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Materials for the Future

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Preparing for Solar Max

Accelerated FGD Corrosion: Understanding the Cause, Finding a Solution

Managing Radiation Exposure

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, 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 more than 90 percent of the electricity generated and delivered in the United States, and international participation extends to 40 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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Our Challenge

“In addition to asking what we must do, we must ask how we go about it. Two words come to mind: *Think big.*”

The challenges facing the electricity sector are so numerous that they can compel us to focus on the trees and not the forest. Although it’s necessary to address the challenges individually, we should not lose sight of what I consider our overarching technical challenge: to produce power in a cleaner, near–zero emission generation fleet and deliver it over an interactive electricity grid, while keeping electricity affordable.

EPRI’s research shows that we can meet this challenge, but it will require a disciplined and sustained effort focused on research, development, demonstration, and deployment of innovative technologies. Here are six major areas where we must focus

- Improve electrical efficiency end-to-end. We need to look at end-use technologies such as LED lighting and more efficient power supplies for consumer electronics, but also at power delivery system efficiency through voltage optimization, and at improving power plant efficiency -- through traditional areas such as improved heat rate and in innovative areas such as capturing plants’ waste heat for re-use.
- We need for renewable energy technologies to become more cost effective at large scales, and we need a diverse portfolio of these resources to match regional resources and markets. Also, for effective, reliable grid operations, we must be able to balance demand with variable-output electricity sources.
- We have already set the bar high for safe, reliable, and effi-

cient operation of our existing transmission, distribution, and generation assets, including our nuclear fleet. We must raise the bar while building public confidence in the goal to extend nuclear plant operating licenses and add new nuclear generation.

- Manage an economic transition to a lower-emission fossil generation fleet, including the use of carbon capture and storage for coal and natural gas generation.
- The "smart grid" has captured the public imagination, but we must address many technical and operational challenges before we have a grid that can balance diverse supply-side and demand-side resources in the kind of dynamic environment that a smarter grid will both create and serve. The demands of our computer-driven economy require ever more exacting standards of reliability and power quality. This will continue to drive innovation in technology, how we operate the power delivery system, and how it interfaces with customers.
- We should begin now to address the long-term challenge to manage much more strategically our limited, essential water resources. The electricity sector will be just one competitor for this increasingly constrained resource, necessitating that we minimize our use and effectively manage our discharges.

In addition to asking what we must do, we must ask how we go about it. Two words come to mind: *Think big.*

Think big for each technology. Aim for new benchmarks for reliability and efficiency. Think big for the environment. The world will add billions of people in the decades ahead, and if we don't provide them with electricity, they will never achieve the levels of health and prosperity necessary to sustain themselves and the environment on which we all depend.

Think big for the satisfaction of thinking big. For us who work in research and development, progress often comes in small increments. That provides us with job satisfaction, but we also get satisfaction from thinking big—for challenging ourselves to make significant advances in knowledge and technology.

Think big picture. Imagine how we can apply innovations from other economic sectors—from information technology, from social networks, from bio-technology, and transportation.

Think big consequences. Test every assumption and hypothesis. As research and development moves new technology forward, we subject it to rigorous, objective engineering and economic analysis to assess its benefits and its costs. Our existing power infrastructure represents an enormous investment of research, development, and wealth. As much as any industry in the world, the electricity sector's customers, investors, and stakeholders expect it to know where it is going before it sets out. Also, we need to communicate how we will get there -- to provide "R&D roadmaps" so that all stakeholders have a clear understanding of the road ahead.

Think big adventure. Yes, the stakes are high. Yes the challenges are daunting. But as we tackle the challenges, we can realize job satisfaction that is second to none. I expect that many of the next generation's best scientists and engineers will be drawn to the electricity sector because they will recognize in our challenge the big opportunities and the big adventures that lie ahead.

Mike Howard
President and Chief Executive Officer

Closed-Cycle Cooling to Get a Closer Look

The U.S. Environmental Protection Agency recently released proposed regulations implementing §316(b) of the Clean Water Act; the proposed revisions establish requirements for cooling water intake structures to reduce impingement (pinning of aquatic organisms against cooling water intake screens or other parts of the intake structure) and entrainment (passing of aquatic organisms through intake screens and into and through cooling water systems). Two of the options considered by the EPA included retrofits to closed-cycle cooling. An EPRI report released in January estimated the cost to replace once-through cooling systems with closed-cycle systems to inform the rule-making of designating closed-cycle cooling as "best technology available" for compliance. At that time, EPRI identified about 428 once-through facilities that meet a criterion of drawing more than 50 million gallons per day (MGD) of cooling water that could be subject to the use of closed-cycle cooling as the best technology available. The report estimated that the cost for retrofitting these facilities could exceed $95 billion. The proposed regulations require facilities using more than 125 MGD of intake flow to evaluate closed-cycle cooling, with the best technology available decided case by case.

The cost estimate includes net present value for the capital cost. Also included are revenue losses from extended outages to retrofit towers, as well as the heat rate penalty and parasitic energy losses that can result from substituting closed-cycle systems for once-through systems.

The estimate does not include the costs of acquiring additional land, debt to finance retrofit construction, labor and chemicals, permitting, electricity system upgrades, replacement generation, and replacement power.

The capital cost for individual plants varies tremendously. To arrive at cost estimates, EPRI assigned a difficulty rating, determined by 11 variables, for each of 125 plants that provided sufficient data in a survey. Variables included location and distance to the new cooling tower; geological and existing plant configurations that could interfere with construction; possible environmental mitigation; and the need to modify other parts of the plant. Difficulty ratings of "easy," "average," "difficult," and "more difficult" were chosen for fossil plants, while "less difficult" and "more difficult" were chosen for nuclear plants. Using data from independent cost estimates at 82 plants, a cost factor was calculated for each difficulty rating. The total capital cost was estimated by multiplying this cost factor by the once-through cooling-water flow rate. Results were extrapolated to all 428 potentially affected plants, and the resulting capital estimate was $62 billion.

Aerial view of Dunkirk, NY. The Niagara Mohawk power plant can be seen at left.

For work that could not be done while the plant is operating or during scheduled maintenance outages, costs associated with lost revenues were estimated to contribute $17.3 billion.

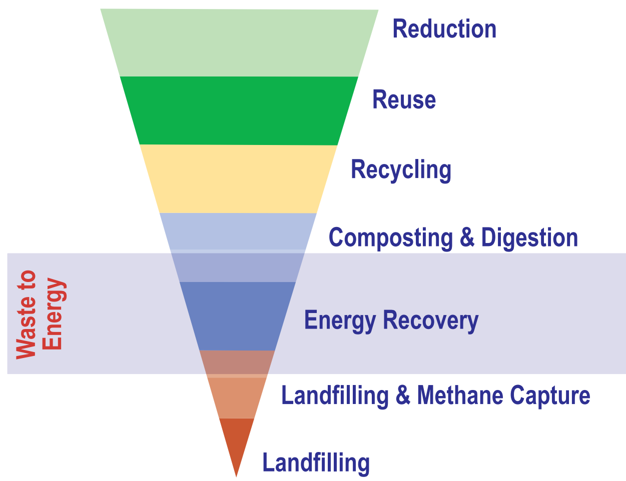
Retrofitting is expected to reduce energy output, and the resulting revenue loss is also included in the estimate. Part of the reduction occurs because closed-cycle systems almost always operate at higher temperatures than once-through systems. The resulting heat rate penalty increases turbine backpressure, reducing the amount of energy that can be extracted from the turbines. The heat rate penalty can depend on climate and time of year. Also, mechanical-draft cooling towers (the most common closed-cycle cooling systems) have parasitic losses to fans and water pumps, reducing the plant's energy output by 0.9% to 1.7%.

The net present value of losses due to the heat rate penalty is estimated to be $8.8 billion, while parasitic losses (to cooling tower pumps and fans) are estimated to contribute $7.1 billion to the cost.

For more information, contact David Bailey, dbailey@epri.com, 703.978.6226, or Doug Dixon, ddixon@epri.com, 804.642.1025.

Is the U.S. Waste-to-Energy Resource Going to Waste?

Waste-to-energy technology is regarded in some countries as a prudent means for reducing landfill use while generating power from a renewable source and reducing greenhouse gas emissions associated with landfills. Not so in the United States, where it remains unpopular. No new incinerators have been built since 1996, and more than half of municipal solid waste (MSW) still goes to landfills, according to a white paper, *Waste-to-Energy Technology: Opportunities for Expanding Renewable Generation and Reducing Carbon Emissions* (1022361), published in January by EPRI.



Environmental Hierarchy for Solid Waste Management

Incineration and advanced thermal conversion of the residual waste remaining after recycling and composting represent environmentally sound MSW management options.

Solid-waste incineration is the most common and most mature waste-to-energy technology. Landfill gas recovery systems are gaining popularity, primarily for reducing methane emissions, which have many times the global warming potential of carbon dioxide. Growing demand for landfill gas systems has kept the waste-to-energy resource second only to wind for load-serving generation from non-hydro renewable sources.

A third technology, anaerobic digestion, has the potential to reduce methane emissions and produce energy from agricultural sites and wastewater treatment plants.

The economic viability of solid-waste incinerators depends on an unusual mix of factors. Municipalities will pay a tipping fee to dispose of their waste at prices lower than landfill fees. Some states offer investment and production tax credits, viewing waste as a renewable energy source. In some locations, only the portion from biomass is considered carbon neutral, while in others, renewable energy credit is allowed for all burned waste, the reason being that any material in a landfill has reached the end of its useful life and can supplant fossil fuels. Other locations ban incinerators altogether on the basis of public perceptions that they are polluting and unattractive.

Detrimental to the cost of solid-waste incinerators is variable fuel quality and the need for labor-intensive handling and feeding to screen out toxic contaminants (such as mercury) or dangerous items (such as gas cylinders). The composition of solid waste can lead to high slagging and fouling rates and accelerated rates of corrosion and erosion. Necessary environmental controls also add to the cost.

Some of these problems potentially could be reduced by processing the waste into higher grades of fuel or syngas, which can be fired in fluidized-bed combustors or cofired in fossil fuel plants. This approach has the added benefit of removing recyclable and noncombustible materials before burning. However, a portion of the available energy must be used to convert the fuel, and specialized facilities have to be built, reducing the cost benefits.

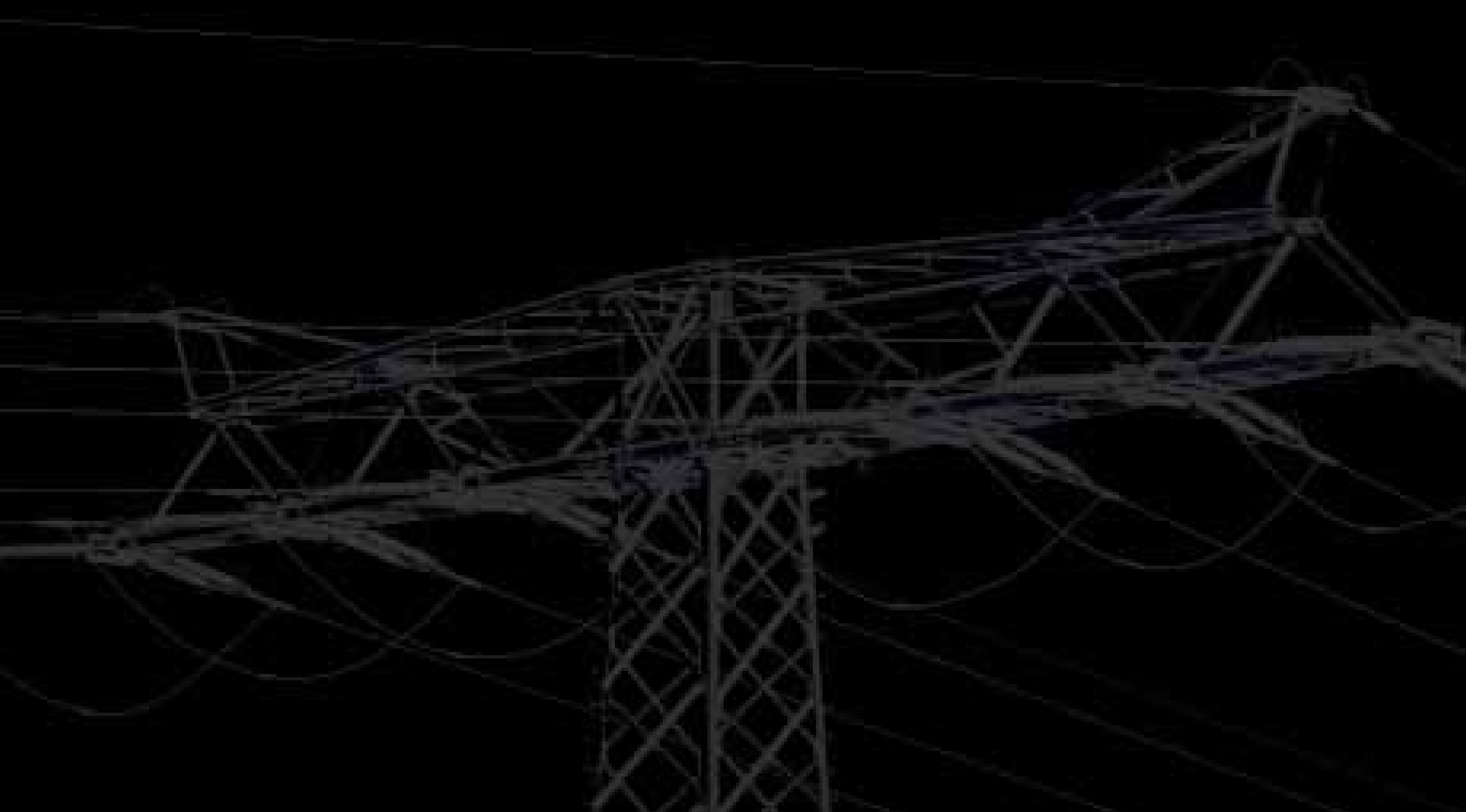
An EPRI analysis forecasts that U.S. waste-to-energy production could quadruple by 2030, assuming a market-based climate policy that would raise the cost of power from fossil fuels while also creating an incentive to reduce landfill emissions. A waste-to-energy program combined with conservation programs for reduction, reuse, recycling, and composting could reduce landfill use by 90% and methane emissions ninefold.

The EPRI white paper provides a foundation for a program of research, development, demonstration, and deployment opportunities that can improve the growth and acceptance of waste-to-energy technologies.

The paper also notes that support for this energy source would have to be broadened and strengthened. Stringent environmental controls and recycling programs have nearly eliminated emissions of dioxins, furans, and other toxic substances, which were problems with early solid-waste incinerators, and even stricter regulations have been proposed. Life-cycle assessments of emissions, costs, and benefits of waste-to-energy programs would help increase public acceptance. To help lower costs, new technologies and processes will be needed in such areas as accurate fuel measuring, transportation, sorting and fuel processing, digestion processes, emissions, and worker and plant safety.

For more information, contact Stan Rosinski, strosins@epri.com, 704.595.2621.

PREPARING FOR SOLAR MAX



In 1989 a severe storm knocked out Quebec's transmission grid, leaving millions of people without electricity for nine hours. The storm wasn't a blizzard sweeping from the arctic, but a stream of charged particles ejected by a violent solar eruption. The particles altered the earth's magnetic field, inducing disruptive currents in Hydro Quebec's power system, triggering the blackout, and damaging equipment, including a generator step-up transformer at a nuclear plant in the northeastern United States.

After the Quebec blackout, EPRI launched a series of research and development efforts to help the utility industry predict and prepare for geomagnetic disturbances and reduce their impact on electric power systems. Despite its severity, the solar storm that triggered the Quebec blackout was by no means the most powerful on record. In 1921 a storm 10 times stronger occurred, and 1859 witnessed the strongest solar storm on record, perhaps 50% more powerful than the 1921 event. While geomagnetic disturbances are possible at any time, they are statistically more likely to occur during the period of greatest activity in the solar cycle—called *solar maximum*. Historically, solar cycle maxima occur approximately 11 years apart, with the peak of the next solar cycle anticipated in 2012–2013.

THE STORY IN BRIEF

It's a high-impact, low-frequency event: A violent storm on the surface of the sun unleashes waves of charged particles that interact with the earth's magnetic field to disrupt power grids and perhaps trigger prolonged wide-area blackouts. With the next peak in solar activity expected in 2012 or 2013, EPRI is building on two decades of research to develop the knowledge and tools to understand, predict, and mitigate the impact of geomagnetic disturbances on power systems.

Priorities: Education, Vulnerability Assessment, Mitigation

"Given the high impact but low probability of a major geomagnetic disturbance from a solar storm, we need to understand the risks and mitigation options," said Luke van der Zel, EPRI Power Delivery and Utilization technical executive. In collaboration with transmission executives, EPRI has developed and is implementing an action plan focused on three key priorities.

"The first priority is education. This is a complex issue, and a clear understanding is essential for making decisions. The second priority is vulnerability assessment: what are the likely impacts on the electricity grid, and what are the dominant influences? The third priority is mitigation. For example, can we effectively block the disruptive currents or develop relaying technology to reliably trip transformers before damage occurs? Addressing these priorities can help utilities understand geomagnetic disturbances and reduce their impact on the power grid, as well as help guide further research and development efforts."

Geomagnetic Disturbances and Grid Impacts

A geomagnetically induced current has the characteristics of direct current (dc), and this dc is of particular concern when it flows through the windings of large transformers as a result of grounded neutral connections. It can saturate the transformer cores and cause internal heating that may lead to loss of transformer life or failure during a solar storm.

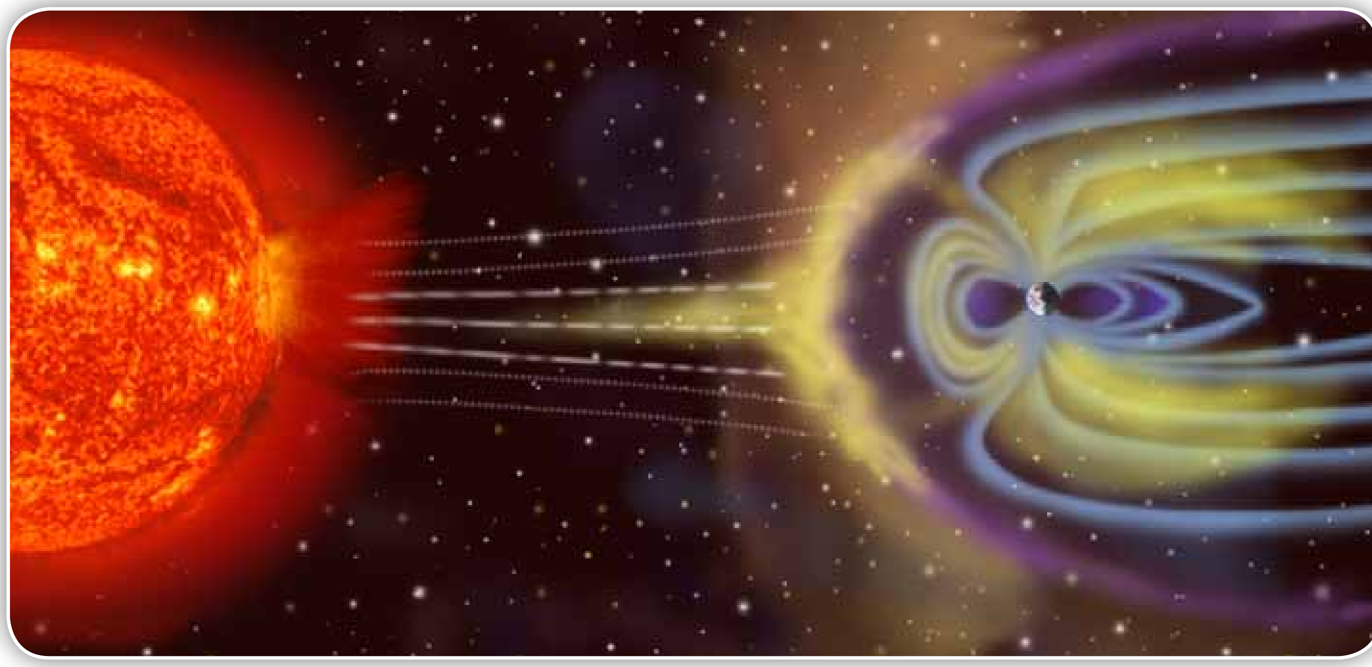
The impacts are not confined to the transformer itself but can affect the stability of the grid through changes in reactive power profiles and extensive distortions of the alternating current. Potential effects include overheating of auxiliary transformers; improper operation of relays; heating of generator stators; and possible damage to shunt capacitors, static VAR (volt-ampere-reactive) compensators, and filters for high-voltage dc lines. Grid operations may also be impacted by solar storm effects on GPS systems and communications.

Assessing Vulnerability

Several factors influence the impact of geomagnetically induced currents on the grid. These include line length and orientation, line resistance, ground resistance, and transformer design.

Greater line length poses an increased risk because of the increased potential difference at the grounded ends produced by the electric field induced on the surface of the earth. The lower dc resistance of transmission lines and transformer windings poses an increased risk because lower resistances provide an easier path for the flow of geomagnetically induced currents. Higher ground resistance poses an increased risk because it can lead to a greater potential difference between the ends of the transmission line.

The impact of geomagnetically-induced currents on transformers is design specific. Winding-core construction plays the major role in vulnerability; transformers



Magnetospere Rendition: Solar storms, which emanate from the sun as coronal mass ejections, can produce an impulsive disturbance to the earth's geomagnetic field over wide geographic regions.

with windings connected in a grounded Y configuration are the ones that are vulnerable. The internal core design further influences the vulnerability. The most vulnerable is a single-phase core design. The least vulnerable is a three-leg, three-phase core design. Transformers with grounded Y connections and other core configurations fall in the spectrum between these.

Risk also rises with latitude. Regions closer to the magnetic poles experience higher levels of geomagnetically induced currents. Performing a dc network analysis can help utilities understand possible system impacts during a geomagnetic disturbance and assess the vulnerability of system components during a solar storm. As early as 1983, EPRI had developed a computer program to model geomagnetically induced currents in power systems. Since then, simulation tools have increased in sophistication. Such studies typically produce a ranked list of substations at highest risk—with estimates of the induced current levels. Further understanding of system impacts can be gathered from a post-storm assessment that examines measured transformer neutral currents, overheating, gassing, and increases in reactive power consumption.

Prediction and Early Warning

Advance warning of an impending geomagnetic disturbance could provide valuable time to safeguard critical grid infrastructure before the storm's full impact. After the 1989 Quebec blackout, EPRI collaborated with utilities to install a small research monitoring network to collect data on geomagnetically induced currents. The network is called *Sunburst* and gathers data such as transformer phase currents, voltages, neutral currents, and hotspot temperatures, as well as electric and magnetic fields. Monitoring parameters that relate to grid impacts are valuable for three reasons, noted van der Zel. "The first is that monitoring data provide grid operators with real-time awareness of a storm's intensity. The second is that monitoring helps with analysis after a storm, assisting in mitigating problems during future storms. Finally, monitoring data are valuable inputs for developing improved forecasting models: comparing forecasts with actual values enables improvement in models." As an example, Sunburst data have been used to develop better forecasting models through a NASA project called *Solar Shield*. In this project, NASA scientists developed a chain of models that link images of solar activity to the resulting neutral currents in power system transformers.

Minimizing and Mitigating Risk

Forewarned of an approaching geomagnetic disturbance, utilities could take specific actions to minimize risk to the grid. Examples include:

- Monitor system voltages to anticipate the impact of increased reactive power consumption
- Maximize reserves for additional reactive power support or added load
- Stop scheduled maintenance in order to maximize asset availability in case a portion of the system should fail
- Add restraint to capacitor trip circuits
- Reduce loadings on susceptible transformers
- Reduce power transfers

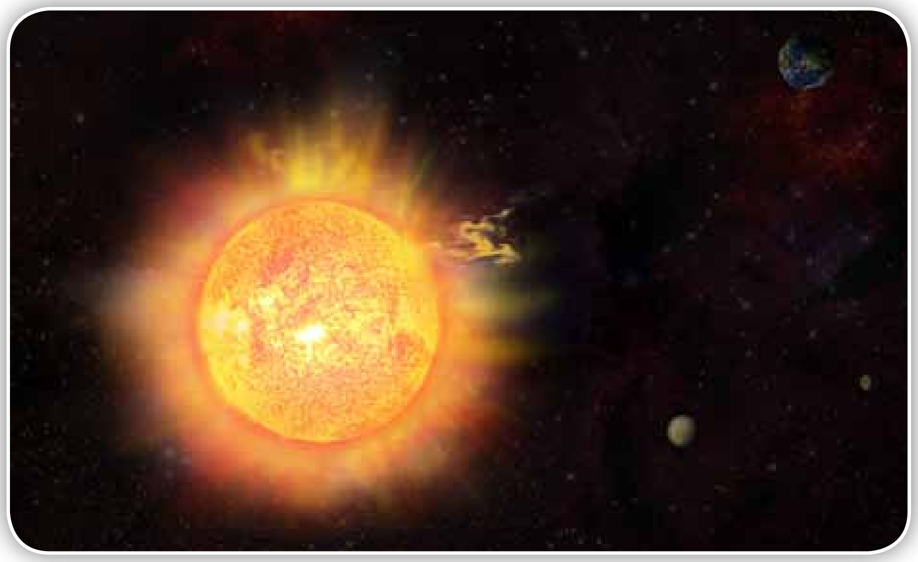
For existing transformers, numerous mitigation technologies have been proposed, including neutral blocking resistors or capacitors, polarizing cells in series with the neutral, series compensation on the line, and even active cancellation of the currents. Understanding the performance of potential mitigation solutions is an important focus of the research. It is vital to examine the possible impacts on transformer operation, both under normal load and under fault conditions.

R&D Action Plan

EPRI is pursuing research in the following areas to assess and reduce the risk of geomagnetic disturbances:

Improved storm warning to increase forecasting accuracy and lead times. This effort involves collaboration among experts, with EPRI Sunburst data providing key inputs into improved forecasting models. EPRI also is working with the North American Electric Reliability Corporation (NERC) on a project to develop a continental model that will help clarify likely impacts on the grid.

Increased real-time system awareness to support informed utility operations during storm conditions. EPRI is exploring three research areas to increase such awareness. The first is research assessing the use of existing microprocessor-based relays to measure and communicate induced currents in real time. The second is research to explore the use of EPRI's existing network of power quality monitors to examine harmonic generation in transformers during solar storms. The third is research on meaningful signal analysis of these data streams to allow an accurate assessment of the risk to a specific transformer and the risk to the grid as a whole. In addition, the data will serve as valuable input into future storm forecasting and assist with forensics of failed equipment.



Scientists study the surface of the sun for sunspot activity and early warning of coronal mass ejections.

Geomagnetically induced currents can saturate transformers, causing them to demand high levels of reactive support, produce large amounts of harmonics, and generate heat that can damage high-voltage and generator step-up transformers.

Increased utility collaboration to shape the R&D portfolio. EPRI has established a new interest group to shape the portfolio, better understand geomagnetic disturbances and other high-impact low-probability events; and share and document current industry best practices.

Said van der Zel, "Given the importance of this issue, the overall goal is to provide a portfolio of research to make the system and equipment more resilient and provide for rapid system restoration."

This article was written by David Boutacoff. Background information was provided by Luke van der Zel, lvanderz@epri.com, 704-595.2726.

Luke van der Zel is a project manager and technical expert in the Substations program area of the Power Delivery and Utilization Sector. His current research activities focus on SF_6 (sulfur hexafluoride) insulation, SF_6 leak detection, gas insulated substations, power transformers, geomagnetically induced currents, sensors for substation monitoring, and wireless applications for substations. Dr. van der Zel's research extends beyond the laboratory to field applications substations, where he helps in the practical aspects of EPRI's research results. He received both his B.S. and Ph.D. degrees in electrical engineering from the University of the Witwatersrand, Johannesburg, South Africa.

Managing Radiation Exposure

Rising Standards Drive Lower Limits and Technical Innovation

THE STORY IN BRIEF

Radiation protection is much more than protective clothing and personal dosimeters. Nuclear plant operators address radiation protection as a broad management discipline, encompassing engineered structures, detailed work planning, elimination of radioactive particles at their source, and even fundamental evaluation of biological impacts. As regulatory exposure limits ratchet down, EPRI research is developing tools and technical guidance to enhance worker safety and reduce dosages.

Japan's dramatic efforts at the Fukushima Daiichi nuclear power plant after the devastating earthquake and tsunami in March drew attention to nuclear plant workers and their exposure to radiation. Minimizing radiation exposure, however, doesn't happen only in extraordinary circumstances. As any nuclear plant manager will tell you, radiation management is a daily commitment, and success comes from using the right technology and employing effective work planning tools.

Federal regulations establish radiation exposure limits for individual workers to keep exposure rates "as low as reasonably achievable," or ALARA, during day-to-day operation. The limits are expressed in "roentgen equivalent in man," or rem, and Sievert (SI unit); these limits have fallen over the decades. At the same time, changes in plant design, operation, and maintenance can impact radiation levels, complicating the tasks necessary to keep dose rates low.

The tasks won't get any easier. The Nuclear Regulatory Commission (NRC), which last revised the limit in 1990, is considering a change to the current exposure limit of 5 rem (50 millisievert [mSv]) per year. For example, a potential standard of 10 rem (100 mSv) averaged over five years, not to exceed 5 rem (50 mSv) in any one year, originated from a scientific review of the health impacts of radiation by the International Council on Radiation Protection. Many countries have already adopted such reduced dose limits, essentially averaging to 2 rem (20 mSv) per year. The NRC is considering these international recommendations in its deliberations.

The nuclear power industry is working to ensure that it can safely meet the lower limit. EPRI has been working with nuclear plants to develop operating guidelines and software for assessing risks and identifying strategies that can reduce radiation exposure, protect worker health, and improve overall plant efficiency.

"Workers already receive very low doses in general, but it's important to manage that carefully so that the collective dose received by the whole population is as low as reasonably achievable as well," said Lisa Edwards, program manager for EPRI's Low Level Waste and Radiation Management program.

Rising Standards Drive Lower Limits

The prospect of a limit of 2 rem (20 mSv) per year per worker will not be easy to meet, yet industry experts expect plant owners to set even tougher administrative goals, at 1.0–1.5 rem (10–15 mSv) per year, to ensure regulatory compliance. This heightens the need for better planning and improved dose reduction tools.

EPRI estimates that the efforts needed to meet lower limits could affect 1,000–1,500 workers. These are workers who currently perform tasks with a cumulative exposure above 1.0 rem (10 mSv) per year and who may have to cut short or otherwise modify their assignments to meet lower limits. Plant managers in many cases will have to evaluate the exposure risks, factors such as the nature of the tasks, locations of the job sites, and the amount of time spent on each job. Then, they will have to implement methods to reduce exposure, such as use of shielding and more efficient use of temporary scaffolding for accessing high-radiation areas during refueling, maintenance, and capital improvement projects. Managers also will likely need access to a larger pool of workers to make sure that their dose rates fall below the lower limit.

"To illustrate how this may impact the industry in balancing individual exposure versus collective exposure, consider the following example," said Phung Tran, senior project manager and technical lead for the Radiation Management program at EPRI. "Under the current limits, a single experienced worker may perform a particular task for 2.3 rem (23 mSv) per year. If the exposure limits are lowered, the task may have to be split between two or three workers, and these workers may be less experienced and require more time or dose than the single experienced worker to perform the same work. So instead of one experienced worker with 2.3 rem (23 mSv), there may be three workers with lower individual doses, but collectively more than 2.3 rem (23 mSv) of exposure is received."

Although the NRC sets individual dose limits, the nuclear industry historically has focused more on reducing the collective exposure rate at each plant. Goals established by the industry through the

Institute of Nuclear Power Operations for 2015 are 110 person-rem for boiling water reactors and 55 person-rem for pressurized water reactors over the course of one fuel cycle. Boiling water reactors are supposed to have met a 120 person-rem goal by now but haven't, underscoring the difficulties of designing and implementing plans to reduce collective radiation exposures.

"With the right tools in place, a focus on individual dose management should help bring down the collective dose while also meeting any new individual dose limit," Tran added.

3D Modeling Provides More Rigorous Assessment

Any plan to limit individual exposure starts with understanding radiation levels in different parts of the plant. To accomplish this, EPRI is working with the FIATECH consortium and a small group of software providers to develop a three-dimensional (3D) modeling software prototype to calculate dose rates throughout the plant.

If this prototype is successful, the modeling tool would crunch dose data and calculate a worker's likely dose when walking around the plant or standing near a significant source of radiation. "Central to this tool's development and testing is a software algorithm that could provide more precise dose estimates than some of today's common methods," Tran said.

The calculations performed by the model would use dose rates collected by a radiation protection technician during a physical plant survey. Based on previous data collections and historical knowledge of the plant, the technician could then determine where workers might encounter higher radiation levels as they move around the job site.

"The 3D modeling tool will formalize the job planning process and facilitate greater engagement with workers so that a more rigorous technical assessment can be performed," Tran said. "The model will be able to calculate the potential dose and dose rate for a person as he walks through the room and stands in certain parts of a room. The end result is a better overall estimate for what that worker's dose would be."

The software would present the calculations in 3D diagrams, providing clear visual images of the relationships between dose rates and locations. "The technician could click on a particular coordinate to see the relevant data points and map out a route for workers that will minimize radiation exposure," Tran said. Workers would learn to position themselves in spots with lower dosage rates. There is growing interest in incorporating 3D images into dose management because such images can be integrated with 3D images of plant piping and equipment—generated using laser scans.

For the EPRI-FIATECH project, EPRI is developing the dose algorithm and recommendations for software development, while FIATECH and its member companies (including Siemens PLM, Dassault Systémes, and CSA) will work with software developers to deliver the 3D tool.

Tran and her team already have created the dose algorithm and demonstrated it in a lab setting. For the project's pilot phase, EPRI has identified a U.S. pressurized water reactor plant that will contribute data from daily operations to validate the software prototype. The project team held a kick-off meeting last November and plans to complete a prototype by the end of this year. In 2012, the group plans to demonstrate the tool at large scale to finalize software development.

Insights Improve Outage Management

"Dose management is particularly critical during plant outages, when workers are in areas normally off limits when the plant is online," said Willie Harris, Director of Radiation Protection at Exelon. "Such work is necessary to shut down the reactors and perform refueling, maintenance, and capital improvement projects. Aside from dispatching workers to locations with lower radiation levels, plant managers also can minimize exposures by spotting and then reducing unnecessary steps during the outage."

EPRI has found that scaffolding work is among the top 10 tasks with the highest plant-wide dose. It also is expensive—running $1–3 million per outage. Yet it is often overlooked in planning because, until recently, there wasn't an awareness of best practices. The result: repeated and unnecessary erecting and disassembling of scaffolding during each outage.

Recognizing this need, EPRI developed the *Scaffold Program Optimization and Dose Reduction Guide* (1021102), which addresses several key areas, according to Edwards: management support, employee training, techniques and equipment for erecting the temporary structure, communication protocol, and remote monitoring. EPRI developed the guide from a knowledge base that included more than 20 industry experts, EPRI's own scaffolding performance database, service and product vendors, eight scaffold workshops, and 18 assessments of nuclear plant scaffolding programs.

Effective scaffolding work should include a defined program manager, accurate work plans, and performance metrics, both for gauging the task's success and for improving future work plans.

EPRI's research has shown that worker training, on site or off, is highly effective in reducing job dose. The scaffolding guide also challenges the need for scaffolding and demonstrates that certain solutions, such as small portable lifts and permanent platforms that can be used multiple times, are in many circumstances more time efficient and less expensive.

Harris said that what makes the guide unique is that it not only aims to reduce cost and inefficiencies in scaffolding work, but it also incorporates recommendations for radiation protection.

"It could be a significant dose saver," Harris said. "We are in the process of implementing it. Once that's done, then we can easily see a 10–20% reduction. That could be a couple of rem at each site."

Source Term and Low-Dose Science

Reducing radioactive materials, or source term reduction, also is key for achieving lower radiation doses for individual workers. EPRI has long offered guidance on selecting the right materials and treating or cleaning them to reduce the source term. The recently updated *Cobalt Reduction Sourcebook* (1021103) (see page 34) provides recommendations for minimizing radioactive cobalt generation, transport, and accumulation.

The sourcebook considers chemistry and other management practices, and it includes discussions of results and estimated costs that can be achieved from each reduction strategy.

Along with tools for reducing radiation exposure, EPRI is launching an effort to conduct long-term research to look at the health impacts of radiation exposure. One ongoing effort looks at the effect of low-dose radiation, which will inform policy and technical discussions on radiation dose limits.

Scientists have amassed troves of data on effects of high-dose radiation as a result of atomic bomb detonations and industrial accidents. Those studies provide data valuable for understanding radiation biology. But because radiation levels at power plants are much lower, the results from high-dose exposures might not be applicable.

EPRI has been evaluating the applicability of the Linear No-Threshold (LNT) model, which is widely used to assess the risk of long-term health impacts from radiation. The LNT model assumes the health impact at a lower dose is direct and proportional to the impact at higher dose. So, the cumulative effect of small doses, applied at a low dose rate, should equal that of one large corresponding dose. "But biological data collected in recent years suggests that this correlation may not hold true," Edwards said.

For instance, the current model assumes a linear relationship between dose and the body's response to that dose. New data seem to indicate that the rate at which the dose is received has a large impact on the actual health impacts observed. A good analogy is a light-skinned person who goes to a tropical area for a week with little or no sun exposure in recent months. The health impacts of spending 7–8 hours in the sun on the same day is very different than spending 15 minutes per day in the sun over four weeks. Some data indicate that the same is true for exposure to radiation.

The current research is piggybacking on previous EPRI work. In November 2009, EPRI published a report, *Evaluations of Updated Research on the Health Effects on Risks Associated with Low-Dose Ionizing Radiation* (1019227), that evaluated scientific literature on the health impacts of low-dose radiation. In reviewing more than 200 peer-reviewed publications in epidemiology and radiobiology, EPRI determined that the health impacts of low-dose radiation may not be linear with dose and could be less than previously estimated. To create a fuller picture of the health impacts from low-dose exposure, EPRI's report recommended investigations into new models that incorporate more recent data on radiation biology and epidemiology, such as the role of DNA repair mechanisms on cancer.

"Our research is helping the public understand and our regulators to be informed of the fact that how people respond to low doses is different from how they respond to high doses, and you need to weigh that accordingly in order to truly assess risks of the levels of exposure to radiation," Edwards said.

This article was written by Ucilia Wang. For more information, contact Lisa Edwards, ledwards@epri.com, 469.586.7468, or Phung Tran, ptran@epri.com, 650.855.2158.

Lisa Edwards is program manager for EPRI's Low Level Waste and Radiation Management programs. Before joining EPRI in 2006, she had 18 years experience in commercial nuclear utilities at Duane Arnold Energy Center, Comanche Peak Steam Electric Station, Cooper Nuclear Station, and Plant St. Lucie. She received her U.S. NRC Senior Reactor Operator license for Comanche Peak Units 1 & 2 in June 2001, after which she assumed Unit Supervisor and STA responsibilities at Comanche Peak. She has extensive experience in both solid and liquid radioactive waste processing and management. Edwards received her B.S. in chemistry from Cornell College.

Phung Tran, senior project manager in the Radiation Management program area, focuses on radiation protection and low-dose health effects. Prior to joining EPRI in 2003, she worked at Centec XXI as a project engineer involved in low level waste and BWR water chemistry. She received a B.S. in chemical engineering from Stanford University, where she was a Merck Engineering and Technology Scholar, and has a Master of Health Sciences in the area of environmental health sciences from Johns Hopkins University.

Accelerated FGD Corrosion

Understanding the Cause, Finding a Solution

THE STORY IN BRIEF

An aggressive form of corrosion has been found in relatively new flue gas desulfurization systems installed in U.S. coal-fired plants. In response, EPRI has launched a rapid-response project to investigate the root cause of the corrosion and to develop inspection and mitigation methods.

State-of-the-art flue gas desulfurization (FGD) systems have been and are being installed in most coal-fired electric generating units in the United States to meet regulatory emission requirements for control of sulfur dioxide (SO_2). These systems are capable of removing 95% or more of the SO_2 in the flue gases. However, in the past year, utilities have been confronted with a troubling trend. Some of the newer wet FGD units have experienced severe corrosion in just three years, and in extreme cases, in as little as three months.

The corrosion most commonly is found below the liquid level in the FGD absorber vessels and piping. It first appears as pitting in weld heat-affected zones, weld metal, and base metal and most often is associated with areas under heavy deposits of gypsum, an FGD byproduct. Corrosion has been serious in some plants and in extreme cases has penetrated vessel walls. The corrosion has been found in many designs produced by several manufacturers.

To date, the cause is unknown, but in preliminary investigations, the common factor appears to be absorber vessels and installations constructed since about 2004 using duplex stainless steel alloy 2205 and possibly other duplex stainless steels. Initial EPRI surveys show that at least 20% of the approximately 360–370 FGD systems in the United States have this material in major components.

"A structural compromise in significant systems such as FGD units is a serious concern for plant operators," said Chuck Dene, EPRI project manager. "FGD units are costly, with total capital costs on the order of $400 per kilowatt. FGD vessels can hold 1–2 million gallons of slurry, which is typically 20% solids. Corrosion that violates minimum wall thickness can jeopardize the structural integrity of a tank. If a tank were to rupture, it could have catastrophic effects on surrounding equipment and shut down a plant. In addition, emission regulations require that a unit not run without the FGD system in service."

Maintenance and outage costs to address corrosion can be significant. Mitigation measures—even temporary stopgap measures—have been reported to cost as much as $8 million. Outages to address the issue typically are unplanned, and it can take weeks to clean, inspect, and repair vessels.

Surveying Systems

The issue was first brought to EPRI's attention before its October 2010 Generation Sector advisory meeting. In early November, EPRI convened a meeting of key stakeholders. In less than two months, EPRI programs 87 (Fossil Materials and Repair) and 75 (Integrated Environmental Control) jointly launched a supplemental project to address the issue.

"Once we saw the seriousness of the attacks and their prevalence throughout the industry, we knew we had to act quickly," said John Shingledecker, EPRI senior project manager. The project aims to identify the root cause, compile guidelines for inspection and fabrication, and develop repair and other mitigation strategies.

First, the project team is surveying U.S. utility FGD systems experiencing corrosion. The survey is collecting information on corrosion in FGD absorber vessels, piping, and spray headers/nozzles, along with detailed data on materials, fabrication techniques, construction quality assurance/quality control, operating environments (basic water chemistry, scaling, etc.), and corrosion levels and locations.

With the survey results, the EPRI team will document all FGD system designs, chemistries, and materials susceptible to accelerated corrosion. Generally, FGD systems include wet scrubbers, spray dryers, and dry sorbent injection systems. The corrosion in question has been found only in wet scrubbers, which typically remove SO_2 from the flue gas with a limestone or lime slurry spray. The industry relies on wet FGD absorber vessels of two main designs: spray towers/tray towers, which spray slurry into the bulk gas flow, and jet bubble reactors, which introduce the flue gas into the bulk slurry.

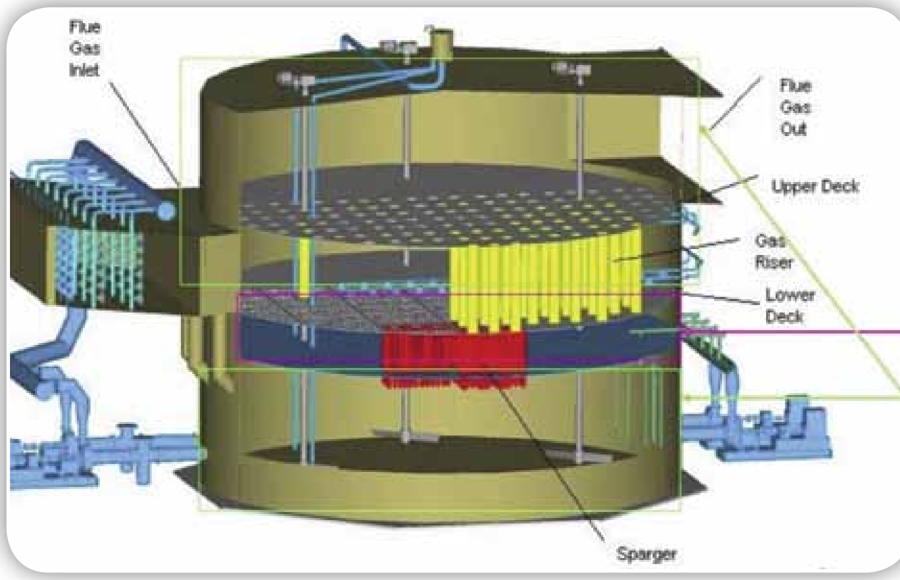
Metal and Chemistry Issues

Early indications point to chemistry issues—evidenced by the presence of hard, tenacious scales and deposits on walls and floors—and/or a factor associated with the fabrication of the metallic vessels.

Prior to the early 2000s, FGD absorbers were designed using Type 317L stainless steel or a variation, such as Type 317 LMN. The LMN grade is fully austenitic and has controlled increased additions of nitrogen and molybdenum. The combination of molybdenum and nitrogen enhances resistance to pitting and crevice corrosion, especially in process streams containing acids, chlorides, and sulfur compounds at elevated temperatures.

Nearly a decade ago, in seeking higher SO_2 removal and different chloride concentrations during operations, a fundamental shift occurred in the way FGD systems were designed and operated. The price of nickel-based alloys spiked, rising by four to seven times. Manufacturers sought other metals, such as duplex stainless steels.

Representative cross-sections, showing corrosion on Alloy 2205 in a weld and in base metal. Left: through-wall leak in 11/16-inch base metal after 11 months in service. Right: surface and subsurface pitting structure after 11 months in service.



Jet bubble reactor. For this schematic, the purple box indicates Alloy 255 duplex stainless steel in the froth zone (wet/dry zone) of the shell, and the green boxes are Alloy 2205 duplex stainless steels above and below. Illustration courtesy of M. J. Crichton.

Duplex stainless steels have a two-phase microstructure consisting of roughly 50% austenitic stainless steel and 50% ferritic stainless steel, making them about twice as strong as regular austenitic or ferritic stainless steels. Depending on their content, duplex alloys have a range of corrosion resistance. With less nickel and molybdenum, these alloys can cost significantly less than austenitic stainless steels, and because of their increased strength, they can be manufactured with reduced section thickness.

Initial evidence indicates many affected FGD systems are fabricated with one of the most common duplex stainless steels, Alloy 2205, a 22% chromium, 3% molybdenum, 5%–6% nickel, nitrogen-alloyed stainless steel. Some affected systems are made of a similar duplex alloy, 255, with a slightly different composition. Concern is mounting that earlier-generation absorber vessels fabricated with austenitic stainless steels may be subject to corrosion as well, but that the attack has gone undetected. As a result, the EPRI study will investigate duplex stainless steels, stainless steels, and alloys prevalent in today's FGD fleet.

Absorber vessel environments are very corrosive and may vary significantly in different plants. Materials selection for each plant must be based on corrosive media, coal quality, available space, operating conditions, plant design, and economics. Slurry chemistry in each plant may be a key factor in driving the corrosion attack.

Flue gas is introduced into an absorber through the inlet duct. Temperatures from 250°F–400°F (121°C–204°C) are usually high enough to preclude corrosion in much of the duct. However, in the portion of the duct immediately ahead of the absorber, the hot gas and moisture mix to create a very corrosive "wet/dry" area, either through the intentional pre-quenching of the gas or through the unintentional recirculation of the saturated gas from the absorber.

Corrosion can be severe in the outlet duct, which carries the scrubbed gas to the stack for discharge. Temperatures range from 109°F–176°F (43°C–80°C), and the gas is saturated with moisture and may contain sulfuric, hydrochloric, or hydrofluoric acid, depending on coal quality, firing, and absorber operation.

Inspection Guidelines

Relatively early in the project, in 2011, EPRI is slated to deliver inspection guidelines. These will provide guidance on pre-inspection planning and cleaning of metal surfaces, inspection procedures for spray tower and jet bubble reactors, and documentation of inspection results. Based on successful utility inspections conducted to date, the guidelines will include detailed photographs of corrosion types and locations to help ensure that all utilities are discovering and correctly identifying corrosion in its initial stages, when signs often are not visible without surface preparation and cleaning.

"The corrosion involves very small pinpoint holes that you cannot see in a typical walk-by," said Tom Hart, manager, Flue Gas Desulfurization and Chemical Engineering, American Electric Power. "You have to use much higher pressure water blasts or a grit abrasion blast to clean the surface of the absorber vessel, so that very small pits are exposed in the base metal or the heat-affected zones of the weld. And then you need to look very closely and use light shining across the surface to cast shadows. You may also need to probe the pits with probing wires or excavate them with dental picks and clean out the residue and actually even sandblast away the covering metal. It's a very time-consuming and meticulous process."

Standardizing inspection procedures will help to ensure that utilities can compare data among many units. Once the inspection guidelines have been published, the project team may return to units where there were questions to ensure that the team is getting all possible data.

Root Cause Analysis

Combining survey findings with a review of past EPRI studies may make it possible to complete a root cause analysis as early as mid-2011. The analysis will include information on materials selection, handling practices, erection processes, weld procedures, corrosion and failure mechanisms, and operation variables and will identify areas requiring more data.

"We expect the root cause analysis will not necessarily give us one smoking gun answer, such as a slight change in pH level," said Shingledecker. "Instead, I think it will define the critical areas where we don't have the proper information and need to do more research in order to make materials decisions or life-type assessments or performance assessments."

The project will identify the most effective mitigation and repair methods to address the cause, including welding, linings, and coatings. It will also review utility field experience with mitigation measures used to date, including welding lap plates over corroded areas on vessel floors and walls, applying coatings, and installing cathodic protection.

To understand the feasibility and effectiveness of recommended mitigation measures, the project team will test current materials and fabrication practices (welding, surface preparations, finishes) in laboratory and field environments and compare them with recommended mitigations (coatings, alternative vessel materials, and alternative cladding materials). Researchers then will formulate standard repair procedures and develop fabrication guidelines, addressing proper construction practices, contamination and surface acceptance, and welding procedures.

Throughout the project, participants will meet at least twice a year as the new Corrosion in FGD Materials Interest Group to review the project status, identify future project research, identify longer-term R&D, and exchange information on FGD materials issues.

Corrosion damage at a wall and floor joint

"This is the kind of project where the industry needs EPRI's leadership," said Hart. "The project is collecting a lot of data on who did what: what types of materials were used, what weldments were made, what weld rods were used, how the vessel was brought into service, what coal is burned, and what chemistries have been in place. We need EPRI to assemble all the data and then bring their knowledge to bear in analyzing the data across the industry to find the root cause. Until we know the cause and find a reliable, long-term fix, utilities are not going to have the level of confidence they need to use these materials and install new systems."

This article was written by Jonas Weisel. Background information was provided by EPRI's John Shingledecker, jshingledecker@epri.com, 704.595.2619, and Chuck Dene, cdene@epri.com, 650.855.2425. Tom Hart of American Electric Power also contributed to the article.

Chuck Dene is a senior project manager in EPRI's Integrated Environmental Controls program. His project responsibilities include improvements in FGD chemistry for removal of SO_2, acid gases, mercury, selenium, and other toxic metals; evaluation of integrated emission control technologies; and continuous emission monitoring technologies for process control and compliance reporting. He received his B.S. degree in chemical engineering from Wayne State University.

John Shingledecker is a senior project manager in EPRI's Major Component Reliability research area. He leads the Fossil Materials and Repair program, which provides the power industry with materials use and selection guidelines, welding and repair solutions, corrosion mitigation methodology, and remaining-life tools to increase plant availability, reduce failures, and improve efficiency. Before joining EPRI in 2008, he worked at Oak Ridge National Laboratory, where he was a principal investigator for projects supported by the U.S. DOE Office of Fossil Energy's Advanced Research Materials Program. Shingledecker holds B.S. and M.S. degrees in materials science and engineering from Michigan Technological University.

Tom Hart is Manager of Flue Gas Desulfurization and Chemical Engineering for American Electric Power. He has worked closely with EPRI on a number of projects, sits on the Generation Sector's Integrated Environmental Controls (P75), and chairs the Particulate and SO_3 Controls (P76). He also chairs the newly formed Corrosion in FGD Materials Interest Group.

DATELINE EPRI

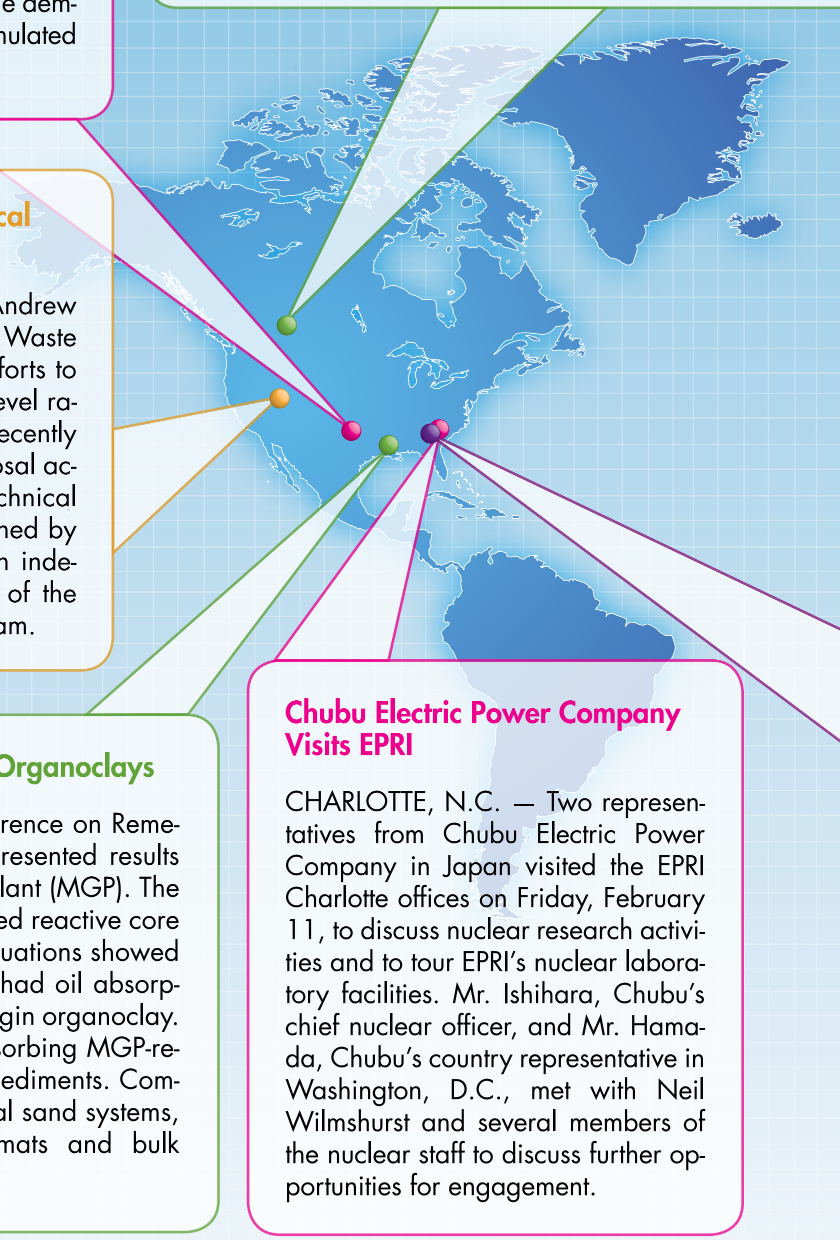
News and events update

Synchrophasor Demo Links Hardware in EPRI Laboratories

FORT WORTH, Tex. — Phasor measurement units, or synchrophasors, provide real-time information about a power system's dynamic performance. The North American SynchroPhasor Initiative (NASPI) in February demonstrated one approach to a network to securely move synchrophasor data beyond a single utility. Participating were CISCO, GE Digital Energy, OSIsoft, InStep Software, SISCO, Space Time Insight, Verizon, and EPRI. The demonstration streamed live synchrophasor measurements between EPRI labs in Lenox, Mass., Charlotte, N.C., and Knoxville, Tenn., and the demonstration presentation in Fort Worth. The Knoxville site simulated a utility operations center and sent data to Fort Worth.

Workshop Charts IGCC Roadmap

CALGARY, Alberta — EPRI staff conducted a workshop or
Coalition for representatives of the U.S. Department of E
nadian government-funded research labs, coal supplier
workshop focused on the future of integrated-gasification-
sults of roadmap studies and detailed technology present
gies under development could contribute to IGCCs with
than the most efficient of today's plants. For more i
704.595.2554, or George Booras, gbooras@epri.com,



EPRI's Sowder Testifies Before Nuclear Waste Technical Review Board

LAS VEGAS, Nev. — EPRI Senior Project Manager Andrew Sowder presented invited comments to the U.S. Nuclear Waste Technical Review Board on lessons learned from U.S. efforts to develop a permanent repository for used fuel and high-level radioactive waste. Sowder shared insights from EPRI's recently completed four-volume technical review of geologic disposal activities in the U.S. and abroad. The Nuclear Waste Technical Review Board, appointed by the president, was established by the 1987 Nuclear Waste Policy Amendments Act as an independent federal agency to provide technical oversight of the Department of Energy's High-Level Nuclear Waste Program.

Absorbing Contaminants: Conference Hears About Organoclays

NEW ORLEANS, La. — At the Sixth International Conference on Remediation of Contaminated Sediments, EPRI's Jeff Clock presented results from a remediation pilot project at a manufactured gas plant (MGP). The project examined the performance of an organoclay-based reactive core mat system in New York's Hudson River. Preliminary evaluations showed that 18-month-old organoclay in the reactive core mats had oil absorption capacity and permeability comparable to those of virgin organoclay. Other tests confirmed that the aged organoclay was absorbing MGP-related nonaqueous phase liquids from the contaminated sediments. Comparisons are ongoing for reactive core mats, conventional sand systems, and a composite system containing reactive core mats and bulk organoclay.

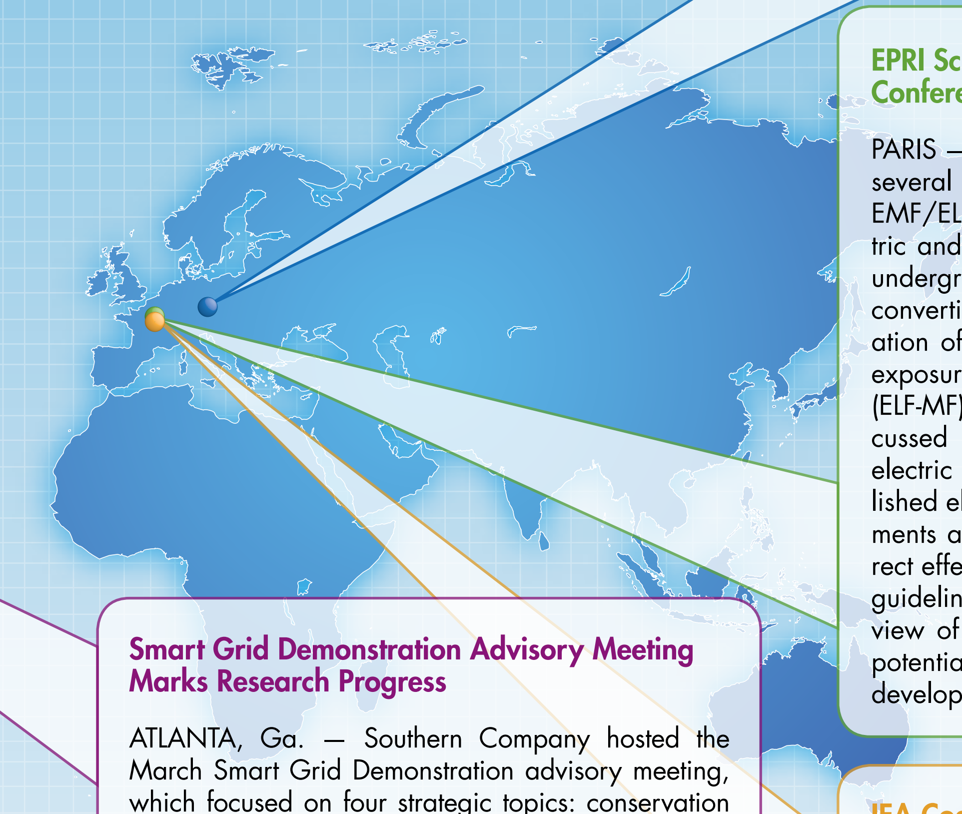
Chubu Electric Power Company Visits EPRI

CHARLOTTE, N.C. — Two representatives from Chubu Electric Power Company in Japan visited the EPRI Charlotte offices on Friday, February 11, to discuss nuclear research activities and to tour EPRI's nuclear laboratory facilities. Mr. Ishihara, Chubu's chief nuclear officer, and Mr. Hamada, Chubu's country representative in Washington, D.C., met with Neil Wilmshurst and several members of the nuclear staff to discuss further opportunities for engagement.

n IGCC Roadmapping for the Canadian Clean Power
nergy's National Energy Technology Laboratory, Ca-
s, electric utilities, and technology developers. The
–combined-cycle technology (IGCC), using recent re-
ations by the developers. A key conclusion: technolo-
90% CO_2 capture producing power more efficiently
nformation, contact Ron Schoff, rschoff@epri.com,
650.855.2471.

EPRI and Czech Utility Launch Three-Year Nuclear Membership

PRAGUE — EPRI and the Czech utility CEZ a.s. met in January to launch CEZ's membership in the EPRI Nuclear Sector. CEZ's daughter company, NRI Rez (Nuclear Research Institute), had previously participated in several nuclear programs as a supplemental member. CEZ, the Czech Republic's largest utility, owns and operates six nuclear reactors at two sites, Dukovany and Temelin. Nuclear power accounts for about one-third of the power produced in the Czech Republic, and additional units are planned for Temelin, with startup in 2020.



EPRI Scientists Examine Issues at EMF/ELF Conference

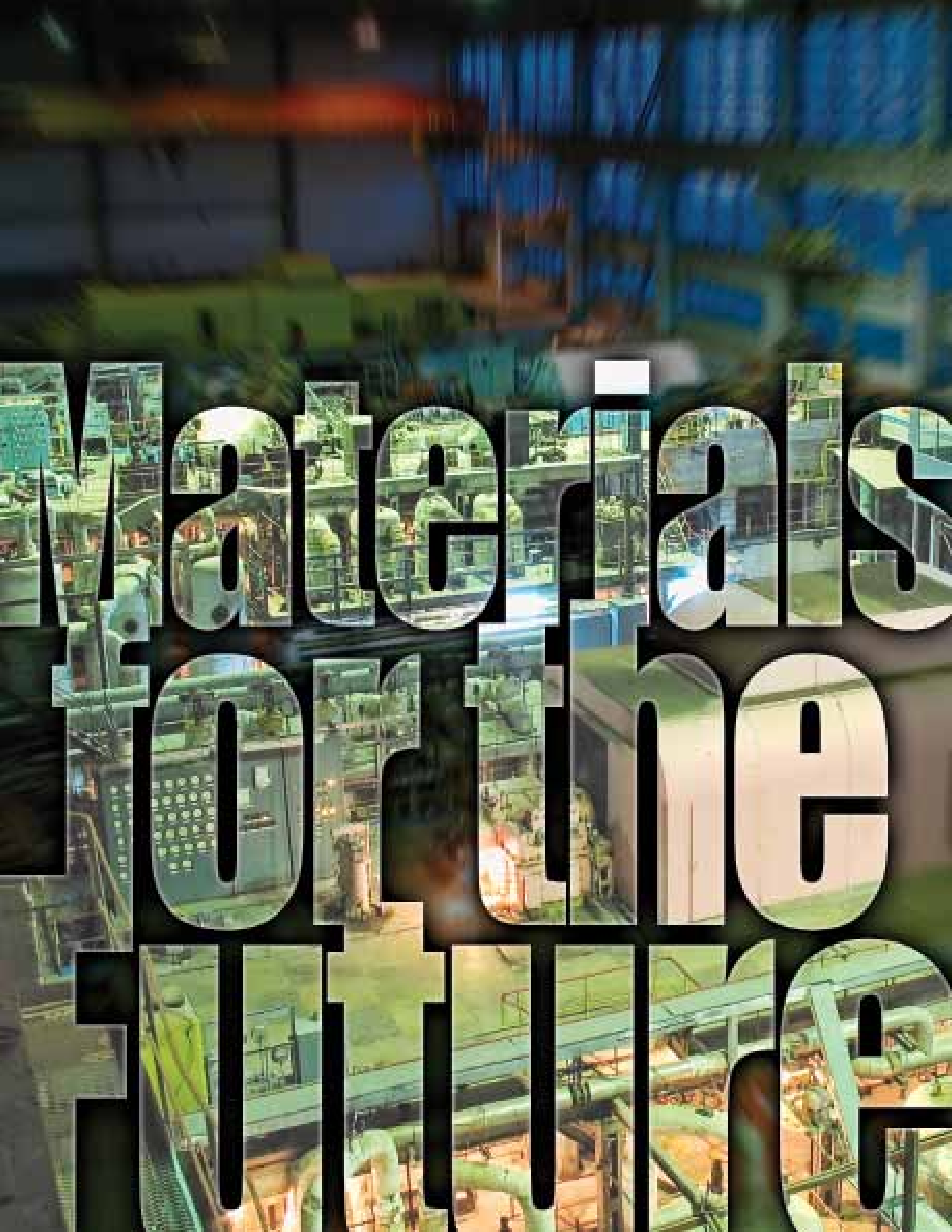
PARIS — EPRI's Gabor Mezei and Rob Kavet presented several papers at the 2nd International Conference on EMF/ELF, an international forum for research on electric and magnetic fields coming from overhead lines, underground or submarine cables, substations, and converting stations. Mezei provided a summary evaluation of the epidemiologic literature on occupational exposure to extremely low frequency magnetic fields (ELF-MF) and neurodegenerative diseases. Kavet discussed two cases of exposures to power frequency electric fields that are incompletely addressed in published electric and magnetic fields exposure limit documents and may be considered when addressing indirect effects of electric fields in exposure standards and guidelines. Mezei and Kavet also presented an overview of epidemiology and laboratory research on a potential link between exposure to ELF-MF and cancer development.

Smart Grid Demonstration Advisory Meeting Marks Research Progress

ATLANTA, Ga. — Southern Company hosted the March Smart Grid Demonstration advisory meeting, which focused on four strategic topics: conservation voltage reduction and volt/VAR optimization; consumer engagement; energy storage monetization; and distribution management system integration and visualization. EPRI provided updates on research progress, and 10 utility members provided project updates. Southern Company reported on its smart grid projects and advanced meter infrastructure, fault location analysis, and distributed photovoltaic (PV) systems, followed by a tour of the Technology Showcase and Georgia Power Annex Distributed PV Systems, which is evaluating several different PV technologies.

IEA Coal Industry Advisory Board Looks at CCS

PARIS — EPRI Director of Generation Stu Dalton reviewed for the International Energy Agency Coal Industry Advisory Board a number of key issues related to carbon capture and storage (CCS) technology. He emphasized the need for research on all technology options, the difficulty and cost of meeting CO_2 goals, and the status of CCS development, including EPRI large-scale tests and demonstrations. The audience included senior executives from electric utilities, coal companies, and railroads.


Materials
for the
future

Reliable and affordable power generation and delivery systems depend on a variety of basic materials. Better materials can minimize capital and operations and maintenance costs, extend the life of key components and infrastructure, increase plant and system availability, and improve efficiency.

"Many people inside and outside the industry do not appreciate how materials research can maximize efficiency and higher-temperature operations and can minimize component degradation that leads to failure," said David Gandy, program manager in EPRI's Office of Technology Innovation (TI). TI's materials research focuses on what Gandy calls the middle ground between basic research and commercial technology. Its dozens of projects run the gamut of nuclear, fossil, and power delivery technologies and draw on the expertise of interdisciplinary teams across EPRI and around the world.

TI's programs address two broad categories of inquiry: materials degradation and the development of advanced materials. The goal of the first is to gain fundamental understanding of microstructural degradation, corrosion, and erosion in order to predict and extend the life of critical components. The goal of the second is to develop materials with superior performance at lower cost and to usher advanced fabrication technologies, such as powder metallurgy, into the industry's supply chain.

Broadly speaking, the challenges in nuclear generation focus primarily on degradation associated with aging, embrittlement, and corrosion. For fossil generation, the central issues include high-temperature performance and corrosion resistance. "The difference," said Gandy, "is that with nuclear, temperatures up to 650°F (433°C) may be observed, but on the fossil side, conventional components operate in environments up to 1050°F (566°C), and advanced components are planned for the 1300°F–1400°F (704°C– 760°C) range. Most ferritic alloys 'loaf,' that is show no microstructural degradation or impact, until they get into the 1000°F (538°C) range. As you move up in temperature, you've got to have alloys that can ensure structural performance."

THE STORY IN BRIEF

The basic building blocks of the electricity system depend on materials that last, materials that can be reliably fabricated and inspected, materials that don't harm the environment, and perhaps—in an age of nanotechnologies—materials that can heal themselves.

For power delivery, EPRI's TI materials research involves extending life and enhancing performance. Examples include the proof of concept for self-healing cable insulation, in which nano-based polymers are released in response to electric fields generated when the cable is nicked or scratched, and the use of nanocoatings to protect fiberglass insulating components subjected to weather-based attacks on the glue binding the glass filaments together. Each project is at least three to five years from commercial development.

International Teamwork

Some of TI's most critical work is international in scope, pooling both financial resources and expertise from around the world. A prime example is EPRI's effort to standardize the testing of materials for high-temperature erosion.

"For over 50 years, we've been engaged in high-temperature operations, and we still don't have a good methodology for evaluating erosion resistance at high temperatures," said Gandy.

The first step in developing such a methodology was to survey more than 100 laboratories around the world about the work under way in this area. TI identified eight—from large laboratories to original equipment manufacturers—where there was enthusiasm about joining forces. EPRI, in conjunction with ASTM, now is performing a round-robin test in which each participant is given a testing matrix and asked to report its data by late summer of 2011. Each lab will be assigned a blind letter (A–H), and the data will be pooled.

"We'll then have a methodology to compare different alloys and different coatings used in high-temperature steam and gas turbine environments," said Gandy.

For the long-standing problem of corrosion fatigue in steam turbine blades, solutions remain elusive for prediction and life estimation. Researchers know that the problem begins with corrosion pitting, but a critical unknown persists: how and when a crack is initiated from the pit, and where it is initiated—from the bottom of the pit, at the intersection of the pit and the surface, or in between. Gandy believes researchers may be on the threshold of a significant breakthrough in understanding. "For the first time, I believe we have a methodology to get us there, to really understand how corrosion fatigue moves from the very elementary stages to an actual crack and eventually to failure."

International participants include the National Physical Laboratory of the U.K., the University of Natural Resources and Life Sciences in Vienna, and STI Technologies, of the SimuTech Group in Rochester, New York.

EPRI technical executive Luke van der Zel is spearheading a new project with the University of Liverpool that could lead to an environmentally acceptable alternative to SF_6 gas, a widely used and effective insulator that can quench arcing in high-voltage breakers.

Haresh Kamath, who manages materials research in Power Delivery and Utilization, said, "The gas is odorless, nonflammable, nontoxic, and highly unreactive, but it has one fundamental drawback. It is the most powerful greenhouse gas known—more than 20,000 times more potent than CO_2."

The team in Liverpool has been working with fluorinated carbons, a solid material similar to Teflon. In the presence of arcing, it vaporizes into a gas that can quench arcs as fast as or faster than SF_6. "We've been assessing this technology over the past year and just signed a contract with the university to begin joint development and testing," said Kamath.

If this alternative to SF_6 lives up to its promise, its performance over time will be tested in prototype equipment.

In Asia, a joint project of EPRI and Japan's Central Research Institute of the Electric Power Industry (CRIEPI) is focused on developing "lifing criteria" for components manufactured of Grade 92 ferritic steel. Lifing criteria require information on microstructure, long-term creep fatigue, and other factors that can indicate when a component is nearing the end of its life. "Grade 91, used around the world, has created a lot of headaches due to improper fabrication and heat-treatment practices," said Gandy. "Over the last decade, the industry has begun to look at Grade 92 for piping and header applications, and we are trying to develop the lifing criteria before many plants install the alloy."

Japanese utilities, EDF, U.S. national labs, and other research institutes are working with EPRI to explore materials behavior at the nanometer scale in order to gain fundamental understanding of when and how damage starts. The earliest stages of stress corrosion cracking, for example, take place over a long period and at extremely small scale, hampering the use of traditional analytical tools. The team, led by EPRI's Raj Pathania, a program manager in nuclear materials, is applying atomic probe tomography and specialized spectroscopy to examine the elemental construction across the grain structure. In 2009, tomography was able to show the segregation of individual boron and silicon

atoms along the grain boundary, a phenomenon that increases the susceptibility of alloys to stress corrosion cracking.

Materials Innovation Through Fabrication Processes

Many countries are pursuing advanced ultra-supercritical coal technology to gain efficiency and reduce greenhouse gases. However, the technology's higher temperatures and pressures would require expensive nickel-based materials for headers and piping. In 2009, EPRI and Carpenter Technology undertook a feasibility study of CF8C-Plus, a lower-cost austenitic stainless steel material developed by Oak Ridge National Laboratory and Caterpillar for high-temperature diesel exhaust. It has exceptional mechanical properties, but is commercially available only in cast form. To test its properties in wrought form, the team produced an ingot of the alloy and evaluated several process reductions called for in fabricating pipe and headers in advanced ultra-supercritical applications.

"We're pleased with the results. It has real potential to be used in place of certain nickel-based alloys at high temperatures. EPRI is now working with [pipe manufacturer] Wyman-Gordon to bring the new alloy to market," said Gandy.

Among the materials TI is investigating, Gandy reserves particular enthusiasm for powder metallurgy, in which an alloy is gas-atomized into a powder, packed into the mold of an intricate component, and subjected to hot, isostatic pressures until the metal fuses. Pressures can range from 7,000 to 45,000 psi (310.3 MPa), with 15,000 psi (103.4 MPa) being the most common. "Of the many things I've worked on in my career, this is one of the most exciting," he said. "Powder metallurgy is going to give us a brand-new technology to manufacture higher-quality components for nuclear and fossil applications."

Powder metallurgy has been around for several decades and has matured enough for the scale, complexity, and service conditions of the power industry. The list of benefits is long: precise chemistry, homogeneous microstructure, improved materials utilization, good weldability, dramatically improved inspectability, and the ability to produce components of "near-net shape."

Near-net-shape components stand in contrast to as-cast parts. According to Gandy, "Near-net-shape components require only minimal machining and clean-up. Castings, on the other hand, all include some level of voids, entrapped slag, hot tears, nonmetallic particles, and so forth. Some large castings may involve 30%–50% rework. This means that someone has to go in and grind out the anomalies and reweld at great expense. With near-net-shape components, manufacturing costs can be reduced as less material and machining are required. Components made with powder metallurgy have a very uniform, homogeneous microstructure that is superior for inspectability, a big plus for nuclear and fossil components."

During the latter half of 2010, EPRI and Carpenter Technology worked with two valve manufacturers to develop a series of valve bodies using powder metallurgy. The goal is to provide a data package to the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code in order to gain acceptance of powder metallurgy/hot isostatic processing. A code case may be required for each alloy, but ASME may consider adoption of broader acceptance, allowing powder metallurgy to move into mainstream use. Fabrication could open up a new domestic supply chain for the industry, significantly reducing manufacturing and delivery time for key components.

Alternative Welding Filler Metals

Joining base metals that have different coefficients of thermal expansion is a challenging task, requiring special filler materials to ensure an enduring weld. "In coal plants, you have hundreds of dissimilar metal welds that connect ferritic alloy tubing to austenitic alloy tubing. These welds have proven to be weak points," said John Shingledecker, EPRI senior project manager. "After roughly a decade of operation, depending upon service conditions, you get carbon migration that creates a zone adjacent to the weld that exhibits lower creep strength. The welds have to be replaced. EPRI developed a filler material, P87, that we believe will provide extraordinarily long service." The first advanced ultra-supercritical coal plant in the United States, the 600-megawatt Turk plant under construction in Arkansas, will incorporate P87 to help ensure reliable service.

Nuclear power plants also have problems with dissimilar metal welds. Nickel-alloy welds connecting stainless steel piping to low-alloy steel vessels in reactor coolant systems have experienced primary water stress corrosion cracking after 20–30 years of operation. Filler metals 52 and 52M are high-chromium nickel-based weld metals with superior resistance to stress corrosion cracking. They are used extensively to repair susceptible welds. Unfortunately, 52 and 52M are prone to micro-cracking and have less than optimal weldability. Process repair and rework with these weld metals have cost the nuclear power industry millions of dollars. "Despite years of effort to optimize welding process parameters and attempts to develop specialized welding equipment, the problems with 52 and 52M continue to plague operating plants and new nuclear plant fabrication and deployment efforts. What's needed is a new high-chromium weld metal that has the desired mechanical properties and stress corrosion cracking resistance but also has significantly improved weldability and superior resistance to micro-cracking," said Steve McCracken, senior project manager, EPRI Welding and Repair Technology Center. EPRI is working with research firms and universities, and also working independently, to develop an alternative to 52 and 52M filler metals. "Right now, we think we understand why the micro-cracking occurs, and we think we can alloy around it," said McCracken

"Projects like these can bridge that important middle ground between basic research and commercial technology," Gandy said "and when they're successful, they can facilitate big improvements in cost, reliability, and efficiency."

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David Gandy is the program manager in EPRI's Technology Innovation program, where he is responsible for promoting innovative, exploratory, and strategic technologies throughout the Institute to accelerate the adoption of these technologies by the electricity industry. His duties include oversight of 18 long-range, strategic programs and management of a strategic program on Advanced Materials—Fossil and Nuclear. Gandy received his B.S. degree in materials science and engineering from North Carolina State University.

Haresh Kamath is a strategic program manager in EPRI's Technology Innovation program and a senior project manager in the Power Delivery and Utilization Sector, where his current research activities focus on the development, assessment, and application of energy storage technologies for both transportation and grid storage applications. Before joining EPRI in 2002, he worked at Lockheed Martin Space Systems as a product engineer responsible for spacecraft batteries. Kamath holds B.S. and M.S. degrees in chemical engineering from Stanford University.

Steve McCracken, senior project manager in the Welding and Repair Technology Center, focuses on weldability issues with high-chromium nickel-based weld metals and on advanced welding and repair technologies for the nuclear power industry. Prior to joining EPRI in 2007, he worked as the Welding and Repair/Replacement Engineer at Ameren's Callaway Nuclear Plant in Missouri. McCracken holds a B.S. degree in mechanical engineering from the University of Missouri and an M.S. degree in welding engineering from the Ohio State University.

John Shingledecker is a senior project manager in EPRI's Major Component Reliability research area. He leads the Fossil Materials and Repair program, which provides the power industry with materials use and selection guidelines, welding and repair solutions, corrosion mitigation methodology, and remaining-life tools to increase plant availability, reduce failures, and improve efficiency. Before joining EPRI in 2008, he worked at Oak Ridge National Laboratory, where he was a principal investigator for projects supported by the U.S. DOE Office of Fossil Energy's Advanced Research Materials Program. Shingledecker holds B.S. and M.S. degrees in materials science and engineering from Michigan Technological University.

FIRST PERSON *with Jen Snyder*

WHAT'S AHEAD FOR NATURAL GAS?

The fuel of choice or one choice among many?

For generation planners, questions of how much natural gas–fired generation to build—and when—will be answered based on many aspects of natural gas markets. *EPRI Journal* interviewed Jen Snyder, head of North American Gas Research at Wood McKenzie, to hear her perspective on power generation, natural gas, and other fuels. Dramatic increases in shale gas reserves, rapidly growing global demand, and the effects of competing fuels and consumers are creating a market that in some ways resembles the 1990s, but in other ways offers unprecedented risks and opportunities.

EJ: Do natural gas markets today have precedents, or are we looking at something really new?

Snyder: Following deregulation and through the '90s, natural gas grew quickly to serve power markets and industry, so we do have some precedent for a really competitive gas resource base and strong industry and market growth. By the late '90s, the supplies that we had counted on weren't evident in the market. There was a real big bet made on deep water gas supplies. The deep water Gulf of Mexico turned out to be much more oily than gassy, and as a result, we just never saw the increase in Gulf of Mexico supplies that was anticipated to keep growing U.S. resources. When gas prices started to spike, the combined-cycle builds just didn't look so good in hindsight. Things are different this time around because the shale gas supply and the resources really are in place. There's no exploratory risk associated with this gas. There are some cost risks, but it's a much more certain resource base this time around.

EJ: What defines this "cost risk"?

Snyder: The market tends to miss the significant question about how much it's really going to cost to access this resource base—costs that sometimes get overlooked—things like labor costs; costs for completion services, which are required to actually deliver gas to market; and the cost of significantly increasing the U.S. rig fleet over time.

EJ: Given a somewhat bullish outlook on the resource, some are saying that the market is excessively discounting natural gas going forward. Is this a fair assertion or a legitimate concern to power producers? Does this present a potential price problem for power producers?

> **"The fastest way to get to $8 gas is for virtually everyone to quickly make decisions based on $5 gas."** *~ Jen Snyder*

Snyder: We completely agree that the current market is not representative of the cost or the likely cost of natural gas going forward. In 2010, the average close for gas was about $4.25 per million BTU. We drilled and delivered about 9 billion cubic feet (BCF) per day of new supplies into the market in 2010. Those supplies went to meet demand growth, but also to offset declines in existing wells and fields. Of those 9 BCF per day of supply developed in 2010, about 40% of the gas was actually out of the money, even when you consider just the short-term drilling costs.

EJ: And when you say "out of the money," you mean not recovering costs?

Snyder: Exactly. To some extent, producers were insulated from that low market price because of hedges they had put on in 2008 and 2009. In some cases they had incentive to drill because they had a production requirement to hold on to their acreage. That was evident in the Haynesville shale in Louisiana. A good bit of the drilling last year just didn't align with the economic signals within the market. In our view, this misalignment between producer incentives and drilling economics and market prices is translating into a very low forward curve relative to the true cost of bringing natural gas into the market. The danger is that the relatively low forward curve could be used to justify capital decisions that will eventually push up gas demand quickly. These include gas-fired combined-cycle investments and—probably more important in the immediate term—decisions to retire a good segment of the aging coal fleet, given its lack of competitiveness with gas longer term. But we're also talking about things like the North American liquefied natural gas (LNG) export capacity, which would have been completely unheard of two or three years ago. The gas resource base and upstream industry can handle healthy increases in demand over time, but not at today's forward curve for gas.

EJ: So power generators could be affected by natural gas exports? What else factors in?

Snyder: Petrochemical companies are considering the expansion of their facilities in North America to take advantage of the low gas price relative to oil and relative to global gas prices. Policy decisions could boost natural gas vehicles by funding infrastructure and providing tax breaks. These decisions could ultimately push up the price of gas relative to the price expectations on which those decisions were made.

Photo courtesy of North American Gas Research at Wood McKenzie.

"In our view this misalignment between producer incentives and drilling economics and market prices is translating into a very low forward curve relative to the true cost of bringing natural gas into the market. The danger is that the relatively low forward curve could be used to justify capital decisions that will eventually push up gas demand quickly." *~ Jen Snyder*

EJ: And all of this adds up to big potential impacts on forward price curves?

Snyder: The fastest way to get to $8 gas is for virtually everyone to quickly make decisions based on $5 gas.

EJ: So, for power generation planners, one caution would be to avoid making decisions based on today's forward price curve?

Snyder: Lesson one is to understand that the forward curve is heavily influenced by the market today.

EJ: So it's a forward curve, but not always a forward-thinking curve?

Snyder: That's exactly right. It's always going to incorporate economics associated with storage. So it will be connected very heavily with today's market with the carry cost, the storage cost, etc. The lesson is: don't make too many planning decisions based on what's happening today or even the expectations represented within the forward curve five years down the road.

EJ: So do you then caution against an "irrational exuberance" near term about going to gas and to consider the diverse portfolio approach?

Snyder: We are extremely bullish on the gas resource. With developments in the shale gas space, we've got enough supply on hand to meet any reasonable growth profile associated with the commodity over the next 30 years, for example. We wouldn't argue with the statement that we've developed enough gas supply to serve 100 years of demand. However, the pace at which this market grows is extremely important, including not just incremental power generation capacity builds, but also retiring older capacity. And power generators won't have any real control over decisions on North American export capacity or investment by petrochemical companies. It's not just the size of the overall demand coming into the market—it's how quickly that demand materializes.

EJ: What else should power companies factor in to their supply side thinking?

Snyder: Along with this kind of shale gas revolution taking place in the North American upstream industry, we've got a real strong prospective play developing for oil within North America. Tight oil and shale oil is being accessed using some of the same rigs, technologies, crews, and completion services that we've used to develop shale gas.

EJ: An example being the finds in North Dakota?

Snyder: That's right. Another is the Monterey play in California, which is primarily an oil play but does have some gas associated with it and could make California a gas exporter.

EJ: Price volatility makes natural gas customers nervous. How should power generators regard future prospects for volatility?

Snyder: You hear a lot about the fact that shale gas wells decline very quickly within the first few years—something like 60% over the first 12 months of a play, depending on the play itself. But people focus less on the fact that after that initial ramp down in supply, you have a very, very long production tail—out 30 years in many cases without declining quickly. It has much, much more of a production tail relative to conventional supplies. So producers have been more willing to fund pipeline expansions themselves than historically, when there was a question about how long the resource would last. Commitments to pipeline capacity that we've already seen have reduced a basis volatility across North America and the potential for volatility through time.

Another thing is we've added a tremendous amount of storage capacity over the past five years, so we do see a much less volatile market relative to what we've experienced in the past. That's not to say we won't be again exposed to periods of upward cost pressure, but the $10 monthly price spikes or $10 regional monthly price spikes are probably things of the past.

With the emergent shale gas resource, our supplies become much more geographically diverse. We've got major producing regions in the Rockies as we've had in the past, and the Gulf Coast and Gulf of Mexico, but we've got real diversity with stronger midcontinent supplies and, probably most important, new supplies in the Marcellus shale. Equally important, this aggressive pipeline build provides flexibility.

EJ: With respect to power generation and natural gas markets, do you see any conventional wisdoms that deserve a closer look?

Snyder: It's conventional wisdom that North American gas prices will remain disconnected from oil in the long term simply because our gas resource base is so vast and can be accessed at measurably low prices, but that's not necessarily our view. First of all, we've seen this real successful development of North American oil plays, and shale oil and tight oil plays will compete with gas plays for capital and will also increase the cost of things like the rigs and completion services we've talked about before. Also, the global natural gas market has strengthened quickly on the back of Asian demand, and the alternative fuel in many markets is high-priced oil. So it's difficult to see North American isolation, given the potential economic industrial investments. Dow announced a 30%–40% increase in their cracking capacity because of all the natural gas liquids coming on line associated with gas and oil plays in North America. More investments like Dow's—and many are being considered—translate into a growing petrochemical industry and material demand for gas. It's very hard to see a world in which North American gas is truly isolated or insulated from global oil markets that look to be heading north all the time. Even if you don't move back to historic relationships with oil in North American gas markets, the oil price long term is extremely important.

Jen Snyder at the 2010 Summer Seminar.

EJ: No way to decouple them entirely?

Snyder: You can certainly change the relationship, but the North American gas market looks very different in a $100-per-barrel oil world than it does in a $65- or $70-per-barrel oil world. We're just not insulated from what's happening within the global market, in the oil states, or in the overall commodities.

I'm not even sure if it's conventional wisdom, but the second thing that we're really watching is the impact of global coal prices on the gas markets in the next few years. We can't look away from what's happening in Asia. Higher global coal prices don't necessarily translate immediately into higher U.S. coal demand or U.S. coal exports because there's just not the capacity to do it. But you could see investments in U.S. coal export capacity. That's how big the spreads are at this point. And any mid- to long-term increase in coal prices feeds right back into our gas price expectation. Just like with LNG, we're watching closely for capital commitments to increasing U.S. coal export capacity.

"…the pace at which this market grows is extremely important, including not just incremental power generation capacity builds but also retiring older capacity. And power generators won't have any real control over decisions on North American export capacity or investment by petrochemical companies."

~ Jen Snyder

Research at a Glance: Development of an EPRI Handheld E-field Directional Sensor

Over the past decade, electric utilities have placed increased priority on locating objects and structures that have inadvertently become energized and may pose a shock hazard to the public. Traditional tools include a voltmeter that directly measures the voltage on an object and a "penlight" that illuminates or signals when in contact with an energized object. Because the large-scale use of such tools is time-consuming and expensive, the goal now is to develop mobile scanning and noncontact methods for detecting the electric fields that surround energized objects. Such fields are present regardless of whether current is flowing.

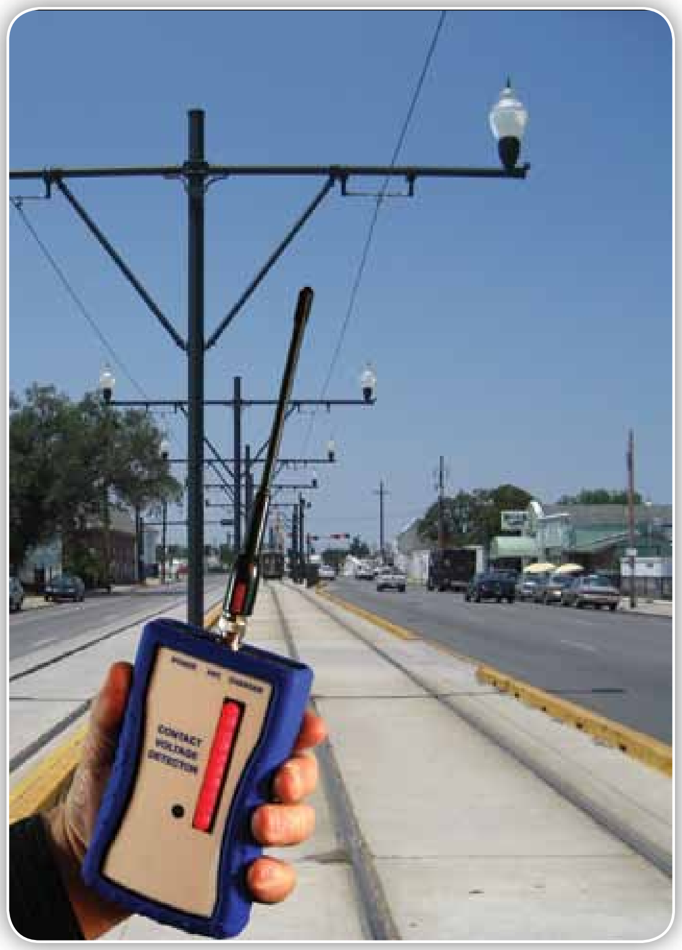
To assist electric utilities in detecting inadvertently energized conductive objects and structures, EPRI has collaborated with Consolidated Edison of New York, Long Island Power Authority, and National Grid to develop a handheld electric field sensor.

This "E-field" detector is designed to detect energized objects in ways similar to hand-held voltage detectors, but without the requirement to contact the object. This new technology has greater sensitivity than other E-field detection technologies and can locate the charged object directionally. Six utilities are participating in the research to test and assess the technology, its modifications, and its uses before development of a production-ready unit.

The current version uses an LED panel that indicates signal strength as the technician either moves closer to the energized object or points the device's antenna in the object's direction. The LED displays a maximum reading when the unit is pointed directly at and is closest to the energized object. The unit is calibrated to identify objects above ground with an electric charge potential of less than 1 volt alternating current at approximately 2 meters (6.6 ft). The device does not detect actual voltage, but it detects the intensity of the electric field that propagates out from the charged object. For a larger object (such as a streetlight), the unit may pick up a 1-volt ac field 6 meters (19.7 ft) or farther from the object.

To optimize the volts-per-meter range and the unit's directional ability, the multi-LED indicator uses a semi-log scale. With a semi-log scale, it is more difficult to saturate the unit (that is, to have all LEDs lighted at one time) than it is with a linear scale. More lighted LEDs could indicate one of three situations:

- Higher voltage on an energized object, when several objects are energized and they are equal distances apart
- Closer proximity to any given energized object in a typical situation (a single charged object)



- Electrification of an object that is larger in terms of conductive surface area and distance from the earth, such as a streetlight

After field trials, the plan is to develop a version with a digital signal processor chip and even better sensing and directional capability. Unlike other E-field sensors, this beta version may be able to distinguish between 60-Hz faults and electrification characterized by a return-path voltage drop. For underground distribution systems, the unit also may be able to locate a charge before it propagates to structures at the street surface and to filter out some common sources of false-positive readings, such as neon lights.

Field evaluations suggest that the EPRI handheld meter is approximately four times more sensitive than existing technologies in its ability to detect and directionally identify a 60-Hz energization.

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New Laser Application May Advance Prospects for IGCC

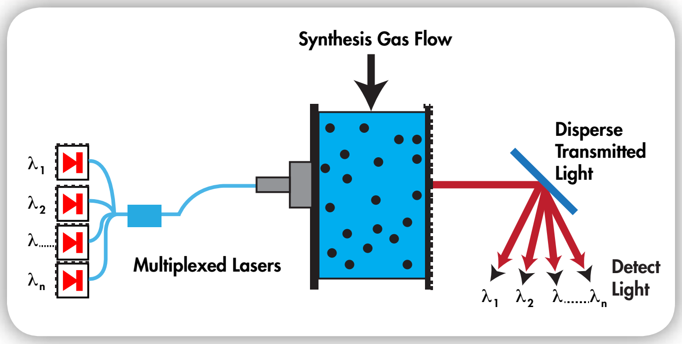
Integrated-gasification–combined-cycle (IGCC) power plants are a promising technology for low-emitting coal generation, but problems with refractory linings in coal gasifiers pose significant challenges to IGCC deployment. EPRI's Technology Innovation program is adapting solid-state diode laser technology commonly used in bar-code scanners, absorption spectrometers, laser pointers, and fiber optics to enable real-time monitoring and control of gasifier conditions. The precise monitoring and control offered by these tunable diode laser sensors could improve the reliability and productivity of coal gasification systems.

With enhanced monitoring and control of conditions within the gasifier, plant operators may be able to eliminate or substantially reduce the temperature excursions that lead to slagging problems and refractory failures. At present, flame temperatures are measured by using probes inserted through or embedded within refractory liners. This method results in a slow temperature response, limiting control capabilities. Direct measurement of temperature and gas composition promises more precise readings and better process control.

The output of tunable diode lasers may be altered to focus on individual wavelengths. EPRI's advanced sensor system employs small laser diodes tuned over the near-infrared absorption lines of chemical species present in gasifier environments. Directing the lasers across the high-temperature, high-pressure gas stream provides for measurement of the concentrations of key species—water (H_2O), carbon dioxide (CO_2), carbon monoxide (CO), and methane (CH_4)—and for calculation of temperature and other parameters.

At Stanford University, a prototype sensor system was developed that integrated multiple diodes, direct absorption spectroscopy, and wavelength modulation spectroscopy to address challenges specific to gasifiers. This led to a prototype system for H_2O vapor monitoring that was installed at the University of Utah's Gasification Research Facility. The system delivered beams from three tunable diode lasers to optical ports providing access to a pilot-scale pressurized bubbling-fluidized-bed gasifier with a black liquor feedstock. The system demonstrated the ability to measure H_2O vapor concentration in real time under a variety of operating conditions and in the presence of significant and varying amounts of particulate scattering.

These first known tunable diode laser absorption measurements in an operating gasifier were used to calculate gas temperatures, with wavelength modulation spectroscopy giving excellent accuracy. Values were within 14°C (25.2°F) (less than 3%) of thermocouple readings, even at low optical transmission. The tunable diode laser sensors provided a more accurate representation of reaction conditions across the gasifier vessel than do thermocouple probes embedded within reactor walls.



Additional work has focused on testing the prototype sensor system in Utah's pilot-scale pressurized entrained-flow slagging coal gasifier. Field evaluation in larger-scale research reactors or industrial gasifiers is scheduled for 2011–12. Commercial applications are anticipated within two to three years, both in new capacity and as retrofits for existing IGCC plants.

If the technology proves commercially viable, improved control and more consistent temperatures in the refractory lining could increase maintenance intervals and extend refractory life, potentially eliminating the need for a spare gasifier.

Tunable diode laser sensors also may be applied to measure H_2O, CO_2, CO, and CH_4 concentrations in the gasifier exhaust. This would allow real-time calculation of syngas heating value in response to variations in fuel characteristics and gasifier performance. Levels of oxygen or steam injection to the gasifier could then be adjusted to optimize the heating value, and fuel input to the combustion turbine could be controlled to increase generation efficiency.

Findings are summarized in these EPRI reports: *Laser-Based Sensors for Monitoring Coal Gasifiers* (1016213) and *Laser-Based Sensors for Monitoring Coal Gasifiers, Part 2* (1020186).

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Is Biomass Torrefaction on the Move?

Torrefaction is a pyrolitic treatment process for raw biomass that could allow power plants to operate reliably and efficiently while cofiring coal with much higher fractions of biomass. Currently, cofired plants can operate effectively using clean, high-quality biomass for up to 10% of the heat input. This limit reflects the high moisture content and fibrous nature of most raw biomass fuels. EPRI research has demonstrated that with torrefied biomass, the fraction could be increased to as much as 25%.

EPRI members have expressed interest in evaluating the potential of torrefied biomass, but quantities of torrefied material are limited. EPRI is working with the Idaho National Laboratory to demonstrate the torrefaction/pelletization process at pilot scale. The demonstration will produce approximately 100 tons of torrefied material from several different types of feedstock, using the laboratory's facilities and EPRI's torrefaction chamber. EPRI members participating in this project will have the opportunity to request supplies of the material to conduct test burns at their facilities.

"One objective of the study is to demonstrate the process of torrefaction and pelletization on a large scale," said Stan Rosinski, EPRI program manager, renewables. "It will also enhance our understanding of the characteristics of torrefied material when higher percentages are cofired."

The study will examine whether various feedstocks require different torrefaction temperatures and times. Also, it will address the extent to which different feedstocks can be combined— either during torrefaction or during subsequent pelletization. Another key question is whether measurable greenhouse gases are produced during torrefaction or combustion.

"Creating a large quantity of material and conducting test burns at coal plants across the nation will demonstrate the viability of various torrefied biomass fuels for cofiring," said Rosinski. "It will also encourage commercial entities to begin developing large-scale torrefaction facilities."

If the pilot tests demonstrate that torrefied material increases the value of biomass and is carbon neutral, the next step will be to build mobile torrefaction units that can be used at different plants burning a variety of biomass fuels. Mobile units brought to the different plants can help reduce fuel shipping costs and allow torrefaction to be adapted to the types of feedstock available in different regions.

For more information about participating in the study, contact Stan Rosinski, strosins@epri.com, 704.595.2621.

Pyrolysis of Biomass Creates Torrefied Material

Biomass feedstocks are roasted at 250°C (482°F) in a low-oxygen atmosphere to evaporate water and drive off the most volatile components. Volatile hydrocarbons may be captured and combusted to supply most of the energy required for torrefaction. The resulting char is compressed into charcoal-like pellets with an energy content per unit of mass about 30% higher than raw feedstock—comparable to the energy content of coal. Because of their high energy density, uniformity, and water resistance, the pellets can be efficiently stored and transported.

Study Evaluates Fine-Mesh Screens for Fish Protection in Power Plant Cooling Systems

A primary challenge for power plants using once-through cooling systems is to ensure adequate water supplies for operations while protecting aquatic life in the lakes, rivers, oceans, and estuaries from which the plants draw their cooling water. The U.S. Environmental Protection Agency (EPA) recently released proposed revisions to §316(b) of the Clean Water Act. The proposed revisions establish technology-based performance standards requiring all power plants to reduce impingement (pinning of aquatic organisms against cooling water intake screens or other parts of the intake structure) and requiring some plants to reduce entrainment (passing of aquatic organisms through intake screens and into and through cooling water systems). The use of ≤2.0-mm (≤78.7 mil) fine-mesh traveling water screens is one option available to plants to meet the new requirements.

To provide the power industry with scientific data regarding the effectiveness of fine-mesh traveling water screens, EPRI conducted a laboratory study of 0.5- to 2.0-mm (19.7 to 78.7 mil) screens. The study involved 10 species of fish, more than 1,160 replicates, and approximately 170,000 test organisms.

This was the first study of its kind to evaluate the performance of fine-mesh screens in a laboratory. Pending the requirements of the final EPA Rule planned for July 2012 promulgation, power companies may be able to use the EPRI study results to support their site-specific technology assessments. If fine-mesh screens are adopted as the technology to be installed, EPRI study results may be used to minimize future site-specific testing.

Post-Collection Survival

Laboratory pilot screens with smaller mesh (0.5–1.0 mm [19.7–39.4 mil]) performed poorly. Forty-eight-hour survival of larval fish <12 mm (<472.4 mil) in size collected off these smaller screens was approximately 30%. The poor survival likely results from the fact that at this development stage, larvae are extremely sensitive to the impingement, collection, and transfer process. Related EPRI work indicates that some young fish may have a greater potential for survival if they are entrained in the cooling system, rather than collected on <2.0-mm (<78.7 mil) screens.

Survival dramatically increased (to approximately 90%) for larger larvae and early-juvenile organisms collected on 2.0-mm (78.7 mil) screens. This is likely because larvae collected off the larger mesh size have developed scales and musculature that decrease sensitivity to impingement and handling stress. Approach velocity was a key factor affecting survival, with survival decreasing as velocity increased.

Collection efficiency was somewhat dependent on the length of the fish and was lower at the two extremes of fish length tested. In general, the smallest organisms tested were not collected and were likely entrained or extruded through the mesh. Some of the largest organisms tested, especially at the lower approach velocities, were able to swim away from the screen and avoid collection.

Implications for Future Studies

Although the study showed high survival rates for many of the tested species using 2.0-mm (78.7 mil) screens, it did not include species that are commonly entrained at power plants. These generally include forage fish, such as freshwater gizzard shad and threadfin shad, marine bay anchovy, and herring, all of which are exceptionally prolific. Many of these species are so sensitive that transporting them to a laboratory is not practical. Future studies may explore new ways of transporting these commonly entrained fish to a laboratory for testing.

Additional studies also may explore how very early larvae interact with <2.0-mm (<78.7 mil) screens. By studying these interactions, EPRI may be able to recommend operational and design changes that could increase survival. Such changes may relate to screen shape and material, how fast the screens turn, and how much pressure is used to wash off the fish.

As the EPA finalizes its §316(b) revisions, EPRI's study provides valuable information regarding the effectiveness of the various screen technologies. Study results also can inform power companies as to the best way to meet the new requirements.

For more information, contact Doug Dixon, ddixon@epri.com, 804.642.1025.

Powering Servers: Direct Current Demonstration Project Points to Big Efficiency Gains

Duke Energy and EPRI are collaborating on a project to demonstrate and measure gains in efficiency that can be realized by converting alternating current (ac) to direct current (dc) and then feeding the dc power to data center servers and storage arrays. Preliminary test results from a Duke Energy data center in Charlotte, North Carolina, indicate that the center's servers and storage arrays use 15% less energy than if equipped with a typical double-conversion uninterruptible power supply and power distribution unit. For the project as a whole, savings of 7%–20% are anticipated in the data center electrical load, depending on the vintage of the equipment compared. When the decrease in cooling load made possible by the switch to dc is taken into account, the savings could double.

Although most data center server racks are not currently powered with dc, the servers and storage arrays can operate with either ac or dc. Data center power typically relies on ac that is distributed within the facility at 480 volts. This power undergoes several conversions from ac to dc and back again. Power losses from inefficient conversion devices add up to a large power loss and increase the energy required to remove the heat produced. While estimates and actual measurements vary, power use by the information technology loads themselves can be as low as 50% of the total data center load.

Using dc power and eliminating unnecessary conversion steps offers several benefits:

- Reduced losses
- Increased reliability
- Reduced cooling needs
- Reduced space requirements
- Simpler power supplies
- Reduced heat-related failures

The Duke Energy–EPRI demonstration retrofitted selected data center computer hardware to operate on 380-volt dc power and compare the efficiency of the power distribution system to the original 208-volt ac power system. Three racks of servers will be run on ac or dc, with the ability to switch between the two sources. Researchers are documenting efficiency gains and determining the feasibility of dc conversion and delivery. They are also identifying issues and best practices and examining ways to use study results to develop standards.

Other companies participating include Delta Products Corporation, Hewlett-Packard, IBM, EMC, Direct Power Technologies, Inc., and Universal Electric Corporation.

If this dc technology were to be used in all 2.5 million U.S. data centers similar in size and scale, the impact could be significant. An average data center, operating continuously, day and night, consumes almost 3 megawatts. The U.S. Environmental Protection Agency reported to Congress that data center industry power consumption doubled between the years 2000 and 2006 and was expected to double again by 2011. If this trend continues to 2016, then reducing data centers' energy consumption could reduce demand by more than 25 billion kilowatt-hours per year.

For more information, contact Brian Fortenbery, bfortenbery@epri.com, 865.218.8012

The Right Way for the Right-of-Way? Integrated Vegetation Management Brings Systematic, Sustainable Approach to Controlling Vegetation

"Integrated vegetation management" is a systematic, disciplined process for controlling vegetation growth along electric utility transmission rights-of-way. It employs sustainable practices that minimize negative environmental impacts while enhancing grid reliability.

In 2006, the North American Electric Reliability Corporation (NERC) implemented Standard FAC-00301 (Transmission Vegetation Management Program) to improve the reliability of transmission systems by preventing outages caused by vegetation located on, or adjacent to, rights-of-way. As a result, some utilities moved away from integrated vegetation management in favor of more aggressive right-of-way clearing.

Site-Specific Vegetation Management

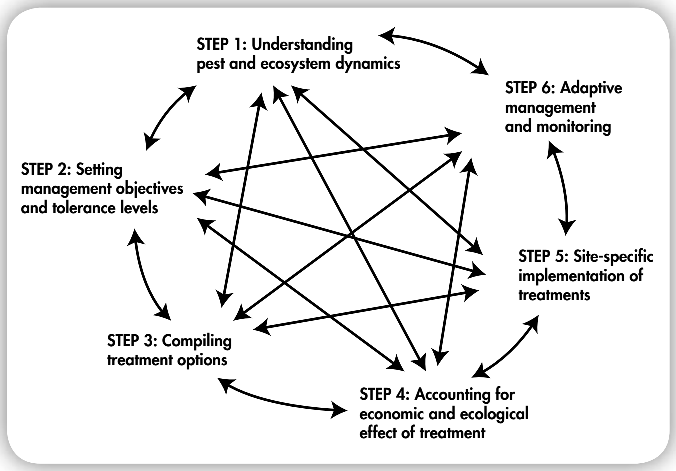
Integrated vegetation management is used to select and apply vegetation control treatments and to monitor and modify the treatments as necessary. It fosters the cultivation of diverse, short-stature shrubs, which minimizes the population of taller, overstory trees. The program is customized for the ecology of each site and can be applied separately to specific areas within a right-of-way. Such detailed application leads to vegetation control without significant environmental degradation.

Various methods are used to remove undesirable tall-growing plants from rights-of-way. Mechanical methods include mulching, brush mowing, and hand-cutting of problem trees. Desirable plants, such as grasses, herbs, wildflowers, and shrubs may grow naturally, following the mechanical removal of undesired vegetation. In some instances, hand-seeding of low-growing native vegetation may be indicated. Herbicides may be used selectively to encourage low-growing plants. As the growth of undesirable trees is reduced, the need for chemical treatments typically decreases.

"While we recognized that the more aggressive clearing methods reflected utilities' commitment to meeting the NERC standard, EPRI continued to see integrated vegetation management as an environmentally sound tool for enhancing compliance," said John Goodrich-Mahoney, EPRI senior project manager for Transmission and Distribution environmental issues. "Integrated vegetation management presents a comprehensive, sustainable model. Its sustainable practices can temper concerns regarding aggressive clearing that some stakeholders have raised with the Federal Energy Regulatory Commission (FERC)."

Application Principles

Integrated vegetation management involves a series of steps that formalize the relationship among key phases of vegetation management. The steps are conducted in a continuous cycle and are linked; as each step is applied, ongoing refinements can be implemented (see figure below).



Source: "A Framework for Applying Integrated Vegetation Management on Rights-of-Way," January, 2005, Journal of Arboriculture

These six steps are also the principles that EPRI uses to assess integrated vegetation management. Four additional principles include: 1) Compliance with the law; 2) Tenure and use rights and responsibilities; 3) Community relations and worker rights; and 4) Management planning. Within the 10 principles, 42 criteria delineate effective application of integrated vegetation management. By practicing the 10 principles and meeting the 42 criteria, utilities can increase biodiversity along their rights-of-way.

For more information about integrated vegetation management, contact John W. Goodrich-Mahoney, jmahoney@epri.com, 202.293.7516.

Cobalt Reduction: It's Everyone's Job

Radioactive cobalt has long been recognized as the predominant source of background radiation in nuclear power plants. It originates in alloys containing cobalt and nickel, which are used throughout the plant because of their wear and corrosion resistance at high temperatures. Keeping the background radiation field low is essential to maintaining worker safety and enabling people to complete tasks without exceeding safe exposure levels.

New sources of cobalt-60 and cobalt-58 have been identified in recent years, prompting EPRI to publish its updated *Cobalt Reduction Sourcebook* (1021103), with revised procedures for reducing cobalt and also preventing the activated cobalt-60 and cobalt-58 from generating radiation fields.

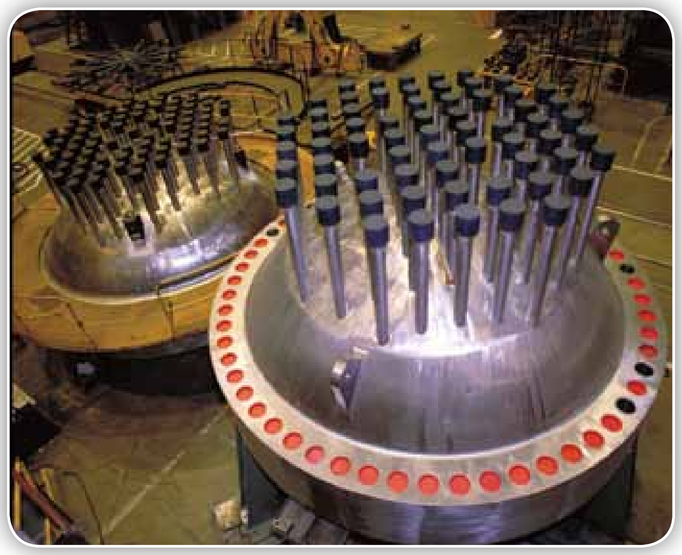
"The new sourcebook emphasizes that every part of the plant has a stake in reducing cobalt and needs the support of senior management," said Daniel Wells, project manager for source reduction at EPRI. "It's no longer just something for maintenance to think about when they are replacing valves."

Historically, valves with hardfacing of Stellite, an alloy containing cobalt, were believed to be the primary sources of cobalt. Particles created by wear, corrosion, and maintenance operations enter the water stream; are transported into the core, where they become activated to cobalt-60; and then spread to other parts of the plant, where they present radiation hazards. The valves are still the greatest contributors, but other components throughout the plant—including stainless steel piping, pump heads, vessels, condensers, and turbines—are now recognized as significant additional sources of both cobalt and nickel. Alloys that release nickel can become activated to cobalt-58, which has a lower radiation energy and shorter half-life than cobalt-60, but still contributes to the overall radiation dose.

The new sourcebook has tables outlining 14 technologies and strategies for pressurized water reactors and 17 technologies and strategies for boiling water reactors. It contains flowcharts that help workers identify sources of cobalt and take appropriate measures to reduce levels of radiation.

The revised procedures were derived through ongoing efforts by EPRI and nuclear plant personnel to identify sources of cobalt and develop methods to reduce dose levels. For example, at the Exelon Quad Cities plant, it was discovered that low-pressure turbine buckets had Stellite coatings that provided a major source of cobalt that had not been previously suspected.

New technologies include the electropolishing of components to reduce surface roughness where corrosion can occur, the use of X-ray fluorescence to test for adequate clean-up of cobalt particles after maintenance activities, and the injection of depleted zinc oxide into the cooling stream to reduce radioactive cobalt in pressurized water reactors.



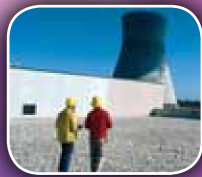
Pressurized Water Reactor Vessel Heads

EPRI worked with TVA during the restart project at Browns Ferry Unit One to implement all of the recommended procedures. The result was the second lowest dose rate of any nuclear plant in the world, surpassed only by a new plant in Japan that followed similar procedures.

While it may not be practical to do complete refurbishment of other plants, incremental improvements can be made by following the recommended procedures during routine maintenance and when replacing components.

A key feature of the tables in the new sourcebook is that they include estimates for dose rate reductions, along with the expected times required to obtain those reductions and forecasts for how long they will last. That knowledge can help when making a business case for proposed improvements.

For more information, contact Dennis Hussey, dhussey@epri.com, 650.855.8529, or Daniel Wells, dwells@epri.com, 650.855.8630.


More Than 35 Years of EPRI Work Fits into Pocket Manuals for Outage Inspection and Boiler Tube Failures

EPRI has published four new pocket field guides that review and compile outage inspection procedures and the fundamentals of boiler tube failures for conventional plant boilers and heat recovery steam generators (HRSGs). Drawing on more than 35 years of EPRI research in boiler tube failure reduction, EPRI technical reports, and utility best practices, the guides describe basic tools for identifying and addressing failure mechanisms.

When dealing with an unscheduled outage, plant operators are challenged to return the unit to service as quickly as possible, but also to invest the time and effort to determine the root causes and make repairs. Effective inspections are critical to all these goals.

Outage Inspections

The two EPRI pocket manuals for outage inspection of boilers and HRSGs are designed to be used by any maintenance engineer or inspector entering a boiler or HRSG during a planned or unplanned outage. They help inspectors focus on abnormalities, deficiencies, and signs of damage and deterioration, and they provide tools for prioritizing actions.

Major sections include recommendations for a hot walkdown of the boiler and inspection procedures for 15 specific systems, including the ash pit, furnace waterwalls, superheat/reheat pendants, economizer banks, backpass walls, penthouse, steam drums, dead air spaces, and desuperheaters. Each section identifies areas to inspect and describes common damage or failure mechanisms that may be evident.

The HRSG manual includes sections on performing visual inspections, developing a risk assessment profile, and identifying plant components with high, medium, and low probability of failure. A technical overview describes major plant components and how they work. The final section reviews common failure mechanisms, including stress corrosion cracking, fatigue, flow-accelerated corrosion, thermal shock, and creep.

Together, the two outage inspection manuals are designed to assist operators in conducting inspections, identifying situations that require further investigation, identifying environments or trends that could be detrimental to unit availability, and quickly assessing a suspicious situation.

As a result, units can be operated with fewer off-normal events and more timely correction of process upsets due to equipment failures or degradation.

Boiler Tube Failures

Two of the four new field guides condense essential, practical information on boiler tube failures. They draw on EPRI's work extending back to 1997 in its comprehensive boiler tube failure reduction program and its cycle chemistry program and are based on the three-volume reference *Boiler and Heat Recovery Steam Generator Tube Failures: Theory and Practice* (1012757), which examines various failure and degradation mechanisms and the technical basis for addressing tube failures.

The guides review field inspection fundamentals and cover both water-touched tubes and steam-touched tubes in conventional boilers and HRSGs. They describe the mechanisms producing failures, identify contributing causes of degradation, present immediate actions that can be taken to remove or reduce the effects of the contributing causes, and address potential implications or ramifications for other parts of the boiler unit.

Screening tables provide information that can be used to screen a boiler tube failure to identify likely contributing degradation mechanisms. They also cross-reference applicable chapters in EPRI's three-volume report. Another feature identifies the possible root causes of boiler tube failure, specifies actions to confirm the root cause, and prescribes immediate actions and solutions.

The 8½-by-4¼-inch ring-bound flip-style books are pocket-sized and easy to use in various plant situations. Hundreds of color photographs provide visual indicators and a ready reference to conditions described in the text. Program members receive a limited quantity of books and may purchase additional copies.

For more information, contact Kent Coleman, Boiler Life and Availability Improvement Program, kcoleman@epri.com, 704.595.2582, or Bill Carson, Heat Recovery Steam Generator Dependability Program, bcarson@epri.com, 704.595.2698.

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 look under My Research Areas.

Corporate Carbon Strategy and Procurement of Greenhouse Gas Emissions Offsets for Compliance with Mandatory Carbon Constraints (1019911)

This report describes strategies that may be employed by electric companies to comply with potential future mandatory greenhouse gas emissions reduction programs with an in-depth look at use of offsets as a key component of future corporate carbon compliance strategies.

EPRI Underground Distribution Systems Reference Book (The Bronze Book) (1019937)

The Bronze Book provides a reference for utility engineers and personnel responsible for the planning, design, manufacture, installation, operation, and maintenance of underground distribution systems. Its development was driven by the impending loss of institutional knowledge through attrition and retirement of experienced people and the consequent urgent need to document industry knowledge and practices.

Quantifying the Benefits of Using Coal Combustion Products in Sustainable Construction (1020552)

This report describes environmental and cost benefits resulting from the use of coal combustion products (CCPs) in place of other raw materials such as portland cement, gypsum, and granular fill in construction applications. Researchers found that substitutions reduced energy consumption by 63 trillion Btu, water consumption by 5.9 billion gallons, and greenhouse gas emissions by 10 million tons of carbon dioxide equivalents, while saving $2.4 to $7.8 billion.

Energy Storage Technology Options (1020676)

A confluence of industry drivers is creating new interest in electric energy storage systems. These include increased deployment of renewable generation, the high capital cost of managing grid peak demands, and large capital investments in grid infrastructure for reliability. New EPRI research offers a current snapshot of the storage landscape and an analytical framework for estimating the benefits of applications and the life-cycle costs of energy storage systems.

Groundwater and Soil Remediation Guidelines for Nuclear Power Plants (1021104)

These guidelines provide technical guidance for evaluating the need for, and timing of, remediation of soil and/or groundwater contamination from onsite leaks, spills, or inadvertent releases to prevent migration of licensed material offsite and to minimize decommissioning impacts.

Evaluation of Storm Water as a Resource for Power Plant Cooling (1021124)

This report evaluates the potential to use storm water runoff in lieu of withdrawals from a freshwater body to meet water needs for different power plant processes. Storm water can be a useful resource for power plant use; however, several site-specific engineering-type analyses need to be performed to better understand the feasibility of its use.

Arsenic Health Research Update: Progress on the Inorganic Arsenic Cancer Slope Factor (1021211)

This report summarizes findings from EPRI's most recent work on the cancer slope factor for inorganic arsenic. The current linear approach does not account for a biological mode of action at exposures to very low concentrations of inorganic arsenic and, if retained, could lead to a substantially higher value for the slope factor.

Water Footprinting Primer for the Electric Power Industry (1022493)

This report contains information on a tool that the electric utility industry can use to track and benchmark water use and assess water risk. Definitions of water footprinting, as well as its potential benefits and drawbacks, are discussed. The report also offers guidance on how to conduct a water footprint and on how water use information can be reported.

U.S. Department of Energy and Ohio Coal Development Office Advanced Ultra-Supercritical Materials Project for Boilers and Steam Turbines—Summary of Results (1022770)

This report summarizes research to date and outlines research needed to develop materials and components that enable power plants to operate successfully with main steam temperatures up to 760°C (1400°F). Areas covered include boiler alloys, steam oxidation and exfoliation, fireside corrosion, fabrication and design, cost and economics, welding and repair, and alloy selection for rotors, discs, and blades.

WIRED IN

Perspectives on electricity

Managing Aging: The Importance of Vigilance and R&D

Jean-Pierre Hutin *has led diverse programs for EDF, including maintenance and life management of the French nuclear fleet, as program director for research and development, and currently as leader of international benchmarking and maintenance strategies for the generation division.*

I have always dreamed of eliminating aging…for power plants, for my car, and for myself. But, as we say in French, “la nature n'est pas bonne fille,” or “nature is not a good girl.” There is simply no way to escape aging. However, you can learn to manage it, which will increase life expectancy. And what is true for power plants is true for your car and yourself as well.

When we started operating our nuclear plants in France, we trusted the vendors and manufacturers when they said their equipment would last forever. We believed such claims, not because we were convinced or we were naïve, but because it was more comfortable. Very quickly, however, we had to face reality. Degradation issues emerged with steam generator tubes, guide tube pins, pressurizer instrumentation nozzles, etc. I say “degradation” because one could hardly speak of aging when the plants were only 5 or 10 years old.

The guide tube pins, which help align control rod insertion into a nuclear reactor, had to be replaced because of stress corrosion cracking. The new ones were supposed to be better, but they also cracked, even faster than the originals. That was when I learned that you cannot definitively eliminate a problem if you don’t understand degradation mechanisms, root causes, and driving parameters. At the time, we did not understand precisely why the corrosion developed. We needed R&D to investigate both in the laboratory and in the field.

Another example involved cracking that we discovered in our steam generator tubes. Using conventional degradation criteria, we would have been obliged to replace many of our steam generators in less than 10 years. An R&D effort that examined more than 300 steam generator tubes allowed us to understand the degradation mechanisms, to make predictions, and to assess the safety relevance of the cracking. As a result, we were able to operate the plants safely for 20 to 30 years instead of 5 or 10 before replacing steam generators—and without any tube ruptures.

Our association with EPRI in addressing this issue was invaluable. And it went both ways: we used information from U.S. plants and laboratories through EPRI, and we transmitted to EPRI a lot of experience, feedback, and R&D results. Such sharing is crucial in helping the nuclear industry establish and maintain credibility with the public, regulators, and other stakeholders. As I like to say, “Being right alone is almost like being wrong.”

Ineffective cooperation also can lead to undesirable results. In France, we decided to replace all reactor vessel heads without first understanding which were susceptible to stress corrosion cracking and which were not. In the United States, utilities, vendors, and regulatory bodies believed they had sufficient technical understanding to determine that the corrosion would not lead to unacceptable degradation. Ten years later, however, one U.S. plant discovered a big “hole” in its vessel head.

Such examples are common to us all. A number of EDF plants were out of service for some time because of steam generator clogging—even though such clogging was predictable based on experience at U.S. utilities, which had effectively managed the problem several years before.

Now, the big question is: After 30 years of operation, have we experienced all possible aging phenomena? On one side, yes, we have experienced all possible aging mechanisms and know a lot about them; on the other side, we tend to forget history, and known aging issues can surface elsewhere.

Continued vigilance and R&D are essential to unearth root causes and unexpected degradation. There is often a close link between R&D results and operational choices, highlighting the importance of a strong relationship between R&D and the power industry.

An important example is the formation of the Materials Aging Institute, a collaborative laboratory in France established by EDF, EPRI, and two Japanese utilities, Tokyo Electric Power Co. and Kansai Electric Power Co. This facility unites some of the world’s best materials scientists and engineers with cutting-edge experimental equipment to advance our understanding of aging phenomena. Notably, in addition to metallic materials, the Institute is carefully studying materials such as polymers and concrete that are critical to the power industry.

Managing aging is not just about making predictions. It’s also about assessing the acceptable limits of aging. Working with EPRI, I am confident we will learn how to do both…and make nature a good girl.

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