's ecosystem services may become an important part of its corporate sustainability. EPRI is helping its members understand their role in protecting and using these valuable land assets.

Ecosystem Services as Liabilities and Assets

Because of laws such as the Clean Water Act and the Endangered Species Act, the presence of some natural resources on private land has historically been a liability. However, with environmental markets that recognize the financial value of carbon, biological species, wetlands, and improved water quality, liabilities can become financial assets. Companies may be able to buy credits for cost-effective environmental compliance; sell valuable ecosystem-rich lands to increase revenue; or, in some cases, sell compliance credits to others. Such actions are particularly attractive because they can provide benefits to many stakeholders and to society. Additionally, there is now recognition that managing environmental impacts may not always involve an engineered solution. Solutions also come in the form of enhancing the ecological functions of otherwise undervalued landholdings.

A frequently cited successful ecosystem services project is New York City's clean water supply. Drinking water for the city comes from three watersheds far upstate in the Catskills region—a rural area of farms, forests, small towns, and growing suburban developments. Water from these watersheds has historically been so pristine that, with a rare dispensation from the Environmental Protection Agency(EPA), drinking water has remained essentially untreated. By the late 1980s, however, agricultural runoff and sewage from septic systems were beginning to degrade this natural purification system. When the water quality dropped below EPA standards, New York City was forced to consider building a drinking-water filtration plant, at an estimated capital cost of $4 billion to $6 billion plus $250 million annually in operating costs. By investing instead in the natural watershed system, New York City was able to avoid those costs. The city purchased conservation easements, which permanently limit a property's uses and development to protect its conservation value; the easements provided for protection of the watersheds' water-filtering forests and for upgrades of the local septic systems. The cost of this investment in ecosystem services was about $1 billion, saving the city around $6 billion.

In some cases, the key is just recognizing and formally establishing the ecological value of an environmental asset. For example, by having EPRI analyze the economic value of ecosystem services for some land it was selling in the Canaan Valley, Allegheny Power was able to realize substantial tax savings from the transaction. The traditional real estate appraisal valued the land at $16 million. But EPRI's assessment identified the diverse and unique species there—600 plant species and 300 animal species—including several that were listed as endangered. In light of these environmental benefits, the appraisal was revised to $33 million on the basis of the price of associated credits in environmental markets. Allegheny Power sold the land for $16 million under "bargain sale" tax provisions to the United States Fish and Wildlife Service for use as a wildlife refuge and claimed a donation of $17 million, realizing more than $5 million in savings after accounting for other expenses.

Decision Framework

It is important for utilities to understand their ecological assets, as well as the tools and guidelines for measuring and reporting them. Advancement of this understanding will enable industry leaders to manage ecosystem services strategically and to link positive outcomes for these assets to financial benefits and regulatory compliance (see EPRI report *An Overview of Ecosystem Services: Considerations for Electric Power Companies*, 1024953).

To provide structure, EPRI has developed a decision-making framework (1026845) to determine what ecosystem services (for example, pollination, climate regulation, water filtration) are relevant in various corporate decisions; when it is important to consider ecosystem services (in preparation for land purchases, sales, management decisions); and how this consideration should be done (by means of models, site visits, desk studies). EPRI will test the framework and anticipates it will facilitate a more quantitative business case for consideration of ecosystem services in day-to-day decisions at power plants.

For more information, contact Jessica Fox, jfox@epri.com, 650.855.2138.

BWR Plant Jet Pump Test Facility

Plant changes such as power uprates, new fuel designs, and changes in fuel-burning strategies can lead to increased flow-induced vibration in boiling water reactor (BWR) plants' jet pump assemblies. More than half the BWR plants in the United States, as well as several BWRs elsewhere in the world, have experienced jet pump degradation caused by flow-induced vibration. In one plant, such degradation resulted in a substantial crack in the jet pump riser that extended two-thirds of the way around the riser's circumference.

Through its Boiling Water Reactor Vessel and Internals Project (BWRVIP), EPRI has been investigating the phenomena thought to cause the degradation and demonstrating jet pump vibration mitigation techniques that can be installed in BWR plants.

Main pump and motor assembly used at the jet pump facility. The pump has a capacity of 10,000 gallons per minute.

A Test Bed for Vibration

Research began with the compilation of plant survey data on jet pump degradation, plant operating history, and repairs; the survey was completed in 2010 and published as a BWRVIP report (1022838) in late 2011. Three vibration phenomena were identified as possible contributors to degradation problems: slip joint leakage flow instability, turbulent flow, and pump vane passing-frequency loading. To investigate these phenomena in greater detail and relate them to plant operation parameters, EPRI funded the design, construction, and testing of a full-scale jet pump test facility.

The facility is configured to represent prototypical BWR/4 or BWR/5 jet pump assemblies (one riser and two jet pumps) and to operate at a drive flow of up to 10,000 gallons per minute (38 cubic meters per minute) (full flow) and at pressures of up to 555 pounds per square inch(3.9 MPa) absolute. The facility is equipped with automated temperature and pressure control, and multiple parameters can be manipulated remotely, including set-screw gap, wedge position, water temperature, M ratio (suction flow/drive flow), and slip joint differential pressure. The facility's high-speed data acquisition system collects information at the rate of 2,000 samples per second.

BWR/5 jet pump testing, conducted in 2011 and 2012, met all design objectives, including system pressure, temperature, flow, and specific jet pump operating ranges. As detailed in a report on the work published last year (BWRVIP-263, 1026577), the testing established a relationship between slip joint differential pressure and M ratio and also reproduced the high-level vibration and slip joint leakage flow instability phenomenon at issue for jet pump degradation. In addition, the tests determined the effect of variation in key parameters on the onset of slip joint differential pressure and resulting jet pump acceleration magnitude.

Vendor Testing

In June 2012, vendors began testing their solutions to flow-induced vibration at the facility in the BWR/5 configuration. Testing of the BWR/4 jet pump configuration and associated mitigation devices is also under consideration.

For more information, contact John Hosler, jhosler@epri.com, 704.252.0780.

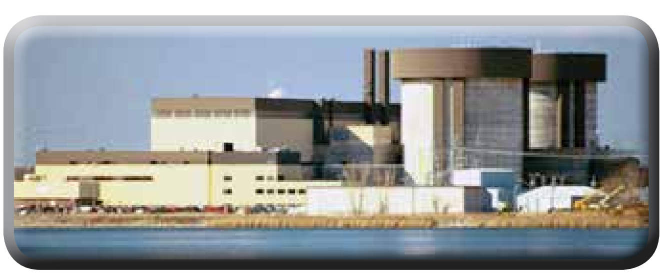
Fleetwide On-Line Monitoring

Exelon Nuclear operates the United States' largest nuclear fleet, producing about 20% of the country's nuclear power from 17 reactors in Illinois, Pennsylvania, and New Jersey. The large number of units and their wide geographic dispersion present logistical challenges for both day-to-day maintenance and broader corporate planning and operations. For over 20 years, EPRI has collaborated with nuclear plant owners, the U.S. Department of Energy, and other public and private entities to develop on-line monitoring technology to promote overall plant health, detect incipient problems, and improve operations and maintenance productivity. Drawing on this experience, EPRI has worked with Exelon to set up an on-line system that can collect and analyze component condition data in real time from across its entire fleet.

Identifying Problems and Trends

Although it is used extensively and effectively in other industries, on-line monitoring is still in the early stages in the nuclear power industry. To support broader application, EPRI has published guideline reports incorporating operating experience and lessons learned from successful implementations over the past two decades. In particular, the reports *Guideline for On-Line Monitoring of Nuclear Power Plant Instrument Channel Performance* (1022988) and *Requirements for On-Line Monitoring in Nuclear Power Plants* (1016725) provide the necessary guidance and requirements for implementing on-line monitoring in both existing and next-generation nuclear plants. Exelon followed these guidelines to set up its system, with EPRI's support.

The heart of the Exelon system is advanced pattern recognition technology adapted by EPRI from technology in development at the national laboratories. The system monitors an array of instrumentation and control sensors that measure such process parameters as temperature, pressure, level, flow, and neutron flux, identifying differences from expected behavior that may indicate sensor degradation, process anomalies, or equipment problems. A server runs the advanced pattern recognition and other software tools to analyze the sensor data and evaluate equipment health and plant performance. Results are sent to systems engineers at each plant via e-mail or pager notifications, indicating when monitored components deviate from normal operating conditions.



The system not only identifies problems at an incipient stage—allowing ample time to take corrective action—but also allows insightful trending at individual plants and across the fleet. "The on-line monitoring program has largely automated the plant engineer's core monitoring and trending function and has halted several incipient degradation trends that could have resulted in equipment failure or a plant trip," said Mohammed Yousuf, senior staff engineer at Exelon. "For example, it identified a degrading temperature trend in the critical condensate/condensate booster system at one of our plants. The early detection helped the plant operators mitigate the degrading condition by balancing cooling water flow to the bearing, thus reversing the degrading trend. The loss of bearing in this case could have resulted in a power reduction of 150 megawatts and diverted valuable plant resources from scheduled tasks to unplanned work during a hot summer day."

Ongoing Work

Building on their early-warning successes, EPRI and Exelon are advancing the technology to perform the next essential step—automatically diagnosing the underlying causes of abnormal conditions. Fleetwide monitoring with both diagnostic and prognostic capabilities could enable plant engineers to closely manage operating conditions that might shorten an asset's remaining life.

To that end, EPRI is developing its Fleetwide Prognostic and Health Management Suite, a software solution designed for compatibility with existing nuclear power plant troubleshooting and asset management processes and capable of leveraging tools already used for on-line monitoring. A research-grade version of the software is available to EPRI members that have sponsored its development.

Such advances are supported by EPRI's Fleetwide Monitoring Interest Group, which provides a forum for utilities, researchers, and vendors to exchange information and experiences on all aspects of fleetwide monitoring. Topics covered include equipment condition monitoring, thermal performance monitoring, operations and maintenance effects of a fleetwide approach, cost-benefit analysis, and identification of R&D and technology gaps.

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Strategies Developed to Reduce Radiation Exposure in Nuclear Plant Refueling Operations

Improved operational practices and the successful deployment of several technologies to reduce the radiation exposure of nuclear plant workers have assisted the industry in achieving results that are much lower than the current regulatory limits. However, activities directly related to refueling operations continue to account for a significant portion of total cumulative fuel-cycle exposure and of individual exposures for a segment of the industry's highest-dose workers. Finding and validating improved dose-reduction options for refueling activities will be important for continuing to meet current standards and responding to future standards and goals.

To investigate the possibilities, EPRI put together a refueling dose-optimization working group, which included representatives from utilities that operate pressurized water reactors (PWRs) and boiling water reactors (BWRs), refueling-related vendors, and the Institute of Nuclear Power Operations (INPO). General direction and focus for the group were informed by a 2010 EPRI industry-wide study of worker dose and exposure for specific tasks (1021100).

Analyzing Issues on Site

The working group spent two days at each of two host sites—Exelon's Dresden BWR and Luminant's Comanche Peak PWR—to review detailed site data related to refueling activities, radiation fields, radiation sources, and reactor-specific challenges to exposure reduction. The collective site and industry data were used to complete a gap analysis using site and industry best practices, operating experiences, and standard practices. Participants used their site- or task-specific knowledge and experience to identify opportunities for improvement, focusing particularly on refueling efficiency, radiation field reduction, and reductions in individual and cumulative personnel exposure.

The identified opportunities were subsequently analyzed to determine the need for development of alternative or new technologies, the challenges to technology implementation, and good practices. For each technology, the group evaluated and documented industry experience, current state of development, and applicability to refueling dose-reduction initiatives—determining, to the extent practical, the technology's effectiveness, challenges, benefits, and the lessons learned in its historical applications.

Assessment Results

A number of opportunities were identified during the course of this project that could be of direct benefit to refueling dose-reduction programs:

- Outage planning: Including a dedicated specialist in ALARA ("as low as reasonably achievable") technology in the planning process results in a more efficient and effective outcome. Use of three-dimensional dose modeling based on EPRI-developed dose-rate algorithms also shows promise for optimizing planning and performance.
- Reactor cavity process optimization: Increasing the purification flow rate and adding submicron submersible filters and submersible demineralizers can reduce the cavity radionuclide and crud inventory. In BWRs, reactor water cleanup systems should be optimized and, if necessary, augmented with portable systems.
- Reactor disassembly and reassembly: Use of automated closure systems that manipulate multiple reactor head studs simultaneously can reduce personnel exposure and reduce critical path times for the outage.
- Radiation field reduction: Custom head-shielding packages, advanced remote shielding, temporary shielding on bridge cranes and work platforms, and molded flexible shielding materials can all reduce worker doses.
- Cavity decontamination: Underwater robotic cleaning and inspection systems show great promise for reducing personnel exposure, eliminating industrial safety hazards, and improving the outage schedule and critical path times. A number of robotic cavity-decontamination options are currently being investigated jointly by EDF and EPRI.

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REPORTS & SOFTWARE

Key deliverables now available

The following is a small selection of items recently published by EPRI. To view complete lists of your company-funded research reports, updates, software, training announcements, and other program deliverables, log in at www.epri.com and go to Program Cockpits.

Predicting the Potential Polychlorinated Biphenyl (PCB) Concentration in Electrical Equipment (1023748)

One alternative to testing individual oil-filled transformers for PCB contamination is to correlate equipment serial numbers or other purchasing information with known manufacturing sources of contamination, such as plants where both Askarel and mineral oil transformers were filled. In a 2010 study, EPRI collected and analyzed data from electric utilities across the country, developing a set of tables and a methodology for predicting the likelihood of electrical equipment PCB contamination.

Protective Coatings Assessment: Laboratory and Field Evaluations of Ceramic and Thermal Spray Coatings (1023899)

Waterwall panels in coal-fired boilers are generally covered with protective coatings to reduce fireside corrosion under low-NOx operation. This EPRI study investigated currently available protective coatings as well as new compositions that may offer better resistance to corrosion, cracking, and slagging. Laboratory tests indicate that the longevity and effectiveness of protective coating solutions depend greatly on coal quality, unit operation, slagging propensity, and installation locations.

Catalyst Management Handbook for Coal-Fired Selective Catalytic Reduction NOx Control (1023923)

The information in this report provides a basis for selective catalytic reduction (SCR) operators to identify a schedule and approach for catalyst replacement or supplementation that will minimize the impact of SCR NOx-control process equipment on power-production cost. The report describes the results of three reference cases, distinguished by coal type: two eastern bituminous coals with different arsenic levels and one Powder River Basin coal.

Overhead Transmission Inspection and Assessment Guidelines—2012 (1024111)

The objective of these guidelines is to provide a self-contained, state-of-the-art resource on transmission line inspection and assessment methods, including technology that is sufficient for the day-to-day needs of both experienced and novice asset managers, inspection personnel, and other maintenance stakeholders. The 2012 guidelines include a reference guide—known in the industry as the Yellow Book—field references, and training resources.

Continuing Efforts for Efficiency Improvements in Electronic Power Conversion Devices (1024341)

This report reviews progress in developing a universal test procedure for measuring the efficiency of all internal ac-to-dc power supplies, regardless of product category and form factor. Highlighted is a test procedure developed by EPRI and ECOVA for computer power supplies that has been accepted by the power supply industry and the EPA's ENERGY STAR program. EPRI efficiency assessments of uninterruptible power supplies, networking devices, and gallium nitride devices are included as well.

Plant Engineering: Medium-Voltage Transformer End-of-Expected-Life Guidance (1025261)

Using empirical methods and input from industry subject matter experts, this report examines the onset of end-of-life failure mechanisms for medium-voltage liquid-immersed and dry-type transformers at nuclear power plants. The report discusses condition-based monitoring techniques, typical lead times from the detection of specific problems to the point of failure, and the logistics of contingency planning and transformer replacement.

Advanced Nuclear Technology: Quality Control of Concrete During Construction—Voids Detection (1025300)

Early detection and repair of honeycombs and voids in concrete structures during the construction of nuclear power plants can decrease degradation that often appears only after 30 or 40 years of plant operation. This report describes the development of sensors that can be installed in typical construction tools to increase quality control in real time and enable repair of newly poured concrete while it is still fresh.

Generator Fan/Blower Design, Inspection, and Maintenance: Best Practices (1025335)

These best-practice guidelines present survey information from owners/operators, manufacturers, service providers, insurance companies, and independent consultants on inspection practices, failure histories, root-cause failure analyses, and corrective actions for generator rotor cooling fans and blowers. Follow-up interviews were conducted, and the resulting best practices are documented in the form of case studies, which are included in the report appendices.

WIRED IN

Perspectives on electricity

Bruce Rogers, *Director of Technology Innovation, TVA*

Why Electrify? It's All About the Power Consumer

Since its earliest days, the Tennessee Valley Authority (TVA) has promoted electrification as a way to improve the quality of life.

In the 1930s, TVA built dams to harness the region's rivers, control floods, improve navigation, and generate electricity. Electricity brought dramatic change to life in the Tennessee Valley as electric lights and modern appliances made life easier and more productive for its residents. Electric appliances could better perform essential, recurring tasks such as storing fresh food, cooking and cleaning, and heating water and homes. TVA promoted electrification, and consumers rapidly invested to bring its benefits into their daily lives.

That tradition continues as TVA works with local power companies to help consumers get more value from their electricity dollar. Homeowners save money with technologies such as heat pumps, electric water heaters, and efficient lighting. Commercial and industrial customers benefit through holistic approaches to electrification that maximize efficiency, control expenses, and boost their bottom line. As in the 1930s, our electrification strategy today is to help consumers produce more in less time at a lower cost and with greater reliability.

An example in industry is non-road electric transportation. Studies show that users can lessen the environmental impact of their operations, reduce life-cycle costs, and improve operating efficiencies by adopting electric-drive equipment for non-road and stationary goods—moving applications. TVA has conducted market studies in Memphis, Tennessee, proving this for equipment such as airport tugs and forklifts used in warehousing, shipping, and manufacturing.

By no means is TVA alone in promoting industrial electrification. In November 2012, TVA. Memphis Light, Gas & Water; and EPRI hosted an executive summit in Memphis to launch a national electrification initiative. Utilities from across the country gathered to discuss how to help our clients identify and apply smarter applications of our product. The top takeaway: electrification takes root only when the benefits to the consumer are clear, well communicated, and sustainable.

To that end, a couple of thoughts dominated our discussion:

- Electrification is not about the utility, it's about the power consumer. While efficient electro-technologies can benefit the utility, the biggest benefits must be realized by the consumer for there to be significant market adoption. Utilities must focus on how technology can lower cost, improve quality and productivity, and enhance environmental performance for the consumer.
- Electrification can occur in any market segment. While electric transportation is an emerging market with numerous electric vehicle and shipping applications, electrification can play a role in most any setting where it provides economic or performance benefits to an end-use consumer. To find the best value, we have to spend the time to understand our customers' processes and needs.
- Electrification is more than fuel switching. Businesses are facing economic pressures to remain competitive, utilities are seeking value-added services to help customers, and society wants to improve the environmental quality of life through reduced carbon emissions. Electrification has the unique potential to be a win-win-win for these constituencies.
- Electrification requires proof points. Power consumers need a clear message, a cost-benefit analysis, and metrics to make informed decisions and track efficiencies. To expand the discussion of electrification, we need to collect and share stories of sustainable success.

The ongoing success of our individual and larger industry electrification efforts will come from communication and collaboration among utilities and our partners. As we work together through EPRI's national initiative, our industries and power consumers can realize tremendous value from our shared electrification innovations and accomplishments.

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