SPRING 2008

EPRI JOURNAL

ELECTRIC POWER RESEARCH INSTITUTE

Plug-In Hybrids

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Henry A. (Hank) Courtright, *Senior Vice President, Member Services*

Contact Information
Editor-in-Chief
EPRI Journal
PO Box 10412
Palo Alto, CA 94303-0813

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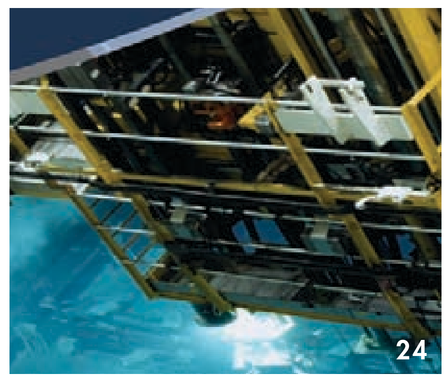

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Editorial

EPRI—A Technology Accelerator

Recently, an important first step was taken in the electricity sector.

In February 2008, EPRI and its collaborative team members, Alstom Power and We Energies, dedicated the first pilot-scale demonstration of chilled ammonia technology for capturing CO_2 from a pulverized-coal plant. The Wisconsin pilot plant, described on pages 4 and 5 of this issue of the *Journal,* is an important and essential first step in the pursuit of large-scale capture and storage of CO_2.

The project grew out of several important aspects of EPRI's collaborative efforts. EPRI's Technology Innovation (TI) program made possible the proof of concept through bench-scale testing of the chilled ammonia process at SRI International. TI funding is supported by all EPRI members to develop emerging, state-of-the-art technologies. The EPRI core R&D collaborative program then developed the concept of the pilot-scale plant for consideration by equipment suppliers interested in supporting the technology's development.

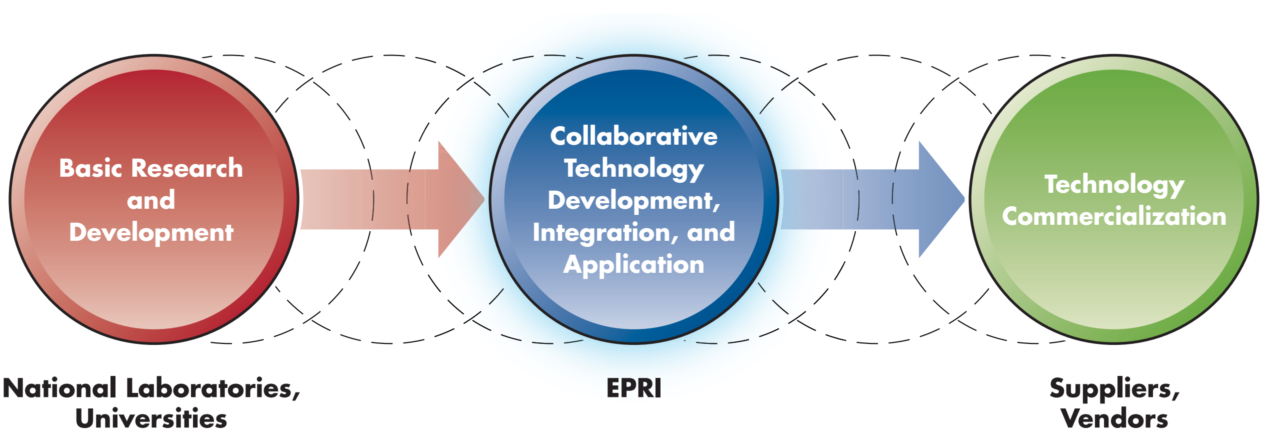
Building on EPRI's work, Alstom stepped forward, acquiring intellectual property rights to the technology and becoming the lead partner in the pilot plant design, construction, and operation. In addition, 37 EPRI members provided cost-sharing for front-end engineering and design and to test and evaluate the technology's performance. The pilot plant is currently in its start-up phase and will be providing valuable information over the coming months to enable process scale-up for CO_2 capture demonstrations at other coal- or gas-fired plants.

This project is an excellent example of EPRI's role as a technology accelerator. This role is diagrammed in the figure at right. Through our TI program we are constantly on the lookout for promising new technologies emerging from basic R&D activities at universities, national labs, or other sources (represented by the left-hand circle). While basic R&D is not EPRI's primary focus, our own technical staff does have the freedom and financial support through the TI program to pursue promising new ideas. The dashed circles on the left depict our involvement in basic R&D.

The TI program then hands off the most promising technologies to an EPRI collaborative program with the objective of leveraging both the funding and the technical expertise of the program participants to accelerate the development of the technology. This is EPRI's "sweet spot," depicted by the center circle. This role, which we uniquely fill within the electricity sector, provides a critically important vehicle to accelerate the process of getting from a great idea to a commercially deployable technology.

In general EPRI does not commercialize technologies; that is the role of suppliers, vendors, and other technology providers, represented by the circle on the right. The dashed circles on the right depict the limited instances where we do commercialize a product or service that is based on a unique EPRI competency. In such cases, one or more technology providers may be active participants in a collaborative program, which facilitates a smooth transfer of the developed technology.

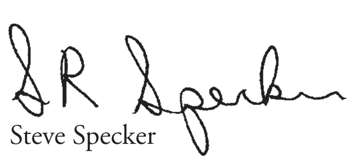
This collaborative model will be the foundation for future climate technology demonstration projects being developed in concert with EPRI members, technology providers, and governments. Several demonstration projects spanning the



full portfolio of low-carbon technologies are being launched in 2008. In the areas of efficiency and renewables, these include demonstrations of new hyper-efficient end-use technologies, integration of smart grid applications with advanced metering infrastructures, and development of new compressed-air energy storage plants. Three projects will help scale up carbon capture and storage (CCS) from both pulverized-coal and integrated gasification–combined-cycle (IGCC) power plants. Another project will seek to further the development of membrane technology to lower the cost of oxygen supply for IGCC and oxy-combustion plants.

These climate technology demonstration projects, and others that will be launched over the coming months, are critical steps toward the goal of a full portfolio of low-carbon technologies that can be broadly deployed across the electricity sector. While these projects are necessary for scaling up the various technologies, they are insufficient on their own to demonstrate commercial-scale integration of CCS. The billions of dollars needed over the next decade for multiple commercial-scale CCS demonstrations is well beyond EPRI's current collaborative funding model. But we are not waiting for the billions. We are determined to keep moving the ball forward through the activities of our core R&D programs, supplemented by appropriately scoped climate technology demonstrations.

Accelerating the deployment of a full portfolio of reliable and affordable low-carbon technologies is EPRI's defining role over the next decade. And the metric of success is pretty simple. It's all about helping reduce the time it takes to get the most promising ideas from the left-hand circle to the right-hand circle.



Steve Specker
President and Chief Executive Officer

In the Field

Technology testing and demonstration on utility systems

Pilot Project Uses Innovative Process to Capture CO_2 From Flue Gas

A pilot project recently launched at We Energies' Pleasant Prairie Power Plant represents a milestone in efforts to capture carbon dioxide (CO_2) from the flue gas of a pulverized-coal generating station. The 1.7-MWe system, designed and constructed by Alstom, uses a chilled ammonia process that has the potential to capture more than 90% of CO_2 in laboratory experiments, at a cost far lower than other technologies currently available. As part of the collaboration, EPRI will conduct a year-long series of performance tests and cost analyses, which can set the stage for further scaling up of the chilled ammonia process.

"Developing cost-effective carbon capture technology is one of the most important environmental challenges facing the utility industry in the twenty-first century," said Gale Klappa, chairman and chief executive of We Energies, at the project's inauguration. "It's important that we take steps now to achieve a long-term technology solution," he added, calling the project a "critical step" in the development process.

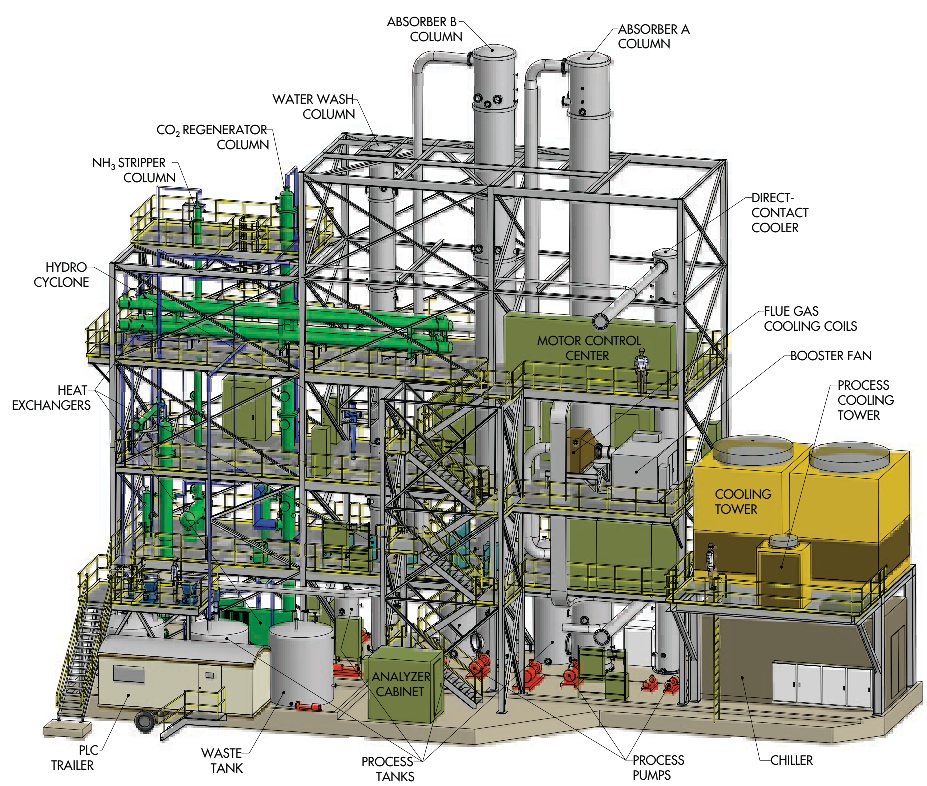
Carbon capture is well established in industrial facilities that provide CO_2 for chemical production, but the scale is much smaller than that required for power plant applications. The capture process most commonly used today is relatively inefficient: applied to a power plant, it could increase the cost of electricity by 50–80% and consume as much as 30% of the plant's energy output. In contrast, the chilled ammonia process is projected to increase the cost of electricity by about 30% and use less than 15% of the output.

The process involves three steps. First, flue gas exiting from the plant boiler and air quality control system is cooled and cleaned before being sent to a tall CO_2 absorber column. There the gas mixes with a solution of ammonium carbonate, in which CO_2 is removed through the formation of ammonium bicarbonate. Finally, the solution is pumped to a regeneration system where it is heated under pressure, reversing the absorption process and releasing pure CO_2.

The pilot-scale equipment at Pleasant Prairie is designed to capture up to 15,000 tons per year (t/yr) of CO_2 by treating about 1% of the plant's flue gas. This first application of the chilled ammonia process at a working power plant is designed to provide proof of concept and facilitate long-term tests to measure performance and energy consumption. Technical and economic data analyses from this pilot project will enable larger-scale demonstration projects.

"This pilot is a significant milestone in our ongoing partnership with We Energies and EPRI," said Jean-Michel Aubertin, senior vice president of Alstom's Energy and Environment Systems Group. "This plant will provide invaluable information for the commercialization of CO_2 capture technology." Alstom, one of the world's leading suppliers of power equipment, holds the exclusive license to the chilled ammonia process.

EPRI's collaborative process brought together more than 30 organizations to support this project, including a large



number of U.S. coal-fueled utilities and international participants. A major goal is to help make CO_2 capture technology ready for widespread deployment after 2020.

"EPRI's R&D model is built on the idea that we can best achieve technological progress through collaboration," said Henry A. Courtright, EPRI senior vice president for member services. "This is especially true in carbon capture and in other generating and efficiency technologies that must be part of our industry's climate strategy."

The next step in scaling up the chilled ammonia process will be to build a 20-MWe precommercial, "product validation" facility. Such a facility is tentatively scheduled to begin operation in 2010 at American Electric Power's (AEP's) Mountaineer generating station in West Virginia. EPRI will provide a confidential review of the final design of the 20-MW system and will then conduct all tests and data analyses needed to assess its performance. Alstom will serve as the project lead for building and initially operating the capture facility.

In contrast with the Pleasant Prairie project, where captured CO_2 will be released, the Mountaineer project's captured CO_2 will be injected into saline aquifer formations via two deep wells. The facility will capture and sequester about 100,000 t/yr of CO_2. Battelle Memorial Institute will work with AEP on the injection effort, which will focus on monitoring the underground acceptance of CO_2 by the porous rock formations. Battelle and AEP have agreed to share their findings with EPRI and its participating members.

Pending a favorable outcome of the Mountaineer project, AEP intends to build a 200-MWe commercial-scale capture and storage facility with the capability to treat approximately half of the flue gas from one of the utility's existing power plants. This system, projected for startup around 2012 or 2013, would capture about 1.5 million t/yr of CO_2, which may be piped to existing oil fields for use in enhanced oil recovery. The facility is expected to confirm the commercial feasibility of the chilled ammonia process and, with EPRI participation, provide the power industry an opportunity to assess the large-scale impact of CO_2 controls on coal-fired generation.

In addition to supporting development and demonstration of the chilled ammonia process, EPRI is also cooperating with other member utilities to select and deploy alternative postcombustion CO_2 capture technologies. Specifically, Southern Company is preparing to host a 25-MWe project that would capture more than 100,000 t/yr of CO_2 by means of a different technology, which has yet to be selected. EPRI is providing technical support that will focus on process integration, with startup anticipated around 2010.

The project would also have an injection and storage component funded in part by the U.S. Department of Energy through its Southeast Regional Carbon Sequestration Partnership Program and managed by the Southern States Energy Board. A deep saline formation will likely be used for storage, as this is the most widely available type of geologic formation suitable for CO_2 sequestration.

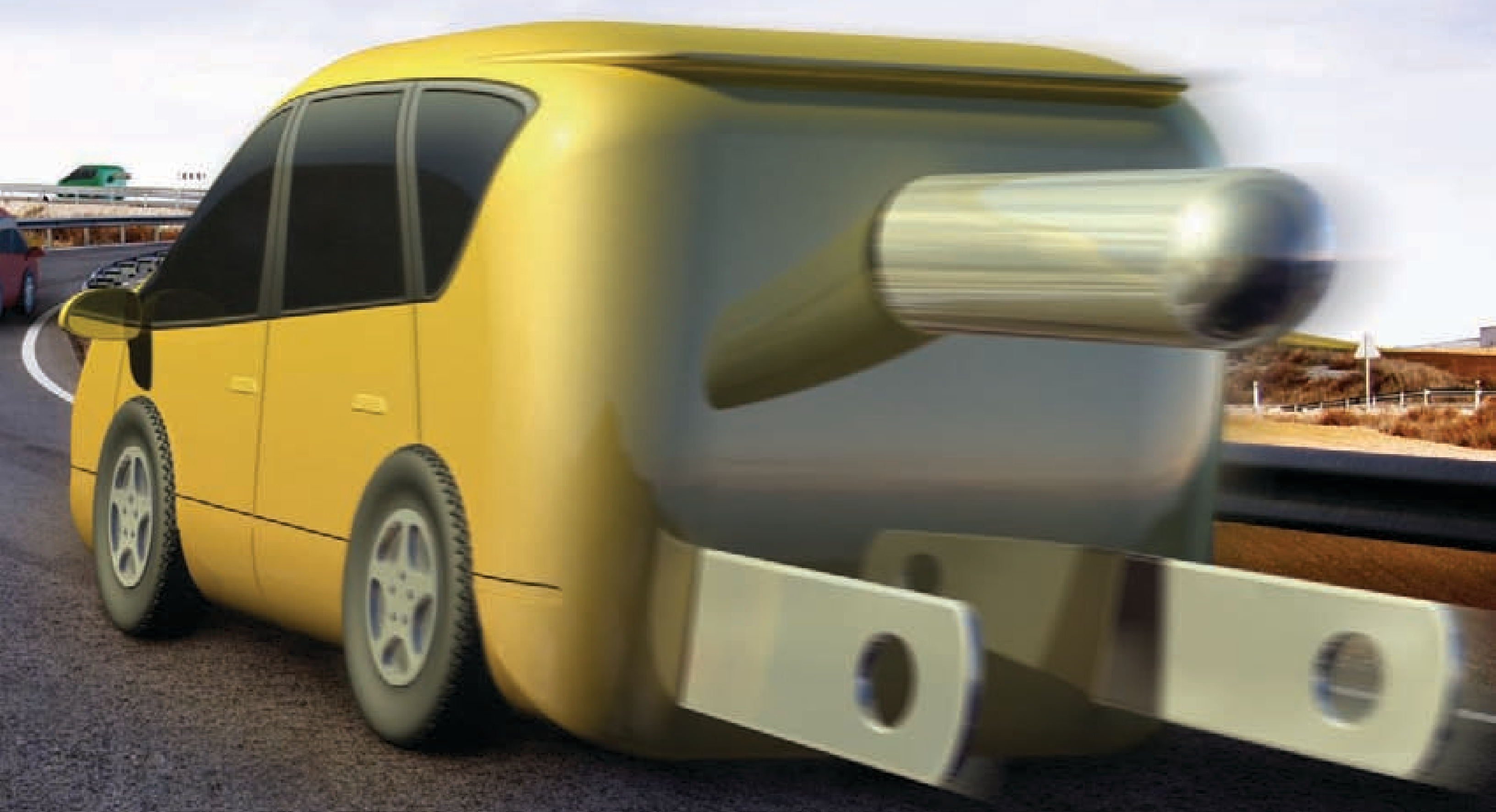
EPRI studies indicate that about 15% of U.S. electric energy production could come from coal plants using CO_2 capture and storage by 2030, and nearly 40% by 2050. The availability of suitable capture technology is considered vital if coal is to remain a major component of power generation when (as is expected) CO_2 emissions reductions become mandatory. Currently coal generates 40% of the world's electricity, and it remains the world's fastest-growing fuel for generation.

For more information, contact Richard Rhudy, rrhudy@epri.com, 650.855.2421.

Plug-In Hybrids

on the Horizon

Building a Business Case



The Story in Brief

Automakers, utilities, and the public are increasingly interested in plug-in hybrid electric vehicles. Recent EPRI studies indicate that society could realize significant benefits to the environment and the economy with PHEVs. EPRI studies also point to sizable challenges and opportunities in technology and utility operations. What's needed is research and development in batteries, the power grid, and generation technologies—and a market that's ready to put substantial numbers of drivers behind the wheel of a PHEV.

Consider these three aspects of electric transportation: It potentially offers consumers a lower-cost alternative to gasoline. It decreases greenhouse gas emissions from the transportation sector. And it reduces dependence on imported petroleum.

Plug-in hybrid electric vehicles (PHEVs) represent the most promising approach to introducing the significant use of electricity as transportation fuel. Unlike battery-only electric vehicles (EVs), PHEVs do not require on-demand, high-power recharging. If the driver misses a charge, the vehicle can run seamlessly on gasoline in hybrid mode until charging is again convenient. While the battery is smaller and less costly for a PHEV than for an EV, the battery is more deeply discharged each day, so many drivers will use as much or more electricity with a PHEV.

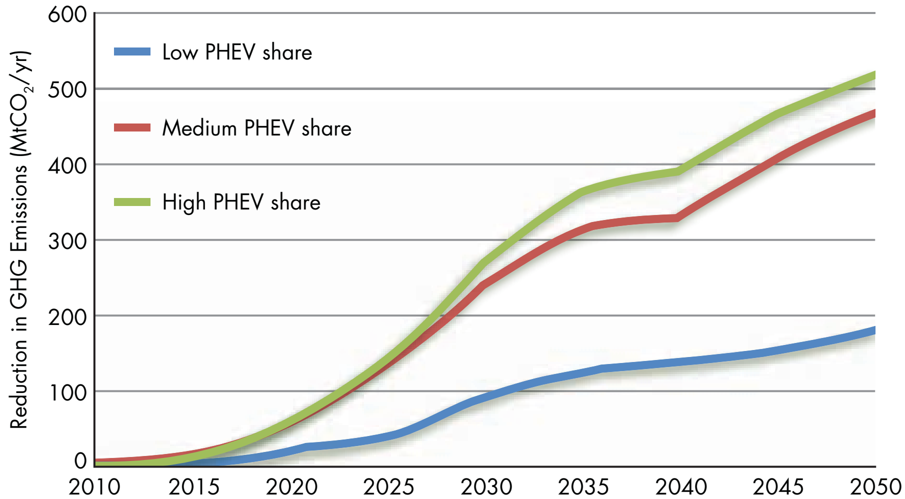
PHEV development can build on more than a decade of experience with conventional hybrids such as the Toyota Prius and Ford Escape, which use a battery and electric motor to augment the power of an internal combustion engine. To this blend of technologies, PHEVs add the ability to charge the battery using low-cost, off-peak electricity from the grid—allowing a vehicle to run on the equivalent of 75¢ per gallon or better at today's electricity prices. A benefit for utilities is that PHEVs draw only about 1.4–2 kW of power while charging—about what a dishwasher draws.

The primary challenges to widespread use of PHEVs, challenges that will require direct utility involvement to overcome, include specification of a convenient grid interface, creation of a two-way communication system to potentially enhance cost savings, and development of a mass market to lower battery costs.

Environmental Benefits of PHEVs

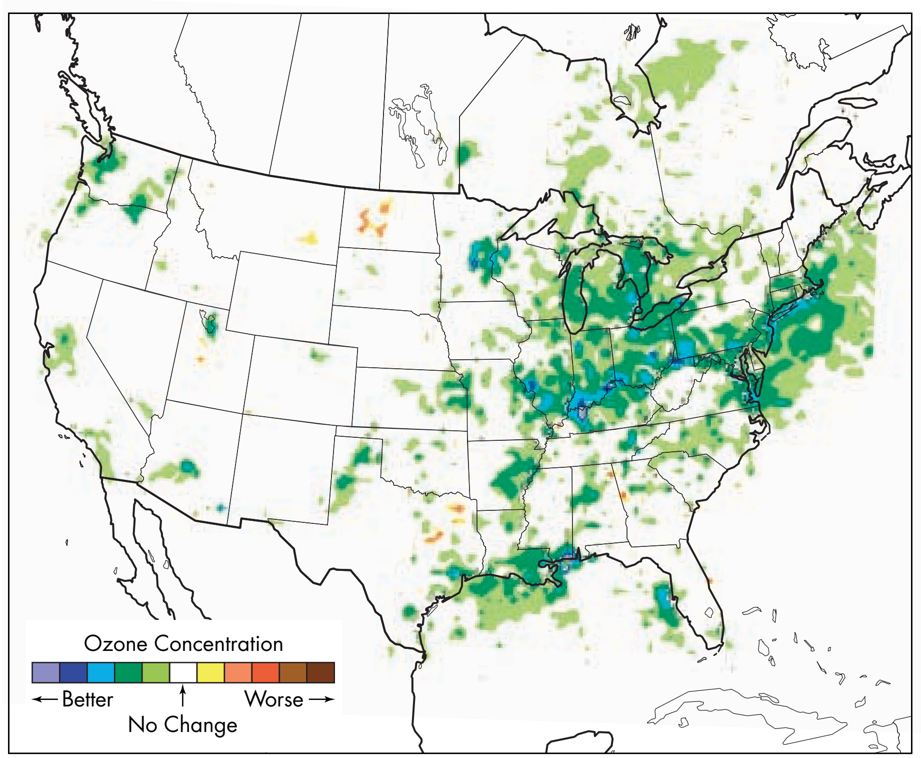
One possible stumbling block to widespread public acceptance of PHEVs is the lingering question about whether charging vehicles with electricity from the grid will just reduce one source of pollution

Annual Greenhouse Gas Emissions Reductions From PHEV Adoption



EPRI studies indicate that putting PHEVs on the road could reduce U.S. greenhouse gas emissions by as much as 500 million metric tons a year by 2050. By that time, cumulative reductions are expected to total 3.4–10.3 billion metric tons, depending on PHEV market share and several other factors.

PHEV Improvement in Ozone Concentration



In addition to reducing greenhouse gas emissions, PHEV adoption is expected to help reduce emissions of other air pollutants as well, including volatile organic compounds, nitrogen oxides, sulfur dioxide, ozone, and particulates. Reductions in ozone emissions are particularly impressive, with improvements expected in most regions.

(gasoline) and substitute another (power plants). EPRI recently examined this question in the most comprehensive environmental assessment of electric transportation to date. Conducted with the Natural Resources Defense Council (NRDC), the assessment focuses on the likely environmental impacts of bringing a large number of PHEVs onto American roads over the next half century.

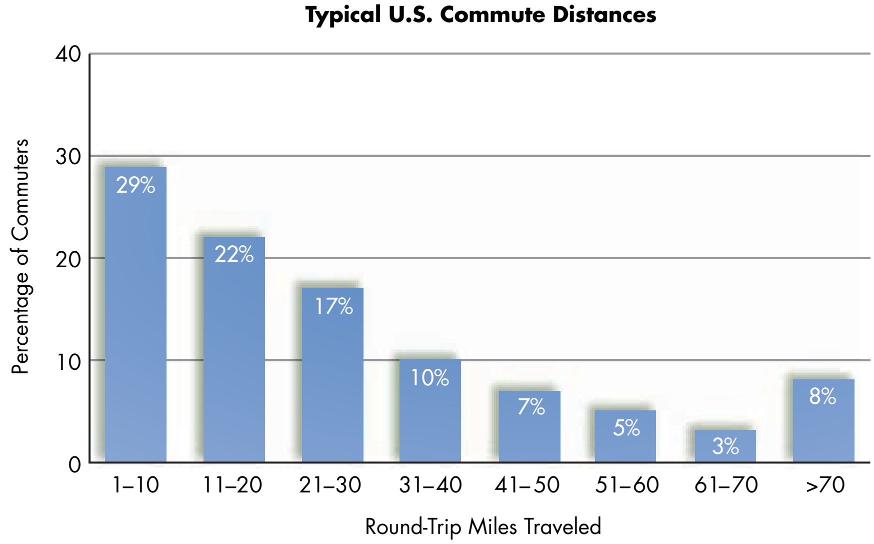
The first part of the study used a scenario-based modeling analysis to determine how PHEVs would change U.S. greenhouse gas (GHG) emissions between 2010 and 2050 under various circumstances. This inclusive "well to wheels" analysis tracked emissions from the generation of electricity to the charging of PHEV batteries and from the production of motor fuels to their consumption in internal combustion vehicles. Researchers used detailed models of the U.S. electricity and transportation sectors to create a range of potential scenarios and changes in both sectors. The three scenarios for the electricity sector represented high, medium, and low levels of carbon dioxide (CO_2) and total greenhouse gas emissions, as determined by the projected mix of generation technologies and other factors. For the transportation sector, the three scenarios represented high, medium, and low market penetration of PHEVs from 2010 to 2050.

Results were unambiguous: GHG emissions were reduced significantly over the nine scenario combinations. The cumulative GHG emissions reduction by 2050 was at least 3.4 billion metric tons (Gt), assuming a persistently high level of CO_2 intensity in the electricity sector and a low level of PHEV fleet penetration. Assuming low CO_2 intensity and a high level of fleet penetration, the cumulative GHG reduction was 10.3 Gt. Reductions were realized for each region of the country.

The second part of the study focused on determining the effect of aggressive PHEV fleet penetration on overall air quality in a single year, 2030. It compared a base case that assumes no PHEV penetration with an aggressive penetration case in which PHEVs achieve 50% of new-vehicle sales and constitute 40% of on-road vehicles by 2030. First, a variety of important emissions were modeled for the transportation and electricity sectors and then merged with emissions from all other sectors. Using these data, key air quality indicators were calculated by means of the U.S. Environmental Protection Agency's Community Multiscale Air Quality (CMAQ) model.

This analysis found that, for most regions of the United States, increased PHEV use would result in "modest but significant improvements in ambient air quality and reduction in deposition of various pollutants." Considering the electricity and transportation sectors together, PHEVs would help reduce emissions of volatile organic compounds, nitrogen oxides, and sulfur dioxide. Ozone levels would decrease substantially for most regions, although there would be very minor increases in some local areas. Ambient levels of particulate matter would also decrease in most regions.

"These studies should put an end to the myth that electrification of the transportation sector would increase pollution," says Mark Duvall, manager of technology development for EPRI's Electric Transportation program. "Even in the worst-case scenario, assuming only limited introduction of new power plant technology, we see an overall reduction in emissions related to both air quality and global warming."



Data from the U.S. Bureau of Transportation show that 78% of commuters travel 40 miles or less each day—the expected battery-only range of PHEVs with routine overnight charging. For longer distances, the vehicles could run indefinitely in hybrid (gasoline/electric) mode.

Economic Benefits of PHEVs

In another study, EPRI assessed regional economic benefits associated with increased market penetration of plug-in hybrids. The underlying context for this study is the increasing involvement of municipalities in policy areas, such as economic development and environmental protection, that were previously regulated only at the state or federal level. Other studies have examined microeconomic benefits of PHEVs or estimated macroeconomic impacts for the entire United States; this assessment was distinct in calculating expected regional financial and labor impacts resulting from a transition to PHEVs.

This approach can explore in more detail the economic multiplier effect of petroleum displacement. Because the per-mile cost of operating a vehicle on electricity is currently about one-quarter to one-third the cost of using gasoline, vehicle owners can anticipate spending less for transportation. Such savings also represent a transfer

Batteries on the Critical Path

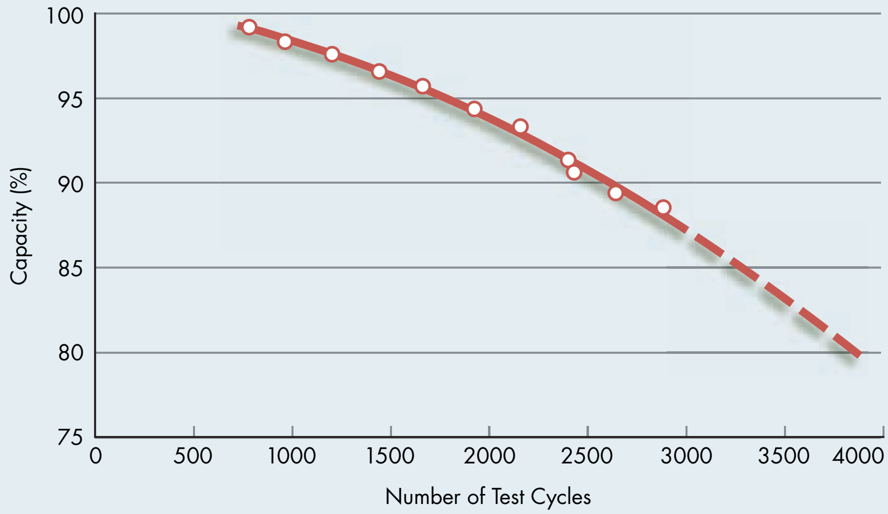
Much enthusiasm for PHEVs is based on the expectation that lithium ion (Li-Ion) batteries can make the leap from electronic devices and small power tools to the much larger application of running a car. Skeptics question whether durable, affordable Li-Ion batteries will be available in sufficient numbers to launch a major automotive revolution within the proposed two- to three-year period. Toyota is making its initial PHEVs with a nickel–metal hydride (NiMH) battery similar to that in its standard Prius vehicle, citing uncertainty about when Li-Ion batteries will be ready for full-scale production. NiMH batteries are not expected to be a widespread choice for PHEV applications because of their low energy density.

The California Air Resources Board (CARB) recently examined a variety of technologies related to the development of zero-emission vehicles. The report noted that although NiMH technology in today's hybrid electric vehicles could probably be modified to meet the technical needs of PHEVs, no substantial efforts appear to be under way to develop NiMH batteries for this application in the long term. Rather, the report concluded, Li-Ion batteries are "making impressive technical progress worldwide," especially with regard to longevity, cycling durability, and safety.

The CARB study projected PHEV introduction at the precommercial level (thousands of units per year) by around 2010, with commercialization (tens of thousands of units per year) by 2015. In contrast, the study concluded that fuel cell electric vehicles running on hydrogen would not be commercialized until about 2020, in part because of the need to establish a new fuel distribution infrastructure.

The main advantage of Li-Ion batteries is that they weigh less than NiMH batteries for the same level of performance. Manufacturing costs for Li-Ion batteries are higher but are expected to fall sharply with improvements in design and manufacturing and with mass production. Also, the cost of nickel is rising rapidly, while lithium is relatively abundant and inexpensive. Although any battery system has safety issues, the overheating concerns associated with the Li-Ion batteries used in laptop computers are not directly applicable to the batteries used in automotive applications, which are made with different electrode materials.

Lithium-Ion Battery Life-Cycle Testing



Battery durability testing sponsored jointly by EPRI and Southern California Edison demonstrate that current lithium-ion batteries are likely to retain sufficient capacity for more than 3000 dynamic deep-discharge cycles—about 10–12 years of typical driving.

EPRI, working with Southern California Edison, began studying the effect of the PHEV duty cycle on the best available Li-Ion battery technologies nearly three years ago. To date, the first test pack has completed over 3000 dynamic deep-discharge PHEV cycles in the laboratory while still meeting the necessary power and energy requirements.

into the local economy of funds that would otherwise have been spent on imported petroleum—an effective boost in regional economic activity and job growth. A 2002 study by the U.S. Department of Energy estimated that if only 1% of American vehicles ran on electricity in 2010, the national economic benefit would be about $1.46 billion (in 1999 dollars)—a benefit far greater than the value of the petroleum displaced—and that 14,000 new jobs would be created.

To examine this effect more closely, the EPRI study sought to quantify the regional economic impacts of significant PHEV market penetration (50% of new-car sales and 40% of all on-road vehicles) in 2030. Six major urban areas were studied: Cleveland, Austin, Birmingham, Kansas City, Newark, and Sacramento. Because actual impacts will vary with changing energy prices, four scenarios used widely different price levels for electricity and gasoline. In addition, two scenarios modeled the economic multiplier effect: in one, displacement of gasoline reduces the demand for *all* industries that support a region's petroleum market, and in the other, demand reduction will *not* affect a region's petroleum refining industry. The researchers note that the former scenario represents worst-case assumptions and that the latter scenario is more realistic, since regional refineries could probably continue to sell their products in the national market.

The results are complex, but in all cases, substantial increases in household incomes were projected from a transition to PHEVs—increases ranging from a low of $188.7 million/year in the Birmingham region, under the lowest energy price assumptions, to a high of $721.4 million/year for Kan-

Several major auto manufacturers have announced plans to introduce PHEVs in the near future. GM is developing its Chevrolet Volt concept car and the Saturn Vue Greenline SUV, which may hit the market in 2010. Ford is providing Southern California Edison with modified Escape Hybrid SUVs to demonstrate PHEVs as part of an integrated grid-connected system. Meanwhile, Toyota is testing a plug-in version of the popular Prius hybrid.

Saturn Vue Greenline SUV

Ford Escape Hybrid SUV

Chevrolet Volt Concept Car

sas City, assuming the highest energy prices. Regional economic output also increases in all cases because of the multiplier effect. Regional employment increases in all cases in which high energy prices are assumed but decreases in some regions if low energy prices are assumed.

The report concludes that “the potential local economic impacts from PHEV use are substantial” and that “policies that encourage PHEV use in any of the six cities could have significant regional economic payback.” If anything, this study may underestimate potential benefits, since it does not consider the additional revenue that could be generated for both vehicle owners and utilities by using PHEVs connected to the grid to provide power management services.

PHEV Value Proposition for Utilities

Additional revenue streams projected for utilities consist of several distinct components, some of which will depend on utilities’ undertaking marketing and infrastructure development initiatives in the near future. Increased sales can be expected as PHEV owners recharge batteries, but the magnitude of this increase will depend on several factors, such as rates that encourage charging during off-peak hours.

Such initiatives will also be essential to realizing the potential benefits of load-leveling, giving utilities an important opportunity to operate their systems more efficiently by encouraging vehicle owners to recharge batteries off-peak. With off-peak charging, the grid could support a high level of PHEV penetration without the need for more generating capacity, and utilities could improve power system efficiency.

EPRI, Ford, and SCE Collaborate on PHEV Integration

In March, EPRI and Ford Motor Company announced a three-year agreement to develop and evaluate technical approaches for integrating plug-in hybrid electric vehicles into the nation's electricity grid—a key requirement for facilitating widespread adoption of the vehicles. To pursue this work, EPRI is putting together a collaborative of utilities in the New York–New Jersey area that will test Ford Escape PHEVs. Subsequent trials will be conducted with customers of the participating utilities.

The new program will build on an ongoing partnership between Ford and Southern California Edison (SCE) to test 20 Escape PHEVs in the Los Angeles area. The new EPRI-Ford agreement will expand the evaluation and demonstration program to include other utilities and will help determine regional differences in how the operation of PHEVs will impact the electricity grid.

"This partnership represents a concerted effort by the transportation and electricity sectors to work together in advancing PHEV technology," says EPRI's Mark Duvall. "This effort should accelerate the pace of PHEV development while enabling the utility industry to prepare for the introduction of these vehicles."

Nancy Gioia, director of sustainable mobility technologies at Ford, agrees. "PHEVs have great promise," she says, "but they still face significant obstacles to commercialization, including battery costs and charging strategies. Ultimately such vehicles must provide real value to consumers. EPRI brings our collaborative efforts related to the potential of plug-in electric vehicle technology to a new level."

Research and analysis by EPRI, Ford, and SCE on the Ford PHEVs will include data from four primary areas: battery technology, vehicle systems, customer usage, and grid infrastructure. The analysis will also explore possible stationary and secondary uses for advanced batteries. The evaluation and demonstration trials are expected to provide solid technical information on PHEVs that will enable the development of common standards among utilities to accommodate the vehicles.

Making this transition will require new rate incentives or direct-control systems.

Finally, the prospect of carbon emissions legislation offers a definite—though highly uncertain and somewhat controversial—possibility for utilities to achieve additional revenue from rising PHEV penetration. In January of 2007, California's governor established a low-carbon fuel standard (LCFS) for the state by executive order. The order essentially directed various state agencies to develop protocols for measuring the "life-cycle carbon intensity" of transportation fuels and to develop a regulatory process to meet a 2020 target of reducing the carbon intensity of transportation fuels in California by 10%. University of California studies found this target to be "ambitious but attainable" and recommended that the providers of non-liquid fuels—specifically electricity—be allowed to participate.

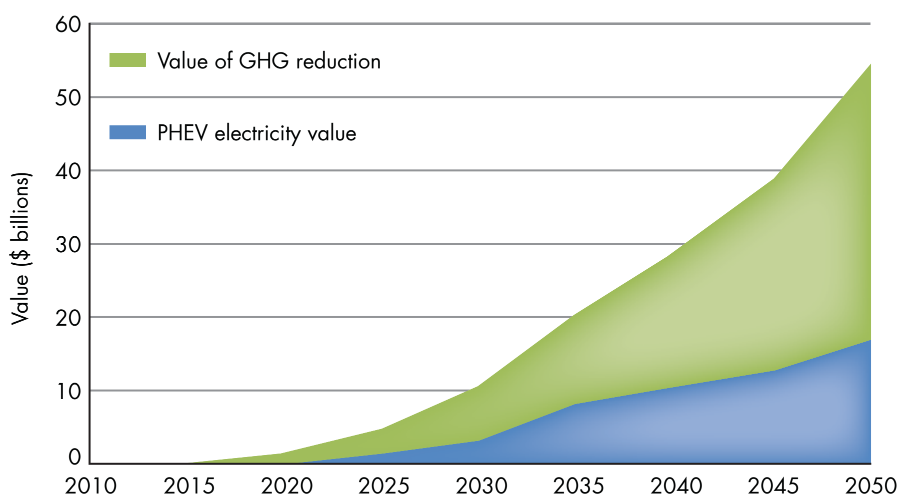
Although the LCFS regulatory process is not yet final, the implications for utilities may be profound, particularly if other states adopt similar standards. As an illustration, suppose a future LCFS should limit the carbon content of vehicle fuel to the equivalent of 8 kilograms per gallon (kg/gal), compared with the approximately 10 kg/gal of today's gasoline. A PHEV could achieve this decrease, and—assuming a tradable carbon value of 20¢ per gallon—the reduction could potentially add 2¢ per kilowatt-hour to the value of electricity. How utilities would realize this added value, however, remains to be seen.

Auto Industry Interest

The theoretical advantages of PHEVs have long been recognized; limited numbers were manufactured more than a century ago, and another attempt to introduce the concept was made in the 1960s. Until recently, conventional batteries were simply too large, too heavy, and too limited in performance to produce a commercially competitive vehicle. Now, with rapid development of lighter, more durable batteries (see "Batteries on the Critical Path," page 10), several major manufacturers have announced plans to introduce PHEVs over the next two years.

Toyota Motor Corporation claims to be the first automaker to have a PHEV certified for use on highways, in Japan, and is planning a series of tests in Europe and the United States as well. Toyota is gaining experience by using a modified version of its Prius hybrid, with nickel–metal hydride (NiMH) batteries, but will probably switch to lighter lithium-ion (Li-Ion) batteries as

Potential Value of PHEV Adoption



If greenhouse gas emissions become regulated in the future, the value of PHEVs in reducing GHG emissions may end up being twice that of increased electricity sales, although it is not clear how this value would be shared among power providers, shareholders, government, and customers.

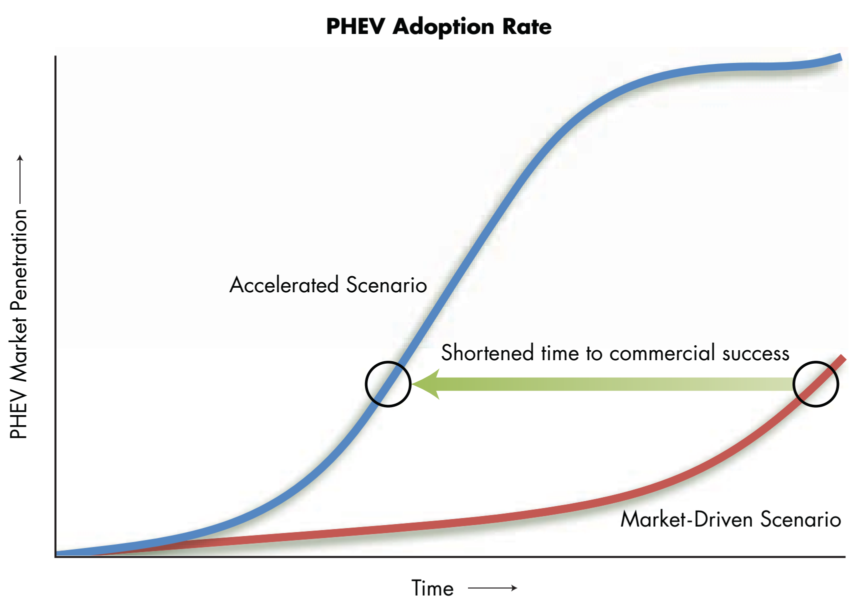
they become available. A small aftermarket has arisen to convert existing Prius cars to PHEV operation, although Toyota does not support this activity.

A major psychological breakthrough for the PHEV market occurred when General Motors introduced its Chevrolet Volt electric concept car at the 2007 North American International Auto Show, claiming that it "could nearly eliminate trips to the gas station." According to GM, the Volt can be fully charged from a standard electrical outlet in about 6 hours and deliver 40 miles of city driving from its Li-Ion battery. When the battery's charge is depleted, a three-cylinder engine recharges the battery and runs the car's electric motor—achieving a gasoline conversion efficiency of about 50 miles per gallon. If the Li-Ion battery is ready, GM plans to market the Volt by 2010. The company also plans to market a PHEV version of its Saturn Vue Greenline sport utility vehicle.

Meanwhile, EPRI, Ford Motor Company, and Edison International—parent company of Southern California Edison (SCE)—have announced a joint program to demonstrate PHEVs as part of an integrated system involving the vehicle, home energy systems, and the electricity grid (see "EPRI, Ford, and SCE Collaborate on PHEV Integration," page 12). The program will evaluate potential benefits of using off-peak electricity to reduce costs per mile while increasing grid productivity and reducing emissions of carbon dioxide and pollutants. Eventually, PHEVs might also be considered for use as home-based energy storage units for solar power generated by rooftop collectors or as a source of stored power that could be tapped as needed by the utility. A modified Ford Escape Hybrid SUV will provide the PHEV platform for the SCE program.

EPRI is currently leading a broad, inter-industry program to develop a PHEV "trouble truck" with an aerial lift for servicing utility distribution systems. Program funders include 36 utilities and two California public agencies. Eaton Corporation is developing the hybrid system on

EPRI is leading a broad inter-industry program to develop a PHEV "trouble truck" for servicing utility distribution systems. Based on a Ford F550, the truck will provide 6 to 8 hours of standby work time with minimal engine idling and, in a high-idle mode, will generate up to 5 kW of ac power to provide grid services in the field.



Market penetration of new automobile technologies tends to grow slowly because of high initial cost and first-of-its-kind risk to early adopters. The involvement of power providers and other stakeholders outside the auto industry can help PHEVs reach higher penetration faster by providing purchase incentives, special PHEV electricity rates, advanced infrastructure options, and consumer education.

Ask the Expert

An interview with Mark Duvall, manager of technology development for EPRI's Electric Transportation program.

Q. There appears to be enormous interest in plug-in hybrid technology. What are the prospects for these vehicles to reach the market by 2010?

A. Plug-in hybrid development is at a crossroads. The technology currently has tremendous momentum, with GM, Ford, Toyota, and others vying to be either first to market or "best to market." The forces driving this interest—pressures to reduce petroleum dependency and the high cost of fuel and to address climate change—all point in the direction of PHEV technology. However, it is important to remember that most transformational automotive technologies fail—often spectacularly, and many times when the technology is right on the cusp of commercial viability.

Why is utility involvement in PHEV commercialization important?

PHEVs are transformational in that they introduce electricity as a meaningful automotive fuel to a potentially very large market. The utilities could have much to gain from a massive shift of cars to PHEV technology, but the success of this transition will depend heavily on their involvement.

What benefits could utilities expect to receive from participating in PHEV penetration of the auto fleet?

The utility value proposition for PHEVs is large and complex. PHEVs, at a minimum, provide predominantly off-peak load—allowing utilities to improve system efficiency and asset utilization. In the long term, however, the potential is much greater. Electricity is a low-carbon, clean transportation fuel, and as utilities increasingly provide electricity as a transportation fuel, their service territories will realize benefits in air quality and reduction of greenhouse gas emissions. PHEVs also represent a storage resource that could be managed to optimally suit a utility's load profile.

But won't major infrastructure changes be required?

It is important to recognize that the market share of PHEVs in the nationwide automotive fleet will grow slowly over time and that the individual load of each vehicle is small. As market share grows, utilities may have to be on the lookout for local impacts, but this is a normal part of their business. Ultimately, if PHEVs succeed, electric utilities will become refueling stations for their customers. Utilities can strengthen their credentials as good environmental stewards and improve customer satisfaction by proactively addressing this new technology.

How sure are you regarding the environmental benefits of PHEVs?

We just completed a comprehensive nationwide air quality and greenhouse gas assessment, in cooperation with the Natural Resources Defense Council. We used the most sophisticated modeling tools available in order to understand, as closely as possible, what the electricity system's response to PHEVs will be in terms of which plants will be dispatched to generate the charging energy, what the net changes to emissions will be in the electricity and transportation sectors, and how the emissions will react chemically in the atmosphere to affect air quality. Even using what we would very much consider to be a worst-case scenario, we found near universal air quality benefits nationwide. This is not an unexpected result, given the maturity of the electricity sector, its closely regulated nature, and declining emissions intensity in the face of increased regulatory requirements.

What about greenhouse gas emissions? There seems to be a lot of debate on this issue.

Under nearly any foreseeable scenario, electricity is a low-carbon fuel, compared with gasoline and diesel. A PHEV charged by the most carbon-intensive generating plants is essentially equal to a conventional hybrid in terms of total greenhouse gas emissions. When you actually look at utilities' responses with respect to new generation, the increased regional requirements for renewables, and expected responses to future carbon constraints, the GHG reductions are considerable.

What should utilities do next, and how can EPRI help?

Utilities should consider joining existing EPRI–automotive industry collaborations. These provide opportunities for vehicle manufacturers and fuel providers (electric utilities) to work closely together on the issue, which can help drive successful commercialization of this important technology. Utilities will have the earliest possible access to prototype vehicles, enabling them to get first-hand experience with the performance of the vehicles in real-world driving and—more important—with the interaction between the vehicles and their systems.

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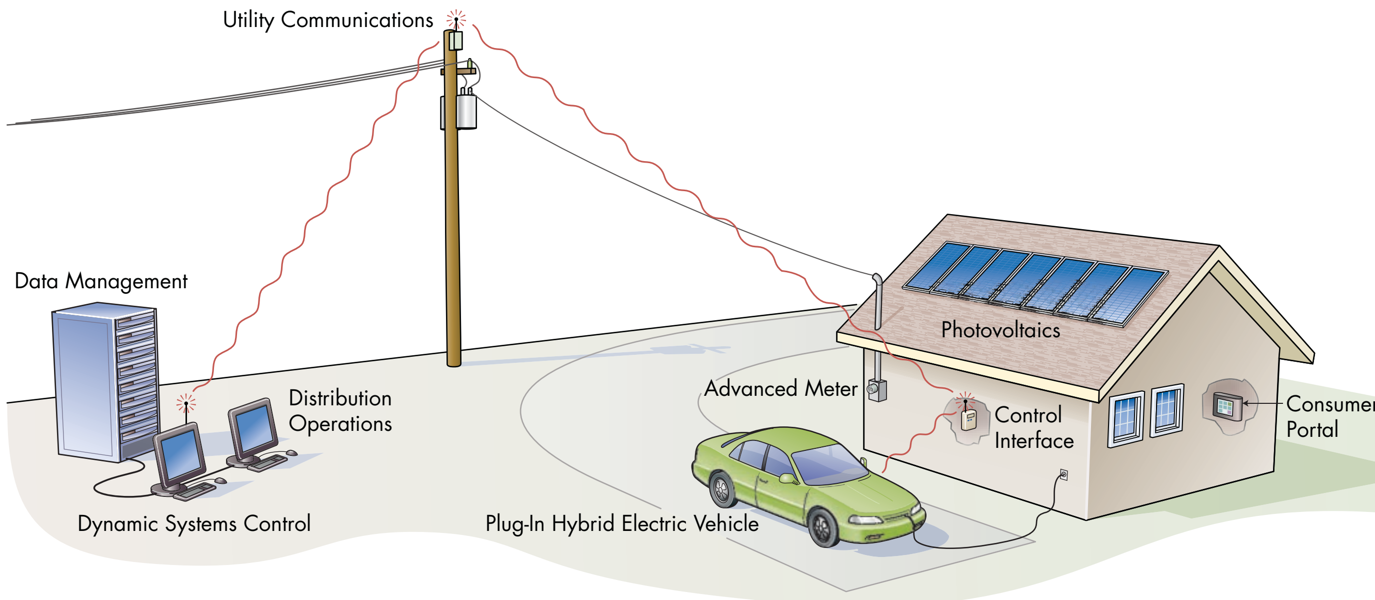
a Ford F550 chassis and will conduct vehicle testing and calibration. Five prototype vehicles—two with diesel engines and three with gasoline engines—will be delivered for utility fleet demonstration, beginning this year.

The choice of a trouble truck as a PHEV test vehicle offers several advantages to utilities, including hands-on experience with the new technology. In addition to reducing fuel consumption and emissions, the truck will be able to provide 6 to 8 hours of standby work time with zero or minimal engine idling, minimizing impacts on neighborhoods and operators. Alternatively, when operated in a high-idle mode, it can generate up to 5 kW of ac power to provide grid services in the field. Once successfully demonstrated in utility use, the technology could be adapted for medium-duty vehicles in the 8500- to 19,500-pound weight classes. Such vehicles—including work trucks and vans, shuttle buses, and even medium-sized

Future Intelligent Infrastructure



With their large, deep-discharge batteries, PHEVs may eventually serve as distributed energy storage units that could support not only the home but the electricity grid as well. The smart infrastructure for such vehicle-to-grid setups would require advanced metering and two-way energy and information exchange, similar to that currently used in home photovoltaic electricity sales to utilities.

motor homes—cover an array of applications suitable for electrification.

Next Steps

EPRI can serve a crucial role in fostering collaboration between the automotive and electric power industries and in integrating PHEVs with the grid. EPRI is organizing a nationwide demonstration program to place early production prototype PHEVs into utility fleets. This effort involves General Motors, Ford, and various U.S. and Canadian utilities in developing critical information on the impacts of PHEVs on utility operations. Eventually utilities are expected to include some of their larger commercial customers in testing the vehicles and to create profiles of customer needs and preferences. EPRI will manage the demonstration program and coordinate data collection and analysis.

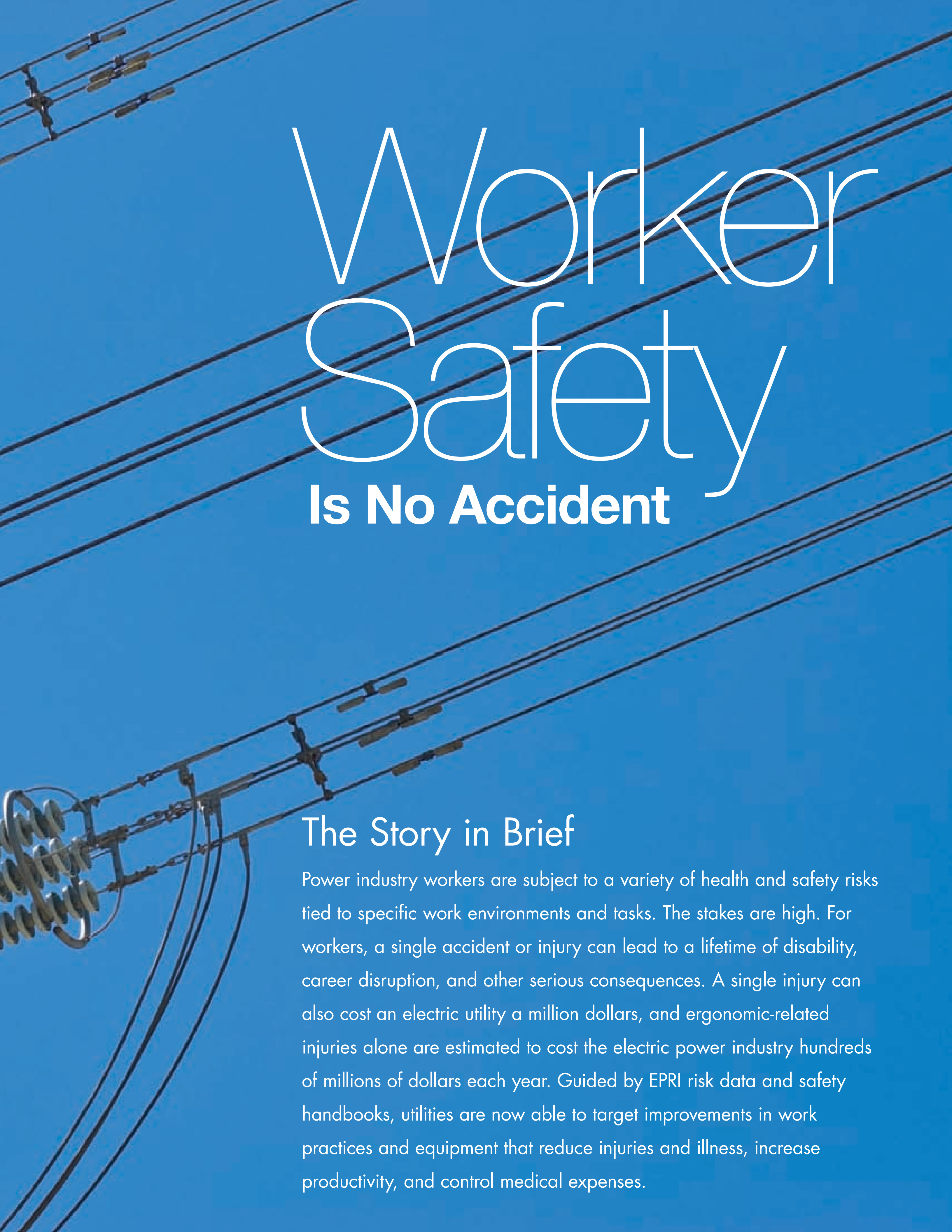
This program will also apply so-called smart grid concepts to help optimize the value of PHEVs for system operations. Smart meters will enable customers to charge vehicles when lower rates are in effect, and a two-way communication connection with the utility would permit further savings by providing remote control of the charging load. The concept of smart charging, which determines the best charging regime in real time, will also be given consideration. Utilities have a direct stake in uniform connection standards that meet the needs of all parties.

Over a longer period, PHEVs may provide the capabilities for load leveling and/or grid support. The vehicle-to-grid, or V2G, option faces substantial hurdles that will require long-range research to resolve. Although conceptually V2G is an example of distributed generation, in practice it differs from most small power sources, which are stationary and professionally operated. In addition, integrating this option into the grid would probably require significant infrastructure investment in order to protect against potential hazards and the possibility of degrading battery performance in the quest to obtain a still-uncertain economic payoff.

"Utilities want to *manage* the charging of PHEVs, which will involve gradual, evolutionary grid adaptation," says Mark Duvall. "But they need to *control* V2G, and that would require careful study and considerable expense. Meanwhile, we hope our new demonstration program will help develop a sustainable business case that can foster PHEV penetration of the North American vehicle fleet while benefiting both vehicle manufacturers and utilities."

This article was written by John Douglas. Background information was provided by Mark Duvall (mduvall@epri.com).

Mark Duvall is manager of EPRI's Electric Transportation program, focusing primarily on plug-in hybrid electric vehicle R&D and advanced battery system development and testing. Before coming to EPRI in 2001, he was principal development engineer at the Hybrid Electric Vehicle Center at the University of California at Davis. Duvall holds BS and MS degrees in mechanical engineering from UC Davis and a PhD in the same field from Purdue University.



Worker Safety Is No Accident

The Story in Brief

Power industry workers are subject to a variety of health and safety risks tied to specific work environments and tasks. The stakes are high. For workers, a single accident or injury can lead to a lifetime of disability, career disruption, and other serious consequences. A single injury can also cost an electric utility a million dollars, and ergonomic-related injuries alone are estimated to cost the electric power industry hundreds of millions of dollars each year. Guided by EPRI risk data and safety handbooks, utilities are now able to target improvements in work practices and equipment that reduce injuries and illness, increase productivity, and control medical expenses.

Job-related illness and accidents can be devastating for workers and have become increasingly expensive for their employers. Although the U.S. Bureau of Labor Statistics reports that the rate of workplace injuries and illnesses for electric utilities is below the national average for private industry employers, the utility operating environment nevertheless involves a number of inherent hazards, ranging from line workers' potential for electrical contact with live conductors to meter readers' risks of dog bites. Occupational exposure to a variety of chemical and physical agents raises concerns about worker health and has led to industry regulations addressing polyaromatic hydrocarbons, heavy metals, fly ash, electric and magnetic fields, noise, and other hazards. Increased awareness and prevention efforts have resulted in a steady decline in injury rates at electric utilities, and EPRI is currently working with industry representatives and academic experts through its research programs—in particular the Occupational Health and Safety (OH&S) program, which focuses on ways to further improve the welfare of workers.

Follow the Stats

Reducing workplace risks starts with understanding where injury and illness are most likely to occur. For more than 8 years, EPRI has analyzed the statistics needed to make these determinations through its Occupational Health and Safety Database (OHSD) project. By monitoring trends of injury and illness over time and across job characteristics and demographic factors, EPRI's OHSD has become the industry's best available source of information concerning risks of workplace injury.

Currently, 16 utilities contribute data to OHSD, including 7 whose records go back to 1995. The full data set now includes more than one million employee-years of follow-up and more than 35,000 observed lost time and recordable injury/illness events among the companies. The study has recorded 41 fatalities, with the largest number (16) observed among line workers. Overall, meter readers have the highest rate of injuries of all types, followed by welders and line workers.

The good news is that the average injury rate across the companies has decreased sharply over the study period—from more than 4.5 injuries per 100 employee-years in 1995 to 1.6 in 2006, the last year for which data are available. Also in 2006, for the first time, no fatalities were reported for the year. The observed decrease is thought to result largely from a growth in utility health and safety programs, improved safety awareness among workers, and increased management attention to occupational safety. Some portion of the decrease may also reflect an increasing use of contractors to perform certain types of work that go beyond routine maintenance—such as new line construction, line renovation, and tree-trimming. Including contractor information is a future goal of this project.

The OHSD differentiates injury rates by job classification, worker age, and cause. Meter readers had the highest rate of injuries—14.07 per 100 employee-years, compared with 12.39 for welders and 12.28 for line workers. By far the largest numbers of injuries for most occupational groups were caused by overexertion and body motions that led to sprains and strains. Meter readers were more likely than other workers to be injured by an animal or insect bite, and line workers were more likely to be injured by falling, being struck, or coming into contact with live electrical conductors. Injury rates tended to decrease with age among trade workers, presumably as a result of cumulative experience and a shift into more-supervisory roles.

"This information is critical for helping individual companies develop targeted interventions to reduce injuries and set benchmarks for specific types of injuries and health problems," says Gabor Mezei, EPRI senior project manager for OH&S. "In particular, the analyses provide utilities with the insights they need to adopt successful, innovative approaches to protect the health and safety of their employees."

Ergonomics for Productivity and Safety

Drawing on OHSD analyses, EPRI has focused on helping utilities develop programs that prevent the largest class of injuries—those involving sprains, strains, and related musculoskeletal problems resulting from awkward body positions or movements. Fortunately, the rate at which such injuries occur can be lowered dramatically by improving the ergonomic aspects of common tasks. This includes changing work practices, modifying tools or equipment, and using ergonomic design in equipment and facilities ranging from vehicle fleets to power plants. In many cases, worker productivity also improves substantially.

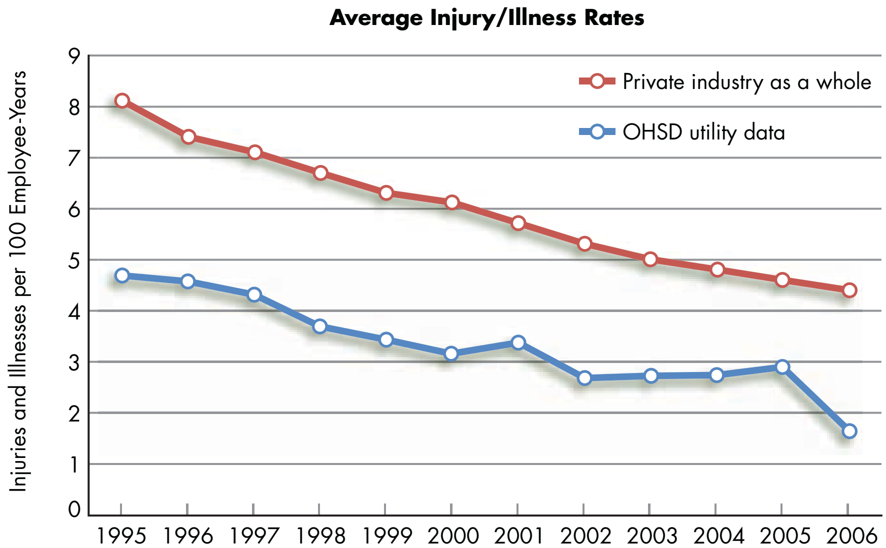
The showcase achievement of this work has been the publication of a series of EPRI ergonomics handbooks, developed from systematic investigation of a large number of tasks. So far, five handbooks have been published, covering overhead distribution line work, underground applications, direct-buried cable applications, electrical work in fossil-fired power plants, and the design of new generating stations.

The first handbook describes 32 ergonomic interventions to reduce injuries among distribution line workers. Of these interventions, 19 can be implemented for less than $100, and only 7 cost more than $1000. The investigating team concluded that the greatest benefit would be realized by providing line workers with two new tools: a battery-operated press to crimp the sleeve connection between two wires, and a battery-operated cutter capable of cutting wire with a diameter greater than about a quarter of an inch. Line workers have traditionally used a manual crimping press that requires handle force of about 70 pounds. Only about 1% of the general population has the strength to make compression connections with this type of manual press; even for the strong, using a power tool would greatly relieve stress on the shoulders. A survey of medical and workers' compensation costs shows that preventing just one chronic shoulder injury, such as tendonitis, could more than pay for the power tools.

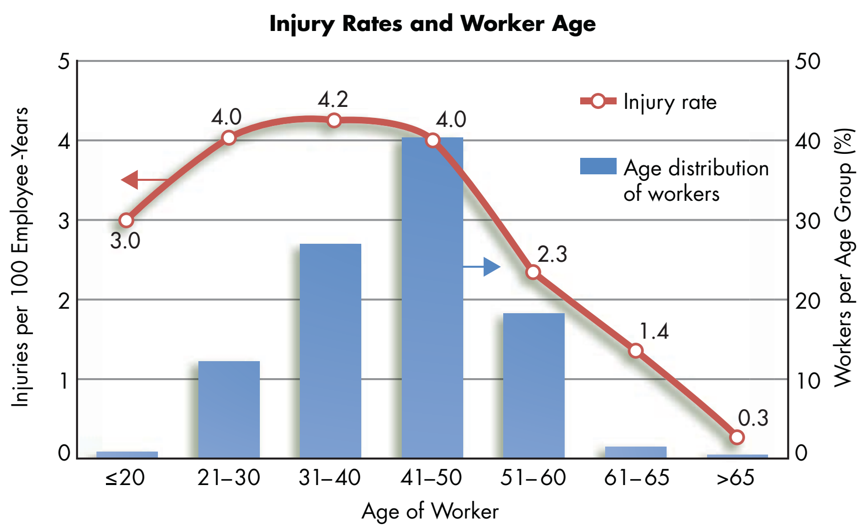
Similar recommendations of ergonomic interventions are made in the handbook for underground (manhole, vault, and conduit) applications and in the handbook for direct-buried cable applications. Again, improvements call for battery-powered tools to replace the types of manual press and cable cutter commonly used, along with introduction of a modified lever to remove manhole covers, which can weigh between 250 and 500 pounds. This redesigned manual tool is expected to significantly reduce risk factors for strains and sprains affecting the shoulders and lower back.

Electricians at fossil-fired power plants, who are generally responsible for the installation and repair of electrical equipment throughout the facilities, face a very different set of health and safety risks. For them, recommended ergonomic interventions focus on changing work practices. Handbook recommendations range from the use of knee protection for tasks done while kneeling to the use of modified hand trucks for moving heavy loads up or down stairs. A handbook is under development for power plant operators and general maintenance workers as well.

New power plants provide opportunities to apply ergonomic principles to facility design—to build in systems that can reduce injuries and increase worker productivity. In March, EPRI published a handbook of ergonomic design that includes guidelines for design engineers and a foundation for improving plant specifications. The handbook cites earlier EPRI research indicating that 30–80% of maintenance task time is devoted to setting up a job and that an estimated 30% saving in overall maintenance time could be achieved if access to equipment were improved, making the most important and frequently used components the most accessible. Specific guidelines prioritize design to provide adequate room to negotiate trouble spots and deploy standard maintenance tools.



EPRI's Occupational Health and Safety Database (OHSD) shows that utility safety programs have consistently kept illness and injury rates significantly below those for private industry as a whole. (Sources: EPRI, U.S. Bureau of Labor Statistics)



According to OHSD analyses, which differentiate injury rates by cause, job classification, and worker age, older workers tend to have fewer injuries as a result of longer experience and eventual shifts to more-supervisory roles.

Investigating Hazardous Substances

Compared with many other workplaces, electric power facilities do not use particularly high levels or large numbers of hazardous substances. Nevertheless, utilities have to minimize worker exposure to a variety of materials, both as a matter of general safety and in response to regulations. EPRI focuses on investigating particular hazardous substances in response to industry needs, and in a long-term project, it is planning to develop an extensive job-exposure matrix to measure worker exposure to both chemical and physical agents.

One current concern is how to comply with new, more-stringent Occupational

Safety and Health Administration (OSHA) regulations regarding exposure to hexavalent chromium—a potentially toxic material produced by certain types of welding commonly used at power plants, substations, and other facilities. Specifically, OSHA now requires employers to evaluate exposures to this material and stipulates that new prevention measures be taken when exposures exceed a level that is one-tenth the previous limit. EPRI is developing a database to represent and evaluate typical welding exposure scenarios. This effort can provide the foundation for determining both the effectiveness of methods to control hexavalent chromium exposure, which OSHA requires to be instituted by 2010, and the need for developing further methods.

interact with cells and anatomical structures with which they come into contact. EPRI research used fly ash samples to develop a new test protocol using a computer-controlled scanning electron microscope. This approach was able to distinguish these particles much more precisely than previous methods. Further research is planned to apply this new test to samples of fly ash collected from the air breathed by workers during specific work tasks.

Although the possible health effects of breathing airborne nanoparticles (<100 nanometers in size) remain unknown, rapid advances in the development and manufacture of these ultrafine particles have raised questions about potential risks associated with inhaling them. No studies have been published regarding concentrations of nanoparticles in power plants, so EPRI recently began a project under Technology Innovation funding to assess their presence and characterize their properties. Field measurements will rely on a state-of-the-art nanoparticle aerosol monitor, and samples will be subjected to chemical analysis based on X-ray spectroscopy coupled with transmission electron microscopy. A report on the preliminary findings is expected by the end of 2008.

Musculoskeletal injuries—typically sprains and strains resulting from awkward body positions or movements —account for the largest class of utility injuries. Ergonomic studies in the field and on full-scale mockups in the laboratory have identified specific causes and solutions, which are outlined in EPRI's series of ergonomics handbooks.

OSHA is also considering tighter regulation of worker exposure to crystalline silica (quartz), which is present in coal fly ash. It will be necessary to better measure the concentration of quartz particles in fly ash that are in the respirable size range (less than 10 micrometers) and to distinguish those that are bioavailable—more likely to

EMF and RF Exposure

For more than 30 years, EPRI has conducted research into the potential health effects of exposure to electric and magnetic fields (EMF), and since 2002, it has led industry efforts to comply with regulations related to worker exposure to radio-frequency (RF) fields. This research is pursued under the EMF Health Assessment and RF Safety program and has led to substantial new insights for applying EMF and RF exposure guidelines. RF exposure among electric utility line workers is a relatively recent development, resulting from the increasing placement of communications antennas on utility infrastructure.

In the 1980s and 1990s, EPRI conducted key epidemiological studies and analyses to investigate whether electrical workers might experience an increased risk of leukemia or brain cancer as a result of workplace exposure to EMF. While these and subsequent major studies in several countries provided somewhat conflicting evidence on this issue, they generally did not establish a strong or consistent connection between EMF exposure and increased risk of either brain cancer or leukemia.

Recent attention has focused on evidence suggesting that electrical workers have a higher risk of amyotrophic lateral sclerosis (ALS), a degenerative nerve disorder commonly known as Lou Gehrig's disease. No specific link to EMF exposure has been established, and the observed increase in ALS may be associated with some other uncontrolled risk factor in electrical occupations; experience with electrical trauma (such as severe shock) is a leading candidate.

The difficulty in attributing specific health effects to EMF exposure—let alone establishing cause and effect—has renewed emphasis on methods to improve dose and exposure evaluation. High-resolution computer models can show how fields interact with the human body and can estimate occupational exposures, taking into account that workers are most likely to experience fields that are highly nonuniform.

Whereas uncertainties surround the possible health effects of occupational exposure to low levels of EMF, the current EMF exposure guidelines are intended to prevent well-recognized neural stimulation and other perceived effects, which occur only at very high exposures. Likewise, for RF it is known that absorption of RF energy can heat body tissue and, in some circumstances, cause RF burns—a phenomenon generally associated with high localized RF current density on the skin's surface. As a result, the U.S. Federal Communications Commission has established maximum permissible exposures to RF fields that are related to the specific absorption rate of energy that would result from exposure. EPRI's research work on RF safety supports electric company compliance with these exposure limits and helps establish safe work practices.

A major challenge for compliance is determining what energy would likely be absorbed by a worker under various circumstances. The most intense exposure occurs when workers get close to RF communications antennas, such as those used for cell phone base stations. Their RF fields are typically nonuniform and may in fact be highly focused, complicating efforts to estimate specific absorption rates in personnel at nearby locations. EPRI's RF safety program, using Technology Innovation funding, sponsored the U.K.'s Health Protection Agency (HPA) in-depth dosimetry study, which is based on specific absorption rate modeling that uses HPA's highly detailed, three-dimensional computer model of a man exposed to RF fields. EPRI has also published practical information that electric utilities can use to develop their own RF safety programs and ensure compliance with regulations.

Beginning in 2008, additional research is examining RF burn hazards in the electric power industry. Such burns can occur when workers touch bare communications antennas or metallic utility towers that are located near transmitting antennas. This research will focus on identifying exposure criteria related to RF burns, work practices that may lead to such burns, and methods to mitigate the effects.

"This research is already helping electric utilities develop training programs for their line personnel who work near RF antennas," says Michael Silva, an engineering expert who manages RF safety research on behalf of EPRI. "Our goal is to work with both electric utilities and companies from other industries, such as wireless carriers, to enhance their compliance efforts and to prevent potentially serious injuries."

Measurements of muscle activity show that a switch from manual to power tools, such as a battery-operated cable cutter, can significantly reduce strain on the shoulders; prevention of a single chronic shoulder injury could easily pay for the power tool.

Designs for new facilities often fail to adequately consider ergonomics and maintenance access. This valve could easily have been re-oriented in the design stage to face the worker.

Sharpening the Research Agenda

EPRI has established a new occupational health and safety advisory committee to help guide its research agenda. At its first meeting, in 2007, the committee recommended that all of EPRI's OH&S-related research be linked more closely across the Institute's technical disciplines, bringing a comprehensive approach to defining research priorities. These will include the illnesses and injuries that are the most common in the utility workforce—with an emphasis on risk prevention—and specific areas of concern that require targeted research.

"The committee's guidance has been extremely helpful," says Robert Kavet, senior program manager for both EMF/RF and OH&S research. "We are already better integrating information from a variety of areas and putting new emphasis on preventive measures, as the committee advised. This effort includes collaborative work between the EMF/RF and OH&S programs to develop a job-exposure matrix that will provide utilities a way to estimate

Safety Research Across EPRI

EPRI conducts safety-related research in all of its business sectors, providing the electric power industry with a comprehensive, coordinated effort to improve the well-being of workers while also protecting the public at large. The most broadly applicable areas of occupational health and safety (OH&S) research are addressed in the Environment Sector. The other business sectors focus primarily on working with utility members to address OH&S problems that most affect their operations in specific areas. In this way, EPRI provides the industry with an unmatched resource for conducting and sharing a wide-ranging portfolio of OH&S work.

Power Delivery Applications

One safety concern addressed in different ways for more than a decade is the rare but potentially lethal explosion of gases in underground distribution systems. The energy released in such explosions can reach the effect of several sticks of dynamite and can blow off manhole covers, causing collateral damage and injury to the public as well as to maintenance workers. Over the years, EPRI has performed numerous tests involving controlled explosions and has explored several mitigation approaches, including energy-absorbing tethers for manhole covers, pressure-relief devices, and low-cost gas detection systems. Recent attention has focused on using high-speed video to understand and model the dynamics of explosions. A field trial is under way in the Midwest of some 1200 manhole covers equipped with a controlled pressure-relief mechanism.

Other power delivery safety work has focused on line workers who perform live-line work—maintenance on energized circuits. Past research led to development of the EPRI Live Working Guide (1008747) and the on-line EPRI Live Working Resource Center (LWRC), which cover topics ranging from worker training to the proper use of helicopters for live-line work on transmission system conductors. The guide, now under revision, will join EPRI's "Color Book" series as the Tan Book, while the LWRC will be a living web site, periodically updated with new materials. Current research is focused on identifying new technologies for, and technological gaps related to, live-line work. Topics include minimizing conditions that can lead to arc flashovers, protecting workers from arc-related thermal exposure in transmission and substation environments, improving structure designs to better facilitate live-line maintenance, and improving the protection of workers from induced voltages and currents while they are working on de-energized lines.

Another area of concern for both electrical workers and the public is so-called contact voltage exposure, in which people or animals receive a shock by touching utility infrastructure or other objects, such as water lines and even swimming pool water. EPRI's research at its test facilities in Knoxville, Tennessee, and Lenox, Massachusetts, has produced a more comprehensive understanding of conditions that can lead to contact voltage and has resulted in development of standard methods for evaluating and mitigating potential sources. This research supports efforts by the Institute of Electrical and Electronics Engineers (IEEE) and other industry groups to set contact voltage standards.

EPRI is also analyzing the electromagnetic compatibility of sensitive electronic devices that must operate in the electromagnetically "noisy" environment of power substations. In the past, standards for ensuring compatibility have sometimes lagged several years behind equipment development. EPRI has drawn on its network of international members and experts to develop best practices for electromagnetic compatibility for the new solid-state power devices and digital electronic control and communications devices now being installed in substations worldwide.

Power Plant Safety

Maintaining safe working conditions at a power plant requires clearly stated goals and procedures, active management participation, and enforced accountability. Although these requirements are met in different ways at different plants, EPRI is well positioned to help identify and com-

the probability of exposure to both chemical and physical agents."

Such efforts are expected to expand the OH&S program's value for the industry. "EPRI has played a strategically important role in helping the industry improve worker safety and control health care costs," says Charles J. Kelly, a member of the advisory committee and director for industry human resource issues at the Edison Electric Institute. "Looking toward the future, EPRI research can help particularly in the areas of reducing injury rates through ergonomic intervention, providing the statistics that utilities need to target their prevention programs, and studying important specific issues, such as radio-frequency burns and worker exposure to fly ash components."

Kavet points out that a comprehensive approach often yields surprising dividends: "Our initial focus, of course, is on prevention of accidents and health problems, but we are finding that companies with good intervention programs might actually be saving more money through increased productivity than through decreased medical costs. Results like that show that you're reaching deeper into a company's culture and influencing it for the better."

This article was written by John Douglas. Principal background information was provided by Rob Kavet (rkavet@epri.com) and Gabor Mezei (gmezei@epri.com), with additional information from George Gela (ggela@epri.com), Wayne Crawford (wcrawford@epri.com), and Sean Bushart (sbushart@epri.com).

municate industry best practices, as well as to work with individual utilities on assessing the safety performance of their facilities.

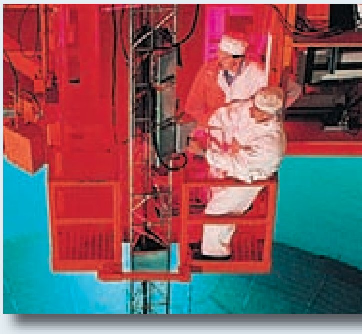
As part of this work, EPRI published the *Operations Assessment Guideline* (1008250), which provided utilities with criteria for conducting assessment activities at their plants and for comparing the results with industry best practices. The newly updated guideline (1014200) includes application experiences resulting from the use of the initial publication. The *Clearance and Tagging Guideline* (1014916) was published earlier this year, providing assistance in equipment isolation to protect workers and equipment. In addition, the *Maintenance Excellence Matrix* (1004705) gives a solid basis for conducting assessments of plant maintenance performance. Future work will focus on guidance for corrective action programs to help members effectively identify causal factors and correct them to prevent recurrence.

Among the most important safety issues at fossil-fired plants are failures of high-energy steam and water piping. EPRI's collaborative international program to improve boiler life and availability has developed a variety of products, including guidelines and special software, that can help manage piping systems as they age. A related concern is flow-accelerated corrosion, which has been implicated in failures of both piping and turbine blades. Surveys have found that improvements in water cycle chemistry that could help prevent corrosion and other failure mechanisms can be hampered by deficiencies in the technology transfer process. Through its focus on technology transfer, EPRI's program has become an effective source of guidance, training, and analytical tools for managing flow-accelerated corrosion.

Radiation Issues

OH&S research in the nuclear area focuses on minimizing workers' exposure to ionizing radiation. EPRI's Radiation Management program includes projects to reduce radiation source term in a plant and to protect workers against radiation from existing sources. A measure of the success of this program is that collective personnel exposure levels are currently at historic lows, and individual exposure levels are well below background for most nuclear power plant workers.

One industry challenge is a lack of international consensus on determining a threshold for releasing workers and materials from radioactively controlled areas, given these reduced exposure levels. Unclear regulatory policy and various monitoring standards mean that clearance for exiting a work area is now effectively determined by the limits of radiation detection equipment, which may vary significantly from plant to plant. In response, EPRI is developing an industry guideline to help standardize best practices for the detection of radioactivity on personnel and materials entering or leaving a nuclear facility.



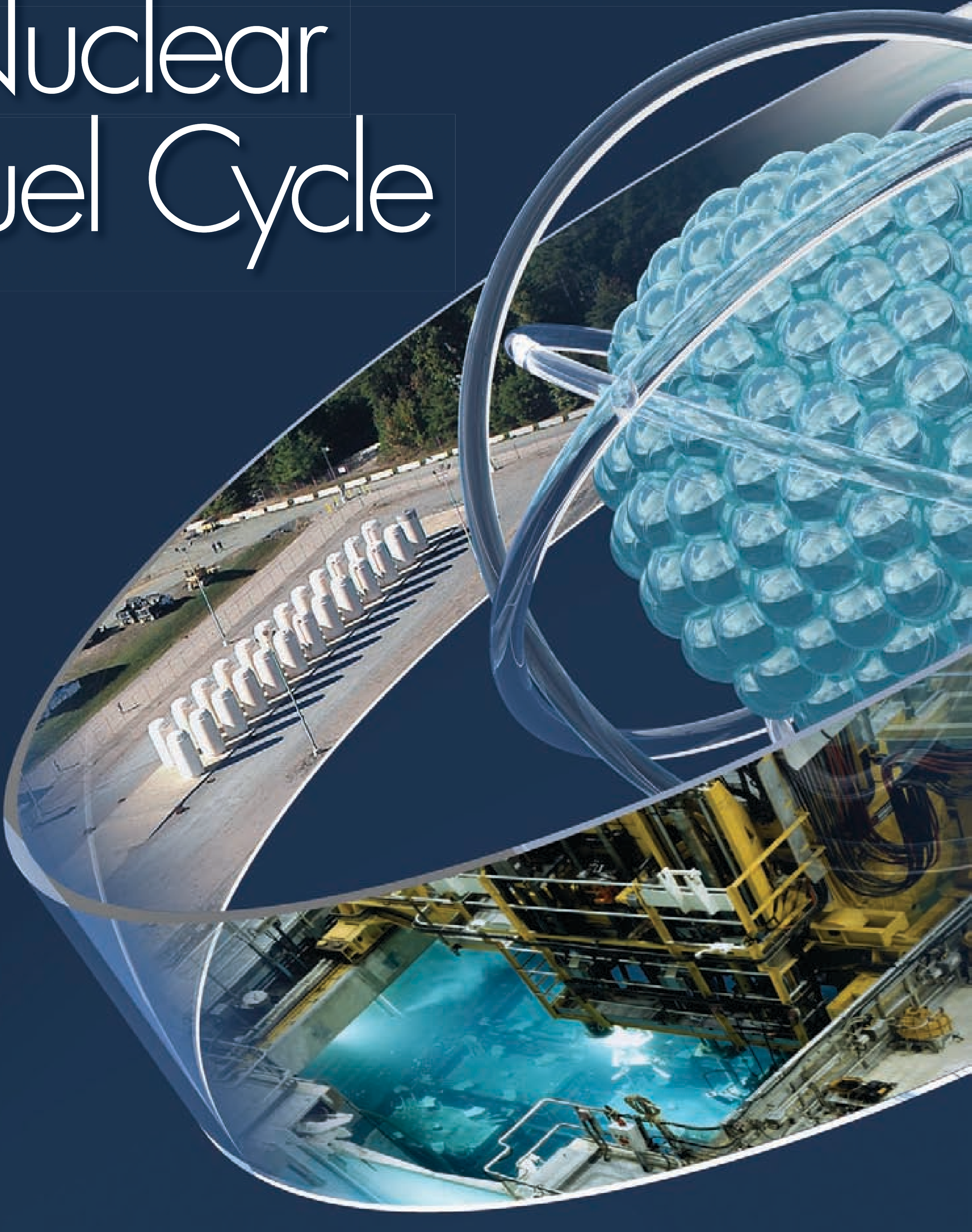
The Radiation Management program is also facilitating the implementation of advanced software that will help utilities reduce the radiation dose received by workers performing specific tasks, such as reactor head inspection. By using virtual reality software, plant operators can determine the dose that would be received by workers in particular situations and use these results to improve planning and training to minimize exposure during dose-intensive work. The three-dimensional visualization software will enable engineers to reduce operational costs associated with certain complex tasks, such as materials inspections.

Looking ahead, EPRI is leading an industry effort to apply current industry best practices, lessons learned, and technological developments related to radiation management to the next generation of nuclear power plants. Documentation of this work, including specific recommendations, will be published later this year.

Robert Kavet is senior program manager of both the Occupational Health and Safety program and the EMF Health Assessment and RF Safety program. Kavet's first tenure at EPRI was from 1978 to 1984, after which he worked for two years at the Health Effects Institute. Following six years as a consultant on EMF health issues, he rejoined EPRI in 1992. Kavet received both a BS in electrical engineering and an MEE degree from Cornell University; he earned an MS in environmental health sciences and an ScD in respiratory physiology at the Harvard School of Public Health.

Gabor Mezei is a senior project manager in the Occupational Health and Safety program. Prior to joining EPRI in 1999, he worked as a physician and epidemiologist at the National Institute of Dermatology in Budapest, Hungary, and at the Toronto Hospital, University of Toronto, Canada. Mezei received a Doctor of Medicine degree from the Semmelweis Medical University in Budapest and a doctorate in epidemiology from the School of Public Health at the University of California, Los Angeles.

Toward an Integrated Nuclear Fuel Cycle



The Story in Brief

Nuclear power's long-term value as a clean and sustainable generation resource may depend on taking strategic action to close the fuel cycle. Momentum is building toward fully integrated fuel cycles based on fuel reprocessing and reuse, interim storage, secure transport, and geologic disposal. Closing the fuel cycle will not be easy, but with a global commitment to advanced technology development and demonstration, there is time to "get it right," leading to more-efficient resource utilization and waste disposal, along with competitive electricity generation costs.

Increased concern about greenhouse gas emissions, energy security, and volatile fossil fuel prices is driving the development of new nuclear power plants in a number of countries. EPRI's PRISM/MERGE analysis identifies a large role for nuclear energy in reducing electricity sector greenhouse gas emissions, with up to 64,000 MW of new capacity by 2030.

Nuclear power's long-term future is tied to the broader issue of sustainability, which encompasses continued safe, reliable, and economic operation; a secure fuel supply; effective waste management; and nonproliferation of nuclear materials.

"When we look at sustainability and how nuclear power can make substantial contributions to energy supply over the long term, we need to carefully reconsider the nuclear fuel cycle," says Albert Machiels, senior technical executive at EPRI. To ensure nuclear power's long-term viability, the fuel cycle must be integrated. That will mean holistically coordinating fuel production and use, spent fuel storage, transportation, and disposal. Integrating the fuel cycle would provide maximum energy recovery with lower quantities of waste for disposal.

Spent fuel reprocessing followed by recycling is central to advanced fuel cycles, providing the mechanism through which additional nuclear fuel is created and through which the quantities of high-level radioactive waste are minimized. Several countries, including France, Japan, Russia, and the United Kingdom, already reprocess nuclear fuel for reuse in existing power plants, storing the waste by-products until they can be permanently placed in a geologic repository. Other countries, including the United States, rely on a once-through, or "open," fuel cycle, in which spent fuel would be placed in a geologic repository without reprocessing.

Experience in fuel reprocessing will prove invaluable as the global nuclear industry moves to close the fuel cycle. While advanced fuel cycles are key to sustainability, there is no need to rush their deployment, says EPRI's Machiels. "There is time to get it right and make the best decisions, recognizing that technology must evolve over time. We need a picture of the advanced fuel cycle that we want 50 years from now, and that cycle has to be one we can successfully implement at a cost we can afford."

The U.S. nuclear industry is pursuing a three-part strategy for developing an integrated fuel cycle, according to Steven Kraft, senior director of used-fuel management at the Nuclear Energy Institute (NEI):

- Research, development, and commercial demonstration of advanced nuclear fuel reprocessing and recycling technologies to close the fuel cycle
- Interim storage until the fuel is recycled or disposal is available
- Disposal of by-products in a geologic repository

Spent Fuel Reprocessing: What Is the State of the Art?

Reprocessing spent fuel separates materials that can be reused for power production—uranium, plutonium, and the minor actinides—from fission products, which are considered true radioactive waste. Differences in fuel cycles are largely a matter of whether, and how, these materials are separated and managed.

Countries committed to at least partially closing the fuel cycle, including France and Japan, use the PUREX reprocessing technology, which separates spent fuel constituents into three main streams:

- Reprocessed uranium (about 94%), which can be stored or reused in existing reactors
- Plutonium (about 1%), which can be used in mixed-oxide (MOX) fuel for recycling in existing or future reactors
- Fission products and minor actinides (about 5%), which are dealt with as high-level waste and require geologic disposal. Fission products include strontium, cesium, iodine, and technetium. Minor actinides include neptunium, americium, and curium.

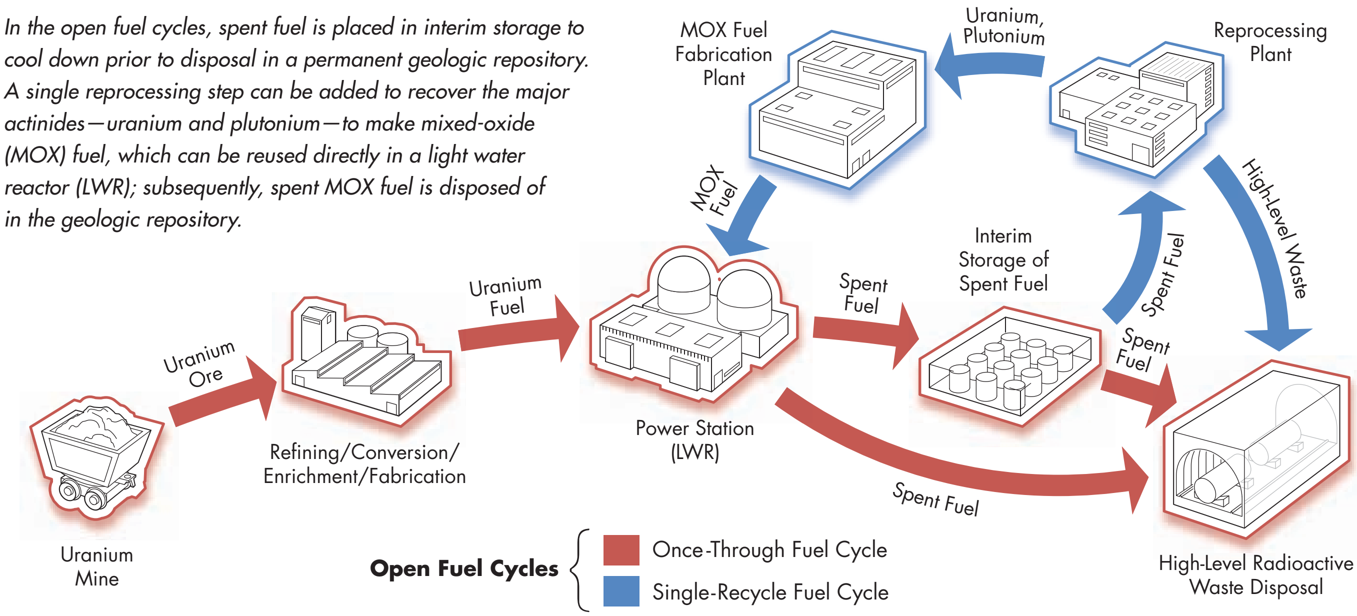
"France's strategy of reprocessing and recycling enables the country to preserve the option of nuclear power for the long term," says Jean-Michel Delbecq, program manager for future nuclear systems at the French utility EDF. French reprocessing has helped reduce the quantity of stored spent fuel and optimize interim storage of high-level waste. "The recycling of plutonium and uranium to fabricate MOX fuel significantly reduces the spent fuel inventory," says Delbecq. "We start with seven spent uranium oxide fuel assemblies, and at the end, we have one spent MOX fuel assembly. The process also substantially reduces the volume of high-level waste requiring disposal."

Recent French legislation mandated three studies that could move France toward a fully integrated closed cycle:

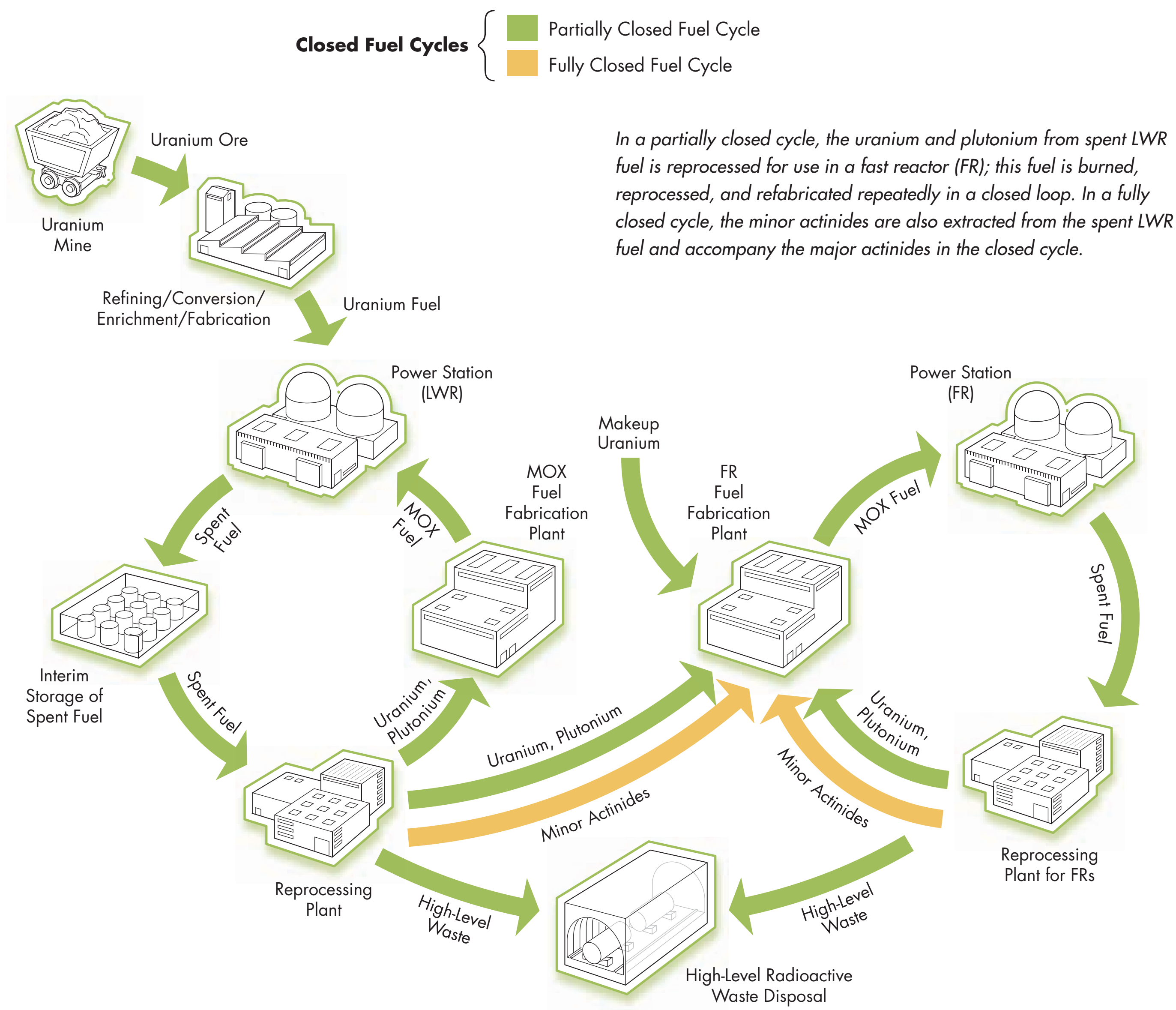
- Assess by 2015 interim storage capacity, including the potential for adapting existing facilities and the need for new ones
- Assess geologic disposal, and develop a licensing procedure by 2015, with implementation by 2025
- Assess by 2012 the transmutation of high-level waste in advanced reactors and the development of a prototype reactor by 2020

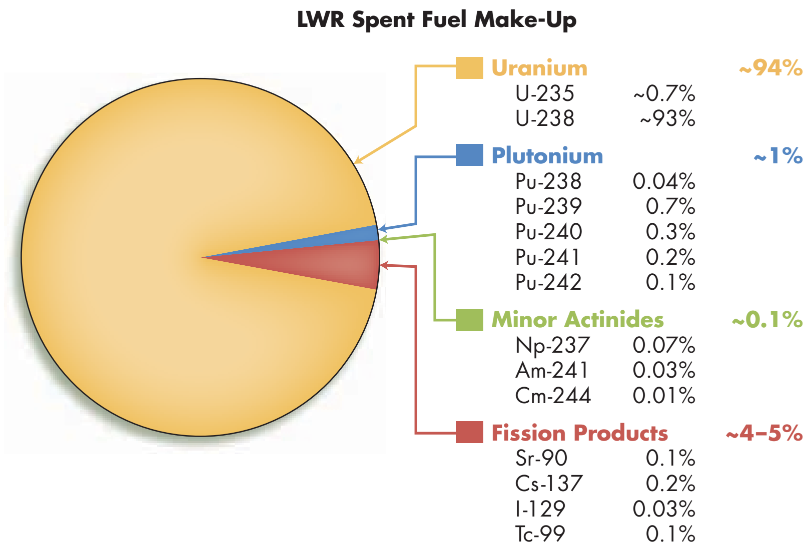
The 2012 decision on advanced "fast" reactors that can process plutonium and the minor actinides into fuel will be important for reducing the volume and radiotoxicity of reprocessed waste products, according to the French Atomic Energy Commission (see "The Status of Advanced Reactor Development," page 29). Deployment of the first such commercial reactor is expected by about 2040. EDF's goal is to evaluate the technological hurdles that must be overcome and the R&D programs that must be undertaken in order to develop fast reactors, with a focus on the sodium-cooled fast reactor. Studies indicate that the plutonium inventory in spent fuel from the current fleet of operating reactors—both spent uranium oxide fuel and spent MOX fuel—would be sufficient to enable operation of fast reactors by 2040, says Delbecq. For this reason, the plutonium resource in spent fuel must be managed with a view to the long term.

In the open fuel cycles, spent fuel is placed in interim storage to cool down prior to disposal in a permanent geologic repository. A single reprocessing step can be added to recover the major actinides—uranium and plutonium—to make mixed-oxide (MOX) fuel, which can be reused directly in a light water reactor (LWR); subsequently, spent MOX fuel is disposed of in the geologic repository.

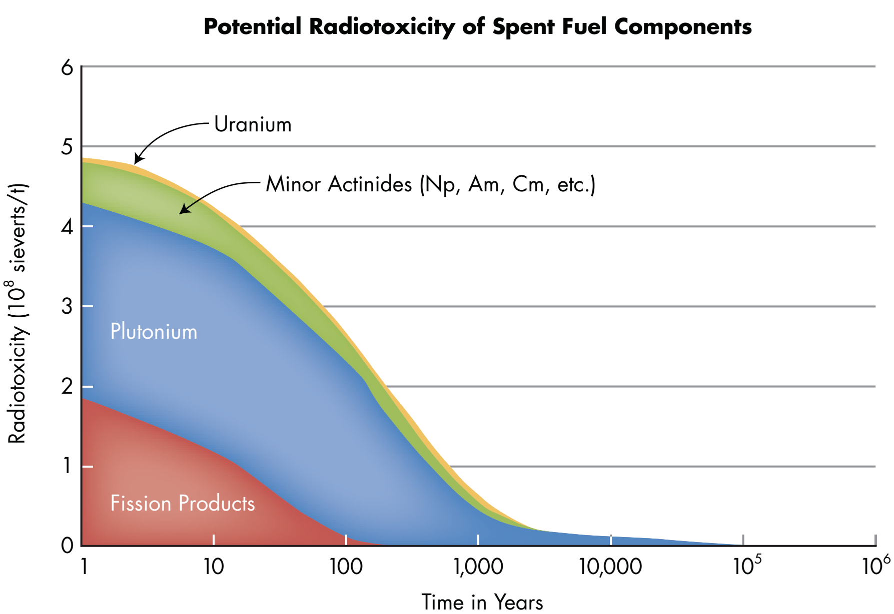


In a partially closed cycle, the uranium and plutonium from spent LWR fuel is reprocessed for use in a fast reactor (FR); this fuel is burned, reprocessed, and refabricated repeatedly in a closed loop. In a fully closed cycle, the minor actinides are also extracted from the spent LWR fuel and accompany the major actinides in the closed cycle.





Spent fuel from today's nuclear plants consists mostly of uranium unaffected by nuclear activity inside the reactor; this material can be recovered and processed for additional use. Plutonium and the minor actinides, which are formed from uranium in the reactor, are also potentially valuable as nuclear fuel. Fission products—more than two dozen elements that can be formed from split uranium atoms—are not suitable for power production and must be discarded as high-level waste.



Uranium, plutonium, and the minor actinides have significantly longer half-lives than most fission products. Removing these elements from spent fuel and burning them in a closed cycle will substantially reduce nuclear waste's radiotoxicity.

Natural resource–constrained Japan, whose nuclear plants produce approximately 1000 metric tons of spent fuel annually, is pursuing reprocessing to address the dual concerns of waste reduction and resource enhancement. "Recycling spent fuel enables nuclear power to play a major role in energy supply over the long term and also minimizes the waste volume," says Sakae Muto, executive officer and deputy chief nuclear officer of Tokyo Electric Power Company. "Moreover, recycling spent fuel can yield uranium resource savings of 10–20%."

Muto expects reprocessing to remain central to Japan's nuclear program. In the near term, recycled uranium and plutonium will be used in light water reactors. Over the longer term, the development of fast reactors is a national technological priority.

The PUREX process presents some disadvantages related to disposal and proliferation. Because PUREX extracts the fission products and minor actinides in a single stream, the minor actinides contribute to waste volume, and their energy content is thrown away. PUREX also produces a plutonium stream, so its use raises proliferation concerns. Commingling plutonium with uranium or even small amounts of the minor actinides can increase its proliferation resistance.

In light of these issues, several technology variations have emerged or are being actively developed:

- Extraction of plutonium mixed with some uranium, and possibly with some neptunium
- Selective separation of minor actinides (by means of DIAMEX-SANEX in France, TALSPEAK in the United States, TOGDA in Japan) for interim storage, followed by recycling in fast reactors
- Group separation of actinides (by GANEX in France, UREX+ in the United States, NEXT in Japan) specifically intended for incorporation in recycled fuel for fast reactors.

Large-scale implementation of these new processes depends on significant research, development, and demonstration and is not likely for several decades. *The Future of Nuclear Power,* a 2003 report issued by the Massachusetts Institute of Technology, notes that studies of the partitioning and transmutation of long-lived fission products have not yet shown that such products can be dealt with effectively. Moreover, it will be necessary to recycle MOX fuel several times to optimize economic efficiency, says Ernest Moniz, MIT professor of physics and engineering systems and one of the authors of the study. "We are not very far advanced in such multiple recycling."

The U.S. Department of Energy (DOE) has proposed the UREX+ reprocessing technology as part of its Global Nuclear Energy Partnership (GNEP) program. The UREX+ process would keep the transuranic elements—plutonium, neptunium, americium, and curium—together, minimizing waste and making the separation more proliferation-resistant than it is in the PUREX process. In general, recycling of the transuranics turns a potential waste liability into an energy asset, although it may involve significantly higher operational complexity and costs.

Interim Storage: From Stopgap to Solution

Regardless of which advanced fuel cycles are eventually developed, interim storage will be key to the integrated system. Spent fuel from U.S. nuclear plants is currently stored on-site in spent fuel pools and in aboveground dry storage systems, awaiting the operation of a permanent geologic repository or centralized interim storage facilities. France currently provides interim storage for three products: spent uranium oxide and spent MOX fuel, stored at power plant and reprocessing-facility sites, and high-level waste from reprocessing, stored only at the reprocessing facility.

"The U.S. industry supports an integrated spent fuel management strategy that includes centralized interim storage until recycling or permanent disposal—or both—can be made available," says NEI's Steven Kraft. "Interim storage sites will enable the movement of used fuel from decommissioned and operating plants to volunteer locations before recycling facilities or a repository can begin operating. The short-term goal is to identify and develop volunteer sites for interim storage, while the medium-term goal is to move used fuel to these sites, ideally at locations where advanced fuel cycles are being developed."

Kraft points out that there is a need to explore the private sector's role in carrying out near-term reprocessing demonstrations as a way to spur reprocessing development in a real-world business setting. Communities that host interim storage are obvious candidates for hosting commercial reprocessing demonstrations.

The requirements for interim storage will depend largely on how storage will fit into efforts to close the fuel cycle. Interim storage allows heat and radioactivity levels to decrease and minimizes worker dose rates and industrial discharges from reprocessing facilities. "To obtain the best results for balancing risks and rewards in deploying advanced-fuel-cycle facilities, it may be best to leave spent fuel in interim storage for 60 to 100 years, at least initially" says John Kessler, EPRI's manager of high-level waste and spent fuel.

MIT's Moniz agrees: "It makes sense to store spent fuel for on the order of a century prior to doing whatever is planned. This conveniently provides several decades to find out if advanced fuel cycles will materialize. We favor the idea of a small number of consolidated storage sites on government property. Then, if the country moves toward a research, development, and demonstration program for an advanced fuel cycle, the pilot-, engineering-, and commercial-scale facilities should be fostered where there is consolidated spent fuel storage."

Ultimate Disposal of Nuclear Waste Still Essential

In addition to interim storage, a common thread in all advanced fuel cycles is the need for a geologic repository. Although the volume and toxicity of the waste vary with the type of cycle, all cycles produce fission products and some unrecycled frac-

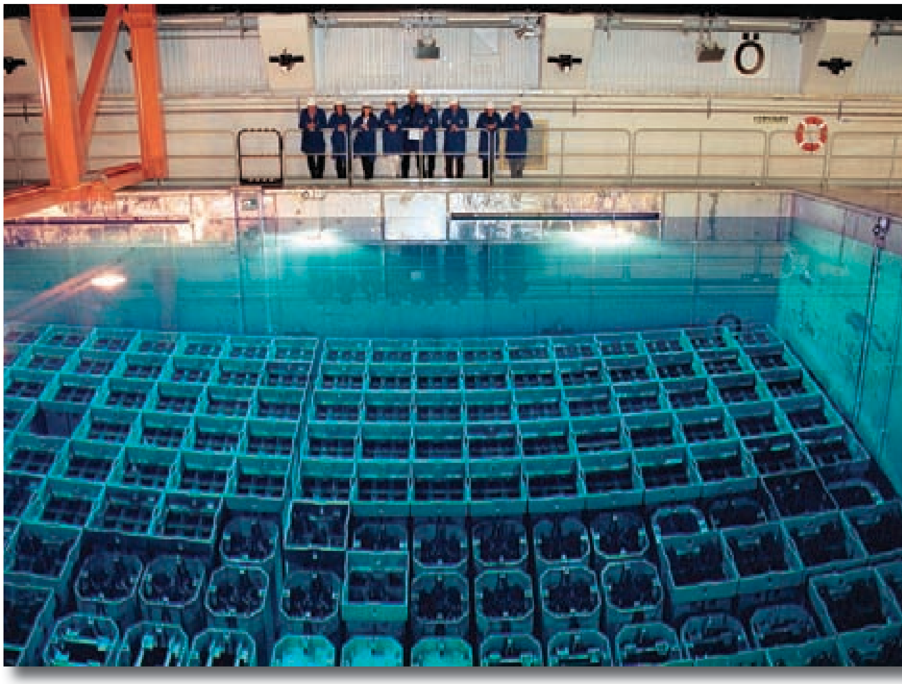
The Status of Advanced Reactor Development

Fast reactors, known as Generation IV reactors, are critical to advanced fuel cycles. Several reactor types are being considered for design and development—gas-cooled, sodium-cooled, and lead-cooled fast reactors, for example.

A number of countries—including France, Japan, South Korea, the United Kingdom, and the United States—organized the Generation IV International Forum to coordinate international R&D on promising advanced reactor designs. Recently the U.S. DOE, the French Atomic Energy Commission, and the Japan Atomic Energy Agency agreed to coordinate the development of a prototype sodium-cooled fast reactor. These countries will establish design goals for prototypes and identify key technical innovations needed to reduce capital, operating, and maintenance costs.

EPRI analyses reveal that break-even uranium prices for recycling plutonium in fast reactors are generally lower than those for recycling in light water reactors. But an increase in capital cost for the fast reactor would possibly offset this difference. MOX recycling in light water reactors could dampen, but not stop, uranium price increases, whereas a switch to fast reactors could stop the rise, according to EPRI. Therefore, a mix of MOX-fueled light water reactors and fast reactors may prove appropriate, at least for a while. Commercial deployment of fast reactors is not likely for several decades.

Fast reactors are able to fission both of the major actinides (uranium and plutonium) and all of the minor actinides (e.g., neptunium, americium, curium). They can be operated in a breeder mode or in a burner mode, depending on whether the amount of plutonium is higher or lower than the initial amount of plutonium in the fuel. Breeder reactors are most efficient when concerns about the adequacy of natural uranium supplies dominate, while burner reactors are best suited to progressively destroying actinides, thus removing them from the waste stream.



Interim storage is an important part of all fuel cycles, allowing the radioactivity and heat of spent fuel assemblies to decline before reprocessing or final waste disposal. The Clab facility in Oskarshamn, Sweden, stores about 4000 tons of uranium from Swedish nuclear plants. While Clab stores the spent fuel in deep water pools, dry storage systems are also an option.

AREVA NC's La Hague plant on the French Cotentin Peninsula reprocesses spent reactor fuel to recover uranium and plutonium, which can be recycled as MOX fuel. La Hague is the world's largest commercial spent fuel reprocessing site, serving the nuclear programs of half a dozen European nations.

tion of the actinides, and these require disposal. "Isolation of radioactive by-products, used fuel, or both in a specially designed underground repository is consistent with the international scientific consensus that deep geologic disposal is the most effective means of protecting public health and the environment," says NEI's Kraft.

No country has yet developed, licensed, or operated a repository for spent fuel and high-level waste, although Finland and the United States have identified sites and begun development, France and Sweden have identified likely locations, and Canada and the United Kingdom are working on site-decision methodologies. The United States does have an operating nuclear waste disposal facility in southeastern New Mexico, but this facility does not accept spent fuel and high-level waste.

The U.S. Congress in 1987 designated Yucca Mountain, Nevada, as the potential site of a permanent repository for spent fuel and high-level radioactive waste. Yucca Mountain has been the subject of innumerable scientific and engineering analyses and assessments. DOE has coordinated a 20-year effort involving 2500 scientists to construct the world's largest underground laboratory. Scientists from the International Atomic Energy Agency (IAEA) and the Organisation for Economic Co-operation and Development's Nuclear Energy Agency have analyzed and endorsed DOE's repository performance assessments.

Still, the project's complexity and the continuing resistance from interveners and from some in the public have slowed progress, frustrating industry leaders. "It may take a national imperative to drive a decision on a repository," says Charles Pardee, chief nuclear officer of Exelon Generation. "If all 50 state governors took a united position on the issue, or if the governors and attorneys general of the states with spent fuel stored at nuclear plant sites started pressing this issue nationally, it would be more meaningful than the same actions by industry CEOs."

As the Nevada project moves slowly forward, questions are surfacing about whether it will be adequate for future needs. "Yucca Mountain has a statutory capacity limit of 70,000 metric tons, with 90% of that capacity designated for commercial spent nuclear fuel," says Kessler. "Projecting over 50 years, we will need a repository with twice as much capacity."

EPRI analyzed Yucca Mountain's capacity in its 2007 report *Room at the Mountain.* "We concluded that through design and waste loading modifications the repository could handle between four and nine times the statutory capacity," says Kessler. This expanded capacity at Yucca Mountain would allow time for the research and development to move toward a full-scale and economically competitive closed fuel cycle.

EPRI has also assembled technical experts in climate, hydrology, materials science, geochemistry, seismology, volcanology, and the biosphere to develop models for long-term processes at the site. These processes include climate change, the slow degradation of waste containers, the slow release of radionuclides, groundwater movement,

Transporting Spent Fuel: New Cycles Bring New Challenges

Spent nuclear fuel has been safely transported for decades. According to the IAEA, there have been more than 20,000 shipments of spent fuel and high-level wastes over millions of kilometers since 1971. None has resulted in an accident in which a container was breached. Going forward, however, spent fuel will have to be moved in ever larger volumes.

Many U.S. nuclear utilities that store spent fuel at plant sites use canisters designed for both storage and transportation. The U.S. Nuclear Regulatory Commission (NRC) has licensed these canisters for use in dry storage, but it has restricted their use for transporting spent fuel that exceeds a certain fuel burnup level. Most spent fuel discharged from reactors today does exceed that level. EPRI is working with the NRC in collaboration with NEI to establish realistic standards for the transportation of spent fuel.

Many NRC concerns focus on the possibility that fissile material in the spent fuel could undergo an uncontrolled nuclear reaction. Water is a particular concern in this regard. As a moderator for neutrons, water slows them down, making it easier for them to be absorbed by fissile material in the fuel and thus increasing the probability of a chain reaction. NRC regulations require that spent fuel remain subcritical in the presence of water. EPRI is modeling the potential changes in criticality posed by the presence of water and the geometric rearrangement of the spent fuel that might occur during a transportation incident.

Regulatory concern has been heightened by the trend toward higher-burnup fuel, which may be subject to more damage during certain potential transportation events, such as accidents. EPRI has developed a probabilistic risk assessment of a criticality event occurring during transportation of spent fuel. "Criticality depends on the probability of an initiating event, the presence of a moderator, the fissile content of the spent fuel, and the presence of neutron 'poisons'—isotopes that capture neutrons, preventing them from sustaining a nuclear chain reaction," says Kessler. "Because of our work, the NRC is permitting licensees to take partial credit for certain actinides in the spent fuel that are neutron absorbers and that would shut down a chain reaction. We're doing similar research on fission products, which are also neutron absorbers."

EPRI research has helped to increase the amount of the so-called burnup credit for spent fuel—the degree to which neutron absorption by radionuclides in spent fuel reduces the risk of a nuclear reaction—that the NRC permits. Use of this burnup credit could increase the amount of spent fuel that could be transported in existing canister designs. "Without the credit, only about 20% of spent fuel could be shipped," says Kessler. "With the credit, that figure could increase to 90%."

"While encompassing all of the issues relevant to U.S. concerns," says Kessler, "our work on spent fuel transportation technical issues also applies to most spent fuel that international nuclear utilities will be moving."

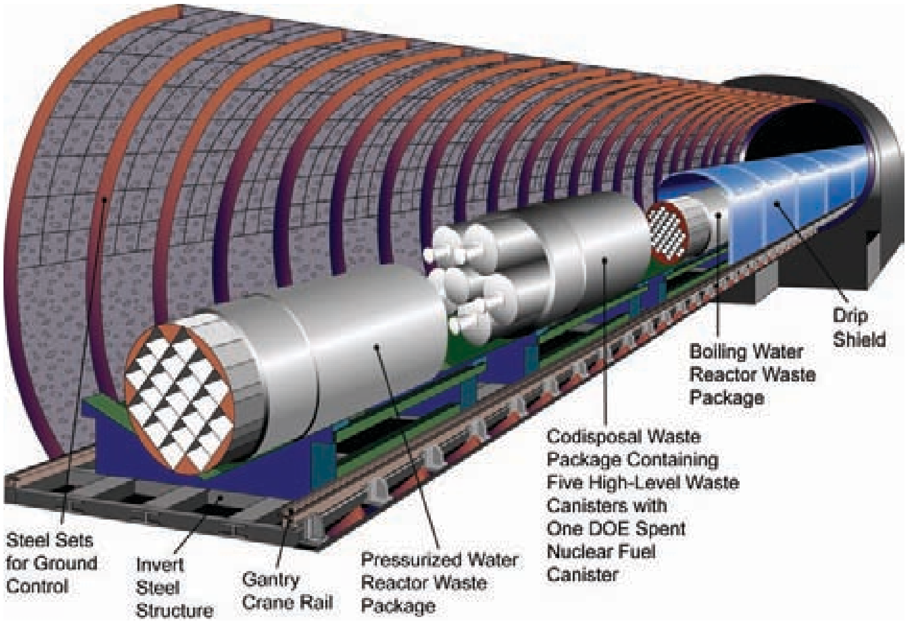
and the transport of radionuclides in the groundwater and their impact on public health. NEI will use the EPRI work in these areas when it represents the industry in the Yucca Mountain construction licensing process. DOE is expected to file an application for construction by June 2008.

Technical Challenges for Advanced Cycles

Closing the nuclear fuel cycle will constitute a multidecade effort. EPRI research points to a number of technical challenges confronting advanced fuel cycles:

- Remote-control fabrication and testing of new fuel types containing minor actinides
- Construction and safe operation of fast reactors
- Chemical treatments that separate fission products from actinides
- Conditioning of waste streams
- Improved diversion resistance of separated fissile materials

Progress on these challenges will be informed by past and ongoing reprocessing and waste management practices, but some key issues have not yet been resolved. The MIT *Future of Nuclear Power* report argues that the best approach to pursuing advanced fuel cycles involves the development of basic tools and advanced codes: "We view the optimization of such fuel



The Yucca Mountain repository in Nevada has been designed to accept a variety of high-level nuclear waste materials for permanent deep geological storage. The U.S. Department of Energy is expected to submit a license application to the U.S. Nuclear Regulatory Commission this year, although operation is unlikely for at least a decade.

cycles as a systems issue, not separate issues about the fuel form or the reactor or the separation technology. They must be integrated all the way to the kind of waste form destined for geologic isolation."

EPRI has come to similar conclusions, calling for integrated process models that dynamically simulate nuclear power systems—from uranium mining to final disposal of the wastes—in order to select the most promising development paths. To further this approach, EPRI and NEI are supporting a five-year interdisciplinary research program at MIT carried out under the MIT Energy Initiative. The program will systematically study the options for managing the technical, economic, environmental, and institutional aspects of the nuclear fuel cycle and propose a technology development and deployment plan.

While this work will consider all aspects of both open and closed fuel cycle architectures, it is placing particular focus on the uncertainties in managing commercial spent fuel and the ultimate disposal of the waste. As part of the study, MIT is currently assessing the ability of four fuel cycle modeling codes to simulate a wide spectrum of fuel cycle scenarios, says EPRI's Machiels.

In addition to the work at MIT, EPRI is collaborating with EDF to develop optimal fuel cycle strategies. "EDF will analyze a scenario in which the current U.S. nuclear fleet of light water reactors moves to a future fleet of evolutionary light water reactors and fast reactors," says Claude Garzenne, a senior researcher in EDF's R&D division.

Getting It Right

Planning out the future shape of nuclear power is a daunting task, complicated by lead times measured in decades and substantial uncertainties in future technical, institutional, and policy developments. But while the long time frames can be problematic, they also offer the opportunity to deal comprehensively with the challenge of closing the nuclear fuel cycle and to create durable, no-regrets solutions.

Success will depend to a great extent on developing a robust understanding of all the elements involved—advanced reactor designs, fuel options, separation technologies, waste forms, and geologic disposal alternatives—and integrating them into a holistic system. Given the many institutions and stakeholders involved, planning will need to include a great deal of flexibility, leading to effective, iterative decision making.

"The nuclear community has made a good start in choosing a systems approach to the nuclear fuel cycle issue," says Machiels. "Now we must get down to the hard work of developing the appropriate technologies and making it happen."

This article was written by Alice Clamp. Background information was provided by Albert Machiels (amachiel@epri.com) and John Kessler (jkessler@epri.com).

Albert Machiels, previously a senior program manager in the Nuclear Sector's Materials and Chemistry program, is currently senior technical executive. Before joining EPRI in 1982, he was an associate professor of nuclear engineering at the University of Illinois, Urbana-Champaign. Machiels received Ingénieur Civil Chimiste and Ingénieur en Génie Nucléaire degrees from the University of Liège in Belgium and a PhD in engineering from the University of California at Berkeley.

John Kessler is a program manager in the Nuclear Sector's High-Level Waste and Spent Fuel Management program. He came to EPRI in 1993, having earlier worked at Nutech Engineers and as a private consultant on dry spent fuel storage system design. Kessler earned BS and MS degrees in nuclear engineering from the University of Illinois, Urbana-Champaign, and a PhD in mineral engineering from the University of California at Berkeley.

Innovation

Emerging technologies and cutting-edge engineering

Tools for Engineering Nanodielectrics

Recent research has shown that the addition of nanoscale spherical fillers to traditional insulation materials such as epoxy or cross-linked polyethylene (XLPE) can produce significant improvements in dc dielectric breakdown strength as well as order-of-magnitude improvements in voltage endurance. These exciting results are generating increased commercial interest in incorporating nanodielectrics into power industry insulators. At the moment, however, the ability to tailor the response in these materials requires a better understanding of the role of the fillers.

Specifically, there is a need to understand the role of the extremely large surface areas in these materials in order to make it possible to optimize the design of nanoparticle-filled polymers. Evidence from prior work suggests that the internal interfacial regions play a key role in electron scattering, depth and number of trapping sites, and local charge mitigation. However, there is still a need to quantify this behavior and to conduct systematic studies of the effects of interface chemistry, polarity, and geometry on these mechanisms.

Electron transport in polymer dielectrics takes place by "hopping" conduction—that is, electrons moving between traps, or localized states. Despite the recognition that this phenomenon is important in insulator dielectrics, and despite extensive literature discussion of the trapping of charge in localized sites, the actual donor and acceptor trap sites have eluded direct spectral and structural identification. The EPRI project team at Rensselaer Polythechnic Institute is investigating the use of two experimental techniques to study the interface behavior of SiO_2/XLPE polymer nanocomposites, including the distribution of oxygen radicals and the distribution of internal charge.

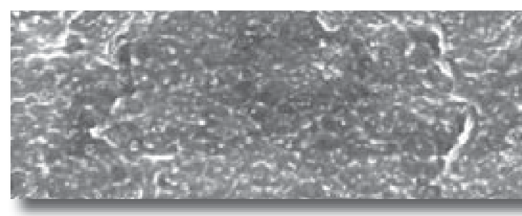
One method for probing these electrically active sites is electron paramagnetic resonance (EPR), a powerful technique for clarifying the structure of localized unpaired electrons. In this technique, the magnetic field on a sample placed in an X-band microwave cavity is increased until the energy difference between the spin-up and spin-down orientations (which are also affected by the local environment) matches the microwave frequency of the instrument. Strong absorption is then detected.

Another technique, pulsed electroacoustic analysis (PEA), provides an evaluation of the space charge density in polymeric materials by measuring the sound wave initiated from the charge when perturbed by an electric pulse. Because reducing the dimensions of the filler in a composite has important implications for the distribution of space charge, the PEA method can be employed to document the impact of particulate size and interfacial activity on the injection and storage of internal charge as well as on the underlying dynamics. In particular, it has been found that the distribution and nature of the trapped charge are affected in a fundamental way as the embedded particulates are reduced to nanometric dimensions.

The EPR and PEA studies of samples of SiO_2/XLPE polymer nanocomposite fabricated under carefully controlled conditions have yielded important insights into the identities of the ions responsible for impurity conduction and the acceptor/donor mechanisms of charge storage and transport in high-voltage insulation systems.

The experimental results on the nature of the donors/acceptors, their relation to oxygen environments introduced during the chemical cross-linking, and their relation to polymer chains elucidate the oxide nanoparticle/polymer interface in a way that can be generalized beyond the polyethylene/SiO_2 system studied in this project. Further comparison of results obtained via the two techniques is expected to provide additional insights into interface behavior.

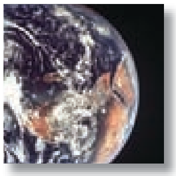
This work will not only impact the development of nanoparticle-filled polymer composites for power production and transmission but will also guide the design and development of nanocomposites in general—particularly in applications where the role of interface behavior is critical. Such applications include transparent, conducting polymer/nanotube composites, which are under development as solar cell electrodes, and nanoparticle-filled amorphous polymers, which are being used as scratch-resistant, transparent coatings in cell phones and CD technology.



Photomicrograph of 12.5% SiO_2/XLPE unfunctionalized nanocomposite at 50,000 X magnification.

Although interest in nanocomposites has focused so far on the electrical properties of this new class of materials, it is likely that many applications will also take advantage of improvements in other attributes, particularly thermal conductivity, coefficient of thermal expansion, and thermal endurance.

For more information, contact Steven Eckroad, seckroad@epri.com, 704.717.6424.



International

Energy developments around the globe

The Materials Aging Institute: A New International Collaborative Aims to Prolong Plant Lifetimes

EPRI has joined forces with the French utility EDF and Tokyo Electric Power Company (TEPCO) on a long-term research effort to better understand and anticipate how materials in power plants age and contribute to plant component degradation. Scientific findings from the new Materials Aging Institute (MAI) will help power companies optimize the operations and lifetimes of existing plants and will support the design of next-generation plants. Although the MAI's primary focus is on nuclear materials issues, research results will also benefit fossil and hydropower facilities.

EDF is recognized as a global authority on nuclear plant materials aging. The utility's fleet of 58 pressurized water reactors has accumulated more than 1000 reactor-years of operation, providing a wealth of data on aging phenomena as well as hundreds of components on which to perform detailed analyses. The MAI, based at EDF's facilities in Les Renardières, France, will pool and leverage the resources of materials research programs in Europe, Japan, and the United States.

"The founding of the Materials Aging Institute reflects both the global nature of the electric power industry and the common challenges facing power plants around the world," says Chris Larsen, vice president of EPRI's Nuclear Sector. "By teaming with research organizations such as EDF and TEPCO, we will be working with recognized experts in materials science and technology, ensuring that research and development efforts focus on critical issues with widespread industry impact."

The Materials Aging Institute's governing board: Shunichi Suzuki (TEPCO), Jean-Pierre Hutin (EDF), and Chris Larsen (EPRI).

Modeling Studies Sharpen Understanding

Many aging processes influencing the performance and life span of plant components occur at the molecular and atomic levels, making diagnosis and mitigation extremely challenging. Despite recent progress, the mechanisms of materials aging are not sufficiently understood to enable researchers and plant operators to predict, for example, a component's remaining life or when it will require repair or replacement in cases where there are no visible or detectable signs of degradation.

To investigate these processes and improve operational decision making, MAI researchers are turning to computationally intensive modeling studies and other powerful tools. The institute recently took delivery of three highly specialized electron microscopes and an IBM supercomputer with Blue Gene architecture and 8000 parallel processors. The sophisticated hardware will enable researchers to study aging phenomena as they occur, and to run digital simulations of materials aging at the molecular and atomic levels.

"In general, MAI activities are geared toward understanding the fundamentals of materials aging issues," says Mohamad Behravesh, the EPRI program manager assigned to the facility. "This means sequentially peeling off layers of ambiguities. For example, in investigating corrosion, one may start from the macroscopic effects that are visible to the naked eye, proceed to the crystalline grain structure, to the molecular state, and then on to the atomic level to try to understand what happens there and what physical laws are at play and govern the corrosion process. The objective is to move from investigation to understanding to simulation to eventual prediction."

Of particular promise are the results of studies on materials aging of secondary-side equipment, including steam generators, turbines, condensers, and feedwater systems. Findings could help researchers and plant operators to optimize secondary system chemistry to minimize aging. An improved understanding of the phenomena underlying corrosion (pH, temperature, and other variables) might enable more-accurate prediction of corrosion rates.

Initial Research Program

The institute will initially be staffed by members of EDF, EPRI, TEPCO, utility organizations, national laboratories, and universities. The MAI officially opened on January 1, 2008, and currently operates out of the existing EDF R&D facilities at Les Renardières. EDF broke ground on a dedicated MAI facility on

March 26, 2008; completion is scheduled for late 2008 or early 2009.

Among the areas that will be analyzed at the facility are equipment corrosion, component and materials degradation due to irradiation, and performance of nonmetallic materials. With an initial budget of $13.1 million, the MAI has selected nine projects to establish the 2008 R&D program:

- Environmentally Assisted Cracking in Nickel-Base Alloys and Stainless Steel
- Radiation Effects Prediction for Reactor In-Core Materials
- Secondary-Circuit Optimization
- Organic Materials in Nuclear Plants
- Lower-Core Internals
- Aging of Coating on Reactor Containment
- Source Term Control and Reduction
- Reactor Pressure Vessel Cladding
- Failure Properties of Fuel Rod Cladding

"The selected projects span a number of operating and design issues for power plant owners," says Behravesh. "It is gratifying to know that we will bring together the best talent in the industry to address the challenges of investigating, understanding, simulating, and predicting how key components in power plants will perform over extended periods."

Training New Generations

The MAI will also perform an important role in training new generations of engineers and scientists to meet global concerns over the availability of a capable workforce for the electric power industry. There are and will be additional opportunities for graduate students from a number of affiliate universities in France and other European countries to do thesis work at the MAI in partial fulfillment of their advanced degree requirements. This effort will not only keep the MAI at the forefront of research activities in areas of interest to the utility industry but also develop a generation of engineers and scientists in tune with utility industry issues—a generation that may consequently gravitate to careers in the nuclear industry.

The MAI's Research Themes

Research at the Materials Aging Institute has been organized into three major areas: understanding and modeling of physical phenomena; issues related to specific materials; and interdisciplinary issues common to all studies of materials aging.

Understanding and Modeling of Physical Phenomena

Thermal Aging, including phase transformations, changes in morphology, and the strong interaction between the microstructure of alloys and creep behavior

Irradiation, including the reliability of aging-prediction formulas, the evolution of the mechanical properties of alloys, and the relationship between irradiation and dimensional change

Physical Modeling of Corrosion, including stress corrosion cracking, fatigue corrosion, and general corrosion

Prediction of Chemical and Radiochemical Behavior, including primary and secondary chemistry of pressurized water reactors, chemistry of cement-based materials, and geochemistry

Research Related to Specific Materials

Concrete: research on the behavior of different concretes, supporting the development of a numerical tool for modeling concrete morphologies and characteristics

Polymers: research that focuses on chemical aging and on predicting the participation of oxidation in the weakening of macroscopic properties

New Materials: research on nanomaterials and materials that are resistant to extreme operating conditions at high temperature

Interdisciplinary Issues Common to All Studies of Materials Aging

Understanding and Modeling the Barrier Behavior of Surface Oxides, with emphasis on understanding the dynamics of the nucleation and growth of the oxide

Behavior, Damage, and Aging of Surfaces and Interfaces, including modeling the behavior and damage of grain boundaries and microstructural interfaces

Morphology and Calculations of Representative Elementary Volumes, to enable MAI researchers to supply pertinent parameters for predictive models needed to estimate the lives of structures

Diffusion, with a focus on predicting diffusion effects to identify margins and corresponding component lifetimes

Technology at Work

Member applications of EPRI science and technology

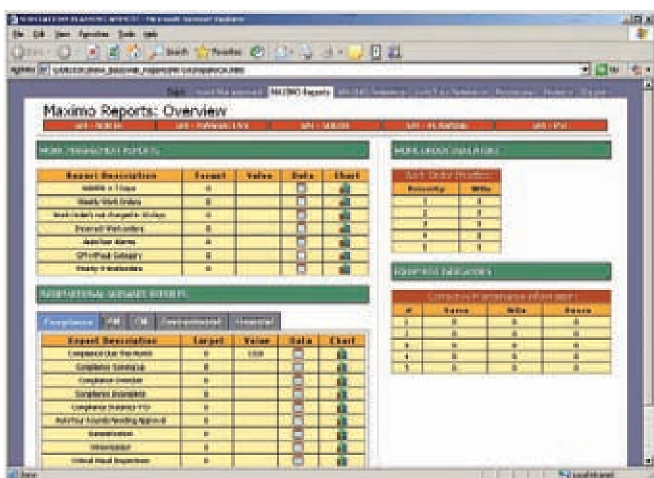
CPS Energy and Con Ed Optimize Programs With Maintenance Management Workstation

Controlling operation and maintenance costs is becoming more difficult as utilities, operating with tighter budgets and leaner staff, strive to provide customers with an ever more reliable supply of economical power. CPS Energy has become an industry leader in this art of doing more with less. Its customer bills rank among the lowest of the nation's 20 largest cities, and the company has earned the highest financial rating of any electric system in the nation. Maintaining that performance record means working smarter and adopting more-efficient approaches to managing and maintaining power system assets.

A pioneer in asset optimization, CPS Energy is applying EPRI's Maintenance Management Workstation (MMW) in novel ways to improve service reliability, automate data acquisition and analysis to improve productivity, and streamline preventive maintenance. MMW—a powerful software platform for companywide data integration—provides a single tool through which analysts can access information from many different applications: operational data, work management information, and outage information. Those data can then be analyzed to illuminate new ways to improve maintenance, system reliability, and interdepartmental coordination.

Clint Johnson, a programmer/system analyst at CPS Energy, is using MMW as an asset management tool to globally assess the company's critical assets—primarily power transformers and circuit breakers. MMW allows the asset management staff to access and analyze a wealth of network data on equipment condition, such as transformer loading or circuit breaker operation. With this information and the insight it provides into system operation, CPS and EPRI have developed approaches to streamline and improve maintenance, reliability, and staff productivity.

In one recent example, Johnson worked with EPRI to develop a function in MMW that tracks and reports on the company's entire fleet of circuit breakers. The concern is that when breakers don't operate for an extended interval, their reliability declines. By reporting on the last time each breaker has opened, the new MMW function enables CPS Energy to direct maintenance crews to long-inactive breakers to ensure they will operate reliably when needed for fault protection. This effort is a key step in the development of approaches for identifying at-risk transformers and areas that may be at risk for an outage.



MMW is helping CPS Energy engineers track the success of overhead line maintenance work as well. The workstation's access to supervisory control and data acquisition (SCADA) trip records and other data enables engineers to determine whether the maintenance effort has in fact measurably reduced the problem. In addition to SCADA records, a circuit breaker database is data-mined for specific work activities to validate the information gathered.

MMW has proved especially successful in improving staff productivity and reducing the work-hours needed for reporting tasks. For example, CPS Energy is required to submit an annual load distribution report to the Electric Reliability Council of Texas (ERCOT). In the past, the development of this report would require an engineer to sift through SCADA-generated text files to extract the pertinent information—around three weeks of tedious effort each year. With MMW's automated reporting capabilities, the data are accessible in seconds or minutes, and the time required to develop the entire ERCOT report has been collapsed from three weeks to one hour.

"MMW is a powerful asset management tool that enables us to access and analyze a huge amount of information," says Johnson. "It has the capability to create reports and graphs quickly, to target maintenance, and to aid in the decision-making process to improve system reliability while maximizing productivity. We're just beginning to appreciate how well it's designed and how powerful it is." Indeed, CPS Energy staff are working further with EPRI to develop MMW applications that will enable risk-based preventive maintenance, equipment condition trend analysis, and eventually, dynamic risk assessment.

Meanwhile, Consolidated Edison, another industry leader in maintenance optimization, has used MMW to develop a new and improved automated work-order notification system for its internal inspection compliance program. Con Ed's Substation Operations Department performs thousands of inspections and tests on substation equipment and safety systems every month as part of the program. This work is driven by internal procedures and external regulations and is critical for safe operations and conformance with laws and codes.

The department's goal with its compliance work is to achieve a 100% completion rate every month. This effort is central to the department's performance indicators and is enforced through corporate audits. During a recent review, it was noticed that some of the compliance tasks were not getting done in the allowed time frame and that some were not being done repeatedly. As a result, Con Ed turned to EPRI to help it set up an automated method to extract information on pending inspections and tests and to notify the staff responsible for their timely completion.

EPRI helped Con Ed capitalize on MMW's powerful data-mining and scheduling capabilities to develop a process that meets the company's specific needs. The new notification feature establishes linkages among the various work types, the due dates of compliance tasks, and the personnel responsible for performing the tasks in each of five boroughs in Con Ed's service area. The system sends concise, targeted e-mail notices to specific individuals or groups, providing customized, clearly formatted information in the subject line and body of the message.

"MMW has helped us streamline and strengthen our substation inspection and testing program, ensuring safe and reliable power system operation and compliance with applicable laws and codes," says Con Ed's Matthew Walther. "The ability to send out customized, timely e-mail messages to all the groups involved has raised awareness of our goal of 100% completion and has helped remove impediments to its achievement."

For more information, contact Bhavin Desai, bdesai@epri.com, 704.595.2251.

Lincoln Electric System Uses EPRI Methodology to Improve Transformer Condition Assessment

Assessing the condition of in-service transformers is essential to developing cost-effective maintenance and replacement strategies. While utilities have traditionally considered age to be the driver of transformer condition, age doesn't tell the whole story: a 30-year-old unit with a history of light duty may operate reliably for decades to come.

Lincoln Electric System (LES), faced with a large group of transformers that were nearing the end of their design life, turned to EPRI for a better approach to assessing their condition. EPRI has developed a systematic methodology for ranking transformer health—not on the basis of age, but according to operating environment and life history. The methodology distills years of EPRI research and development into a practical, quantifiable tool to support informed transformer replacement/refurbishment decisions.

LES provided EPRI with detailed transformer condition data, including information on thermal aging resulting from loading conditions, data on short circuit and lightning exposure in the operating environment, condition indications provided by dissolved gas analysis, and criticality data for the load connected to the units. This information was obtained from a number of disparate but readily available sources: the utility's maintenance management and SCADA systems, GIS maps of connected kVA information, records of lightning-related outages, relay settings, and so forth.

Armed with these data in spreadsheet format, the EPRI project team ranked approximately 80 intertie, substation, and generator transformers with respect to each operating parameter and then combined the rankings to compare all the units. The result was an overall relative ranking of LES transformers according to their susceptibility to failure and potential impact on customers. LES is now evaluating results from more-detailed tests on the ten highest-risk transformers. The next technical steps include validating the findings with a risk-of-failure analysis using EPRI's transformer expert system software XVisor, and conducting a loading analysis using EPRI's PTLoad dynamic rating tool.

In addition to identifying the transformers most likely at risk, the project provided valuable lessons for LES and raised awareness of what parameters influence the transformer fleet, and in what way. One finding, for example, was that the fleet's insulation degradation is very low as a result of conservative loading and cooling practices. This finding indicates that higher-temperature operation may be both safe and economical.

"Focusing maintenance resources on high-risk units is far more cost effective than performing blanket inspections on an entire transformer fleet in which most units are in good operating condition," says Joe Lang, system planning engineer at LES. "The EPRI methodology allowed us to identify the ten highest-risk units and perform our detailed analysis on only those units most likely to have problems. Taking a detailed, quantified look at a transformer's design and operating environment helps us to better understand the integrity of our fleet and to make better decisions regarding transformer repair and replacement."

For more information, contact Bhavin Desai, bdesai@epri.com, 704.595.2251.

Tech Transfer News

Enhancing member use of EPRI technology

EPRI Conference Promotes Power Switching Safety and Reliability

Despite the expertise and close attention of operations personnel, variations in day-to-day power switching dynamics can lead to errors and accidents that endanger lives, cut off customer service, and compromise overall system reliability. While serious errors and accidents are rare, continued efforts to improve training, tools, and procedures are key to the industry's goal of error-free operation.

The EPRI Power Switching Safety & Reliability Conference, held annually since 1997, focuses on exchanges of individual utilities' experiences and findings, as well as data and industry best practices developed through EPRI research. The most recent conference took place at the Radisson Plaza Hotel in Lexington, Kentucky, in September 2007. For two days, 165 utility representatives from the United States and nine other countries met to hear experts in situation awareness and human performance describe how utilities can redesign their control rooms and procedures to ensure safe and reliable power switching operations.

"This was the most successful conference to date," said Jerry Willms, 2007 chairman of EPRI's Power Switching Safety & Reliability Task Force and superintendent of system operations at the Lower Colorado River Authority. "Participants tell me they always learn something they can take back and apply right away. That's certainly been the case with me."

In all, there were five major presentations to the full conference and 22 afternoon breakout sessions over the two days of the conference. Dr. Mica Endsley, CEO of SA Technologies, led off with a keynote presentation on the benefits of applying situation awareness techniques to complex operations of power switching in dynamic control room environments. According to Endsley, 60–80% of errors in complex systems are the result of human error, and 80% of all human error is the result of problems with situation awareness. "Generally, system operators don't need *more* information—they are inundated with information," said Endsley. "However, we need to bring the available information together in a way that fits the human brain. Designing control rooms and systems to meet the needs of the operators is the key to high levels of performance."

Human performance issues were further examined in the second day's keynote by L. D. Holland of Global Technical Training Services. Holland, who appeared in a full-dress ship captain's uniform, described in vivid detail the numerous human and process errors that led to the sinking of the RMS Titanic, pointing out that the same errors also threaten safe power switching today. According to Holland, the Titanic disaster highlights five principles of human performance that continue to be critical in modern systems operation: (1) people are fallible; (2) situations where error is likely are predictable, manageable, and preventable; (3) individual behavior is influenced by organizational processes and values; (4) people achieve high levels of performance largely through the encouragement and reinforcement received from leaders, peers, and subordinates; and (5) events can be avoided through an understanding of the reasons mistakes occur and the application of lessons learned from past events.

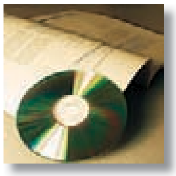
The most gripping sessions were those that focused on real power industry events. Pat Budler, technical training team leader at Nebraska Public Power District, detailed how his utility coped with the devastating December 2006 ice storm that downed 10 transmission lines. Some lessons learned: stagger shifts at the control center; man critical substations; communicate with neighboring systems; keep an adequate inventory of parts and materials; expect aftereffects from stretched conductors; and include storm structures in the system—they work.

Steve Millican, a project manager at Oklahoma Gas & Electric, discussed three near misses his company experienced with high-voltage lines during the past three years; in one case, the event could have caused multiple fatalities. Millican described not only the cause of the events—improper blocking and locking of motor-operated switches—but also what OG&E is doing now to ensure error-free switching.

Perhaps the most riveting presentation of the entire conference was given by Andy Cooper, transmission safety and training manager at the Lower Colorado River Authority. Cooper detailed the events that led to the deaths of two linemen, noting that complacency and shortcuts very likely were the principal causes of this tragedy.

The Twelfth Annual Power Switching Safety & Reliability Conference will take place September 15–16, 2008, at the St. Anthony Hotel in San Antonio, Texas. Registration for the conference can be handled through Cvent, the EPRI on-line registration system.

For more information, contact George Gela, ggela@epri.com, 413.499.5710.



Technical Reports & Software

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Environment

PISCES Database
1014011 (Software)
Program: PISCES—Plant Multimedia Toxics Characterization
EPRI Project Manager: Naomi Lynn Goodman

EMF Workstation 2007
1014012 (Software)
Program: EMF Health Assessment and RF Safety
EPRI Project Manager: Brian Cramer

Laboratory Screening Tests for Permeable Reactive Barrier Media
1014018 (Technical Report)
Program: Coal Combustion Products—Environmental Issues
EPRI Project Manager: Kenneth J. Ladwig

Management of Non-Cooling Water Releases
1014023 (Technical Report)
Program: Watershed and Water Resource Sustainability
EPRI Project Manager: Robert A. Goldstein

Methodologies for Cross-Pollutant Trading
1014025 (Technical Report)
Program: Watershed and Water Resource Sustainability
EPRI Project Manager: Jessica Anne Fox

Water Use for Electric Power Generation
1014026 (Technical Report)
Program: Watershed and Water Resource Sustainability
EPRI Project Manager: Robert A. Goldstein

Long-Term Performance of a Passive Waste-water Treatment System: The Albright Project
1014029 (Technical Report)
Program: Effluent Guidelines and Water Quality Management
EPRI Project Manager: John Goodrich-Mahoney

Occupational Health and Safety Annual Report 2007
1014041 (Technical Report)
Program: Occupational Health and Safety
EPRI Project Manager: Gabor Mezei

EPRI Ergonomics Handbook for the Electric Power Industry
1014042 (Technical Report)
Program: Occupational Health and Safety
EPRI Project Manager: Gabor Mezei

The Costs of Reducing Electricity Sector CO_2 Emissions
1014044 (Technical Report)
Program: Greenhouse Gas Reduction Options
EPRI Project Manager: Thomas F. Wilson

A New Dosimetric Basis for RF Exposure Compliance Assessment
1014048 (Technical Report)
Program: EMF Health Assessment and RF Safety
EPRI Project Manager: Robert I. Kavet

Assessment of Treated Wood and Alternate Materials for Utility Poles
1014064 (Technical Report)
Program: T&D Facilities and Equipment: Environmental Issues
EPRI Project Manager: Mary E. Mclearn

Multimedia Mercury Fate at Coal-Fired Power Plants Equipped With SCR and Wet FGD Controls
1014095 (Technical Report)
Program: PISCES—Plant Multimedia Toxics Characterization
EPRI Project Manager: Babu Nott

Program on Technology Innovation: Economic Analysis of California Climate Initiatives, An Integrated Approach, Volume 2—Full Report
1014862 (Technical Report)
Program: Global Climate Change Policy Costs and Benefits
EPRI Project Manager: Geoffrey Blanford

Program on Technology Innovation: Economic Analysis of California Climate Initiatives, An Integrated Approach, Volume 3—Modeler's Appendices
1014863 (Technical Report)
Program: Global Climate Change Policy Costs and Benefits
EPRI Project Manager: Geoffrey Blanford

Introduction to Radio Frequency Measurements DVD
1014933 (Software)
Program: EMF Health Assessment and RF Safety
EPRI Project Manager: Robert I. Kavet

Pilot Study for the Replication of the Draper Study of Leukemia, Brain Tumors, and Distance to Power Lines in California
1014939 (Technical Report)
Program: EMF Health Assessment and RF Safety
EPRI Project Manager: Gabor Mezei

EPRI Ergonomics Handbook for the Electric Power Industry
1014942 (Technical Report)
Program: Occupational Health and Safety
EPRI Project Manager: Gabor Mezei

Ohio River Ecological Research Program (ORERP): 2005 Ohio River Monitoring Results
1015422 (Technical Report)
Program: Fish Protection at Steam Electric Power Plants
EPRI Project Manager: Douglas A. Dixon

Kentucky Transmission Line Siting Methodology
1016198 (Technical Report)
Program: ROW: Siting, Vegetation Manage-ment, and Avian Issues
EPRI Project Manager: John Goodrich-Mahoney

Generation

ESPM (Electrostatic Precipitator Model) Version 4.0
1012686 (Software)
Program: Particulate and Opacity Control
EPRI Project Manager: Ralph F. Altman

Steam Turbine Bolting Maintenance Guide
1013341 (Technical Report)
Program: Steam Turbines, Generators, and Balance-of-Plant
EPRI Project Manager: Alan Joseph Grunsky

BLESS 5.0 Boiler Life Extension and Simulation System
1014102 (Software)
Program: Boiler Life and Availability Improvement Program
EPRI Project Manager: Kent K. Coleman

Compilation of EPRI Boiler Guidelines
1014103 (Technical Report)
Program: Boiler Life and Availability Improvement Program
EPRI Project Manager: Kent K. Coleman

Compilation of EPRI Fossil Plant Cycle Chemistry Guidelines
1014105 (Technical Report)
Program: Boiler and Turbine Steam and Cycle Chemistry
EPRI Project Manager: James A. Mathews

Computer-Based Training Course: Fossil Planners Guide, Version 1.0
1014107 (Software)
Program: Maintenance Management and Technology
EPRI Project Manager: Stephen H. Hesler

Gas Turbine Overhaul Plan (GTOP) for GE 9FA
1014109 (Software)
Program: Combustion Turbine (CT) and Combined-Cycle (CC) O&M
EPRI Project Manager: John R. Scheibel

CTCC O&M Cost Analyzer, Version 7.0
1014111 (Software)
Program: New Combustion Turbine/Combined-Cycle Design, Repowering, and Risk Mitigation
EPRI Project Manager: Dale S. Grace

Compilation of EPRI Heat Recovery Steam Generator (HRSG) Guidelines
1014114 (Technical Report)
Program: Heat Recovery Steam Generator (HRSG) Dependability
EPRI Project Manager: Charles Thomas Alley, Jr.

Technical Assessment Guide (TAG®)—Power Generation and Storage Technology Options
1014115 (Technical Report)
Program: Technology-Based Business Planning Information and Services (TAG)
EPRI Project Manager: Gopalachary Ramachandran

Technical Assessment Guide (TAG®)—Advanced Technologies
1014116 (Technical Report)
Program: Technology-Based Business Planning Information and Services (TAG)
EPRI Project Manager: Gopalachary Ramachandran

Boiler Water Deposition Model for Fossil-Fueled Power Plants
1014128 (Technical Report)
Program: Boiler and Turbine Steam and Cycle Chemistry
EPRI Project Manager: James A. Mathews

Condensate Filtration Technologies for Electric Power Generating Stations
1014129 (Technical Report)
Program: Boiler and Turbine Steam and Cycle Chemistry
EPRI Project Manager: James A. Mathews

Condensate Polishing Performance Assessment: Use of Separate Bed Single Vessel Designs
1014130 (Technical Report)
Program: Boiler and Turbine Steam and Cycle Chemistry
EPRI Project Manager: James A. Mathews

Simulated Boiler Corrosion Studies Using Electrochemical Techniques: AVT(O) Contaminant Limits
1014133 (Technical Report)
Program: Boiler and Turbine Steam and Cycle Chemistry
EPRI Project Manager: James A. Mathews

Boresonic Inspection Primer
1014140 (Technical Report)
Program: Steam Turbines, Generators, and Balance-of-Plant
EPRI Project Manager: Paul Zayicek

2007 Workshop on Selective Catalytic Reduction
1014168 (Technical Report)
Program: Postcombustion NO_x Control
EPRI Project Manager: David R. Broske

2007 Status of Multi-Pollutant Process Development
1014170 (Technical Report)
Program: Integrated Environmental Controls (Hg, SO_2, NO_x, and Particulate)
EPRI Project Manager: Charles E. Dene

Mercury Control Technology
1014172 (Technical Report)
Program: Integrated Environmental Controls (Hg, SO_2, NO_x, and Particulate)
EPRI Project Manager: Ramsay Chang

Guidelines for Obtaining Compliance Assurance Monitoring Permits
1014175 (Technical Report)
Program: Particulate and Opacity Control
EPRI Project Manager: Ralph F. Altman

Optimizing Ash Handling—SmartAsh™ System Evaluation
1014176 (Technical Report)
Program: Particulate and Opacity Control
EPRI Project Manager: Ralph F. Altman

Status of Particulate Matter Continuous Emission Monitoring Systems 2007
1014180 (Technical Report)
Program: Continuous Emissions Monitoring
EPRI Project Manager: Charles E. Dene

Continuous Mercury Monitoring Demonstration
1014181 (Technical Report)
Program: PISCES—Plant Multimedia Toxics Characterization
EPRI Project Manager: Charles E. Dene

Renewable Energy Technical Assessment Guide—TAG-RE: 2007
1014182 (Technical Report)
Program: Renewable and Hydropower Generation
EPRI Project Manager: Charles R. McGowin

Metallurgical Guidebook for Fossil Power Plant Boilers
1014183 (Technical Report)
Program: Fossil Materials and Repair
EPRI Project Manager: David W. Gandy

Shutdown Protection of Steam Turbines Using Dehumidified Air
1014195 (Technical Report)
Program: Heat Recovery Steam Generator (HRSG) Dependability
EPRI Project Manager: Charles Thomas Alley, Jr.

Guidelines on Optimizing Heat Recovery Steam Generator Drains
1014196 (Technical Report)
Program: Heat Recovery Steam Generator (HRSG) Dependability
EPRI Project Manager: Charles Thomas Alley, Jr.

Burner Management System Maintenance Guide for Fossil Power Plant Personnel
1014198 (Technical Report)
Program: Fossil Maintenance Applications Center (FMAC)
EPRI Project Manager: Ray Henson Chambers

Emergency Management Guideline for Fossil Generating Stations
1014199 (Technical Report)
Program: Operations Management and Technology
EPRI Project Manager: C. Wayne Crawford

Updated Operations Assessment Guideline
1014200 (Technical Report)
Program: Operations Management and Technology
EPRI Project Manager: C. Wayne Crawford

Root Causes of Circumferential Cracking in Waterwalls of Supercritical Units: State-of-Knowledge
1014205 (Technical Report)
Program: Thermal Fatigue Cracking in the Waterwalls of Supercritical Boilers
EPRI Project Manager: Anthony Facchiano

Work Management Guidelines for Fossil Power Plant Personnel
1014208 (Technical Report)
Program: Operations Management and Technology
EPRI Project Manager: C. Wayne Crawford

Risk-Informed Maintenance Decision Analysis Methodology
1014243 (Technical Report)
Program: Maintenance Management and Technology
EPRI Project Manager: Stephen H. Hesler

Understanding Mercury Chemistry via the Reaction Engineering International (REI) ProMerc™ Model
1014893 (Technical Report)
Program: Integrated Environmental Controls (Hg, SO_2, NO_x, and Particulate)
EPRI Project Manager: George R. Offen

Creating Incentives for Electricity Providers to Integrate Distributed Energy Resources
1014899 (Technical Report)
Program: Distributed Energy Resources
EPRI Project Manager: David Thimsen

Negative Sequence Effects on Generator Rotors
1014910 (Technical Report)
Program: Steam Turbines, Generators, and Balance-of-Plant
EPRI Project Manager: Paul Zayicek

Generator Control Testing to Certify Reactive Power Capability, Excitation System Functions and Frequency Response
1014911 (Technical Report)
Program: Steam Turbines, Generators, and Balance-of-Plant
EPRI Project Manager: Jan Stein

Review of Combustion Modification Emerging Technologies
1014912 (Technical Report)
Program: Combustion Performance and NO_x Control
EPRI Project Manager: Richard Marshall Himes

Clearance and Tagging Guideline for Fossil Electric Generating Stations
1014916 (Technical Report)
Program: Operations Management and Technology
EPRI Project Manager: C. Wayne Crawford

Drivers of New Generation Development—A Global Review
1014920 (Technical Report)
Program: Coal Fleet for Tomorrow—Future Coal Generation Options
EPRI Project Manager: Jeremy B. Platt

Global Natural Gas Market Analysis
1014921 (Technical Report)
Program: Coal Fleet for Tomorrow—Future Coal Generation Options
EPRI Project Manager: Jeremy B. Platt

International Coal Market Analysis
1014922 (Technical Report)
Program: Coal Fleet for Tomorrow—Future Coal Generation Options
EPRI Project Manager: Jeremy B. Platt

State of Knowledge: Grades 92 and 122 Steel for Fossil Power Plants
1014929 (Technical Report)
Program: Fossil Materials and Repair
EPRI Project Manager: David W. Gandy

Diagnostic Advisor Module Process Specification
1015180 (Technical Report)
Program: Maintenance Management and Technology
EPRI Project Manager: Stephen H. Hesler

Program on Technology Innovation: Interlayer Mixing in Selective Catalytic Reduction Systems
1015438 (Technical Report)
Program: Postcombustion NO_x Control
EPRI Project Manager: David R. Broske

Productivity Improvement for Fossil Steam Power Plants, 2007
1015445 (Technical Report)
Program: Steam Turbines, Generators, and Balance-of-Plant
EPRI Project Manager: Alan Joseph Grunsky

Intelligent Sootblowing at NRG Texas W. A. Parish Plant
1015483 (Technical Report)
Program: Combustion Performance and NO_x Control
EPRI Project Manager: Jeffrey Stallings

Assessment of Secondary Air Distribution on an Opposed-Fired Unit
1015498 (Technical Report)
Program: Combustion Performance and NO_x Control
EPRI Project Manager: Jose C. Sanchez

Fossil Plant High-Energy Piping Damage: Theory and Practice
1015505 (Technical Report)
Program: Boiler Life and Availability Improvement Program
EPRI Project Manager: Kent K. Coleman

Instrument Development for Continuous Flux Monitoring in Hydrogenerators
1016148 (Technical Report)
Program: Renewable and Hydropower Generation
EPRI Project Manager: Jan Stein

Flame Doctor for Cyclone Boilers
1016149 (Technical Report)
Program: Cyclone Interest Group (CIG)
EPRI Project Manager: Richard Marshall Himes

Program on Technology Innovation: Improved Probability of Failure Analysis Using On-Line Equipment Condition Monitoring Data
1016173 (Technical Report)
Program: I&C and Automation for Improved Plant Operations
EPRI Project Manager: Aaron James Hussey

EGEAS—Electric Generation Expansion Analysis System, Version 9.02BW
1016192 (Software)
Program: Technology-Based Business Planning Information and Services (TAG)
EPRI Project Manager: Gopalachary Ramachandran

Fossil Plant High-Energy Piping Damage: Theory and Practice
1016212 (Technical Report)
Program: Boiler Life and Availability Improvement Program
EPRI Project Manager: Kent K. Coleman

Guidelines for Reducing the Time and Cost of Turbine-Generator Maintenance Overhauls and Inspections, Volume 2—Repair Procedures
1016345 (Technical Report)
Program: Steam Turbines, Generators, and Balance-of-Plant
EPRI Project Manager: Alan Joseph Grunsky

Guidelines for Reducing the Time and Cost of Turbine-Generator Maintenance Overhauls and Inspections, Volume 4—Turbine Generator Component Procurement Specifications
1016346 (Technical Report)
Program: Steam Turbines, Generators, and Balance-of-Plant
EPRI Project Manager: Alan Joseph Grunsky

Demonstration of On-Line Elemental Coal Analyzer at TVA's Cumberland Fossil Plant
1016364 (Technical Report)
Program: Combustion Performance and NO_x Control
EPRI Project Manager: Jose C. Sanchez

Bull Run Fossil Plant Online Coal Flow Adjustable Riffler Test
1016365 (Technical Report)
Program: Combustion Performance and NO_x Control
EPRI Project Manager: Jose C. Sanchez

Austenitic Stainless Steel Handbook
1016374 (Technical Report)
Program: Fossil Materials and Repair
EPRI Project Manager: David W. Gandy

Remaining-Life Assessment of Austenitic Stainless Steel Superheater and Reheater Tubes Subjected to Long-Term Overheat-Creep Damage
1016375 (Technical Report)
Program: Fossil Materials and Repair
EPRI Project Manager: David W. Gandy

Nuclear

Plant Support Engineering: Guidelines for Optimizing the Engineering Change Process for Nuclear Power Plants, Revision 2
1008254 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Leigh Aparicio

Nuclear Maintenance Applications Center: Considerations for Developing a Critical-Parts Program at a Nuclear Power Plant
1011861 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Lee Alvin Rogers

BWRVIP-183: BWR Vessel and Internals Project, Top Guide Grid Beam Inspection and Flaw Evaluation Guidelines
1013401 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Robert G. Carter

BWRVIP-180: BWR Vessel and Internals Project, Access Hole Cover Inspection and Flaw Evaluation Guidelines
1013402 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Robert G. Carter

BWRVIP-181: BWR Vessel and Internals Project, Steam Dryer Repair Design
1013403 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Robert G. Carter

PDD/QDA Version 4.0 Performance Demonstration Database/Qualified Data Analyst for UNIX
1014495 (Software)
Program: Nuclear Power
EPRI Project Manager: Steven M. Swilley

ORSIM, Operational Risk Simulation Model, Version 1.0
1014553 (Software)
Program: Nuclear Power
EPRI Project Manager: Nicholas Ronald Camilli

EOOS, Equipment Out of Service, Version 3.5
1014786 (Software)
Program: Educating Risk Staff
EPRI Project Manager: Frank J. Rahn

Operations and Maintenance Development: Preventive Maintenance Program Implementation Self-Assessment Guidelines for Nuclear Power Plants
1014798 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Lee Alvin Rogers

Seismic Qualification Case Study for a New Inverter
1014870 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Robert Kassawara

Plant Support Engineering: Temperature Stability Criteria for Heat Exchanger Testing
1014882 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Timothy Eckert

SG Degradation Database and Progress Report
1014956 (Software)
Program: Nuclear Power
EPRI Project Manager: Heather M. Feldman

ChemWORKS Tools, Version 1.0
1014959 (Software)
Program: Nuclear Power
EPRI Project Manager: Keith Paul Fruzzetti

CIRCE—PWR Secondary Water Chemistry Optimization Tool, Version 1.0
1014960 (Software)
Program: Nuclear Power
EPRI Project Manager: Keith Paul Fruzzetti

Boron-Induced Offset Anomaly (BOA) Risk Assessment Tool, Version 2.0
1014961 (Software)
Program: Nuclear Power
EPRI Project Manager: Jeffrey Charles Deshon

Computer-Based Training Module for Microbiologically Induced Corrosion (MIC)
1014967 (Software)
Program: Nuclear Power
EPRI Project Manager: Shane Findlan

PM Basis Version (Preventive Maintenance Database) 2.0
1014971 (Software)
Program: Nuclear Power
EPRI Project Manager: Leonard Loflin

Program on Technology Innovation: Prediction and Evaluation of Environmentally Assisted Cracking in LWR Structural Materials
1014977 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Rajeshwar Pathania

Pressurized Water Reactor Hideout Return Sourcebook
1014985 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Keith Paul Fruzzetti

Pressurized Water Reactor Primary Water Chemistry Guidelines
1014986 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Keith Paul Fruzzetti

Application of Raman Spectroscopy to Evaluate Lead Species Under Pressurized Water Reactor Secondary Chemistry Conditions
1014987 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Samuel S. Choi

Pressurized Water Reactor Steam Generator Layup: Corrosion Evaluation
1014988 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Samuel S. Choi

Steam Generator Management Program: Thermal-Hydraulics and Studies of Foreign Objects in Steam Generators
1014989 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Heather M. Feldman

Factors Affecting PbSCC in Alloy 600/Alloy 690 Steam Generator Tubing
1014990 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Heather M. Feldman

Steam Generator Management Program: PWR Steam Generator Tube Wear—Alloy 690/Supports
1014991 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Heather M. Feldman

TR-105696-R10 (BWRVIP-03) Revision 10: BWR Vessel and Internals Project
1014993 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Robert G. Carter

Materials Reliability Program: Testing the Resistance to Stress Corrosion Cracking of Alloy 690 and its Weld Metal in Supercritical Boron/Lithium/H_2 Solutions (MRP-225)
1015004 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Kawaljit Singh Ahluwalia

Materials Reliability Program: Effects of Dissolved Hydrogen, Temperature, and Hydrogen Peroxide on Low-Temperature Crack Propagation (LTCP) Fracture Resistance of Weld Metals 182, 52, and 152 (MRP-209)
1015005 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Kawaljit Singh Ahluwalia

Materials Reliability Program: Development of Alternate ASME Section XI Appendix G Methodology—Validation and Verification of FAVOR, V06.1 (MRP-226)
1015012 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Jack C. Spanner

Materials Reliability Program: PWR Internals Age-Related Material Properties, Degradation Mechanisms, Models, and Basis Data—State of Knowledge (MRP-211)
1015013 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Anne Genevieve Demma

Evaluation of Altering the Hydrogen Concentration for Mitigation of Primary Water Stress Corrosion Cracking
1015017 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Keith Paul Fruzzetti

Dispersants for Tube Fouling Control, Volume 5: PWR Application Sourcebook
1015020 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Keith Paul Fruzzetti

Elevated pH Demonstration at Comanche Peak Unit 2
1015022 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Jeffrey Charles Deshon

Corrosion Product Transport Model for PWR Primary Circuit Applications
1015023 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Jeffrey Charles Deshon

Performance Assessment of High-Burnup Fuel From Limerick
1015026 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Erik Mader

Eddy Current Method to Determine Hydrogen in Fuel Rods and Fuel Assembly Components
1015027 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Erik Mader

Hot Cell Examination of GE11 and GE13 BWR Fuel Exposed to 52 and 65 GWd/MtU at the Limerick 1 and 2 Reactors
1015028 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Erik Mader

Hot Cell Examination of AREVA Fuel Channel Coupons From LaSalle 2006/2007
1015030 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Erik Mader

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1015034 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Boching Cheng

Solubility of Zinc Silicate and Zinc Ferrite in Aqueous Solution at Light Water Reactor Temperatures
1015035 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Boching Cheng

Investigation of Browns Ferry 2 Reactor Cycle 12 Fuel Corrosion Failures, Volume 3: Assessment of Results
1015038 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Erik Mader

Hot Cell Examination of Failed and Sound Sibling Fuel Rods From Hatch-1 Cycle 21
1015040 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Erik Mader

Visual Inspections and Initial Characterizations of IFA-649 Rods
1015041 (Technical Report)
Program: Fuel Reliability and Margins
EPRI Project Manager: Suresh Yagnik

Fuel Fragmentation Scoping Studies
1015042 (Technical Report)
Program: Fuel Reliability and Margins
EPRI Project Manager: Suresh Yagnik

Program on Technology Innovation: EPRI Yucca Mountain Spent Fuel Repository Evaluation
1015045 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: John Kessler

Spent Fuel Transportation Applications—Assessment of Cladding Performance
1015048 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Albert J. Machiels

Nondestructive Evaluation: Surface Examination of Nickel Alloy Welds—Examination of Welds With Difficult Access
1015051 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Pedro Felipe Lara

Nondestructive Evaluation: Boiling Water Reactor Bottom Head Drain Line Examination—Field Trial
1015052 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Pedro Felipe Lara

Nondestructive Evaluation: Nondestructive Evaluation for Material Characterization
1015053 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Kenji J. Krzywosz

Nondestructive Evaluation: Enhanced Ferromagnetic Tubular Inspection Techniques for High-Performance Thin-Walled Ferritic Stainless Steel and Carbon Steel Tubing
1015055 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Jeganathan Maruthamuthu

Nondestructive Evaluation: Examination of Large-Diameter Buried Piping for Small-Pit Detection and Preferential Weld Corrosion Attack
1015056 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Pedro Felipe Lara

Nuclear Maintenance Applications Center: Isolated Phase Bus Maintenance Guide
1015057 (Technical Report)
Program: Equipment Degradation
EPRI Project Manager: James P. Sharkey

Nuclear Maintenance Applications Center: Condenser Air Removal Equipment Maintenance Guide
1015058 (Technical Report)
Program: Equipment Degradation
EPRI Project Manager: Martin L. Bridges, Jr.

Nuclear Maintenance Applications Center: Condenser Cleaning Equipment Maintenance Guide
1015059 (Technical Report)
Program: Equipment Degradation
EPRI Project Manager: Martin L. Bridges, Jr.

Nuclear Maintenance Applications Center: Maintenance Guide for Fluid Drives and Other Variable-Speed Drives
1015060 (Technical Report)
Program: Fossil Maintenance Applications Center (FMAC)
EPRI Project Manager: Martin L. Bridges, Jr.

Nuclear Maintenance Applications Center: Guide for the Storage and Handling of Fuel Oil for Standby Diesel Generator Systems, Revision 3
1015061 (Technical Report)
Program: Equipment Degradation
EPRI Project Manager: Wayne Johnson

Fatigue and Capacity Testing of High-Density Polyethylene Pipe and Pipe Components Fabricated From PE4710
1015062 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Shane Findlan

Nuclear Maintenance Applications Center: Airborne/Structure-Borne Ultrasound Technology Sourcebook
1015064 (Technical Report)
Program: Equipment Degradation
EPRI Project Manager: James P. Sharkey

Turbine-Generator Auxiliary Systems, Volume 3: Generator Hydrogen System Maintenance Guide
1015066 (Technical Report)
Program: Steam Turbines, Generators, and Balance-of-Plant
EPRI Project Manager: Jan Stein

Plant Support Engineering: Life Cycle Management Planning Sourcebooks—Chillers
1015075 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Gary John Toman

Plant Support Engineering: Large Motor End of Expected Life and Planning Considerations
1015076 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Gary John Toman

Plant Support Engineering: Aging Effects for Structures and Structural Components (Structural Tools)
1015078 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Gary John Toman

Plant Support Engineering: Replacements for Obsolete ASCO Red Hat Series Solenoid Valves on CD-ROM, NQA Safety Related
1015079 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Marc Howard Tannenbaum

Clearance and Tagging Guideline for Nuclear Electric Generating Stations
1015082 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: David Ziebell

On-Line Monitoring: Univariate Methods for Statistical Analysis of Plant Data
1015086 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Richard Lee Rusaw

Guidance on Use of Simulation to Support Digital I&C and Control Room Modifications
1015088 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Joseph A. Naser

Handbook on Regression Testing of Digital Systems
1015090 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Raymond C. Torok

Nuclear Asset Management (NAM) Process Model
1015091 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Stephen Michael Hess

Investigation of Inter-System Common-Cause Failures
1015096 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Ken Canavan

Review of Current Practices for Configuration Risk Management at Nuclear Power Plants
1015098 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Ken Canavan

Option 2, 10CFR50.69 Special Treatment Guidelines
1015099 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Patrick Joseph O'Regan

Program on Technology Innovation: Probabilistic Risk Assessment Requirements for Passive Safety Systems
1015101 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Stephen Michael Hess

Risk-Informing Construction and Operating License (COL) Plants—A Scoping Study
1015102 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Patrick Joseph O'Regan

Program on Technology Innovation: Education of Risk Professionals
1015103 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Frank J. Rahn

MAAP Applications Guide
1015104 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Ken Canavan

Program on Technology Innovation: Effects of Spatial Incoherence on Seismic Ground Motions
1015110 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Tom J. Mulford

Program on Technology Innovation: Validation of CLASSI and SASSI Codes to Treat Seismic Wave Incoherence in Soil-Structure Interaction (SSI) Analysis of Nuclear Power Plant Structures
1015111 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Tom J. Mulford

Program on Technology Innovation: New Plant Deployment Program Model
1015113 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Tom J. Mulford

Waste Class B/C Reduction Guide
1015115 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Phung Kim Tran

Application of Continuous Electrical Deionization for Liquid Radwaste Processing at Braidwood Generating Station
1015116 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Dennis Hussey

Program on Technology Innovation: Development of the EPRI Magnetic Molecules Technology
1015117 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Sean P. Bushart

Groundwater Protection Guidelines for Nuclear Power Plants
1015118 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Sean P. Bushart

Application of the EPRI Standard Radiation Monitoring Program for PWR Radiation Field Reduction
1015119 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Dennis Hussey

Pro-Active Exposure Reduction Practices to Improve Process Efficiency and Reduce Personnel Exposure for Emergent PWR/BWR Material Inspection and Mitigation Activities
1015120 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Phung Kim Tran

Rancho Seco Nuclear Generating Station Decommissioning Experience Report
1015121 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Sean P. Bushart

Nuclear Maintenance Applications Center: Emergency Diesel Generator Governing System Maintenance Guide for Nuclear Applications
1015157 (Technical Report)
Program: Equipment Degradation
EPRI Project Manager: James P. Sharkey

Operations and Maintenance Development: Work Planning Assessment Guidelines for Nuclear Power Plant Personnel
1015253 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Lee Alvin Rogers

Nuclear Maintenance Applications Center: Lube Notes Compilation, 1989–2007
1015254 (Technical Report)
Program: Fossil Maintenance Applications Center (FMAC)
EPRI Project Manager: Nicholas Ronald Camilli

Nuclear Maintenance Applications Center: Material Handling Application Guide
1015271 (Technical Report)
Program: Equipment Degradation
EPRI Project Manager: Martin L. Bridges, Jr.

Nuclear Maintenance Applications Center: Maintenance Engineer Fundamentals Handbook
1015307 (Technical Report)
Program: Equipment Degradation
EPRI Project Manager: Lee Alvin Rogers

MAAP Version 4.07 (Modular Accident Analysis Program) for Windows 2000/XP on CD-ROM, Nuclear Safety Related
1015309 (Software)
Program: Educating Risk Staff
EPRI Project Manager: Frank J. Rahn

Nuclear Maintenance Applications Center: Bolted Joint Fundamentals
1015336 (Technical Report)
Program: Equipment Degradation
EPRI Project Manager: Martin L. Bridges, Jr.

Nuclear Maintenance Applications Center: Assembling Gasketed Flanged Bolted Joints
1015337 (Technical Report)
Program: Equipment Degradation
EPRI Project Manager: Martin L. Bridges, Jr.

HRA Calculator 4.0
1015358 (Software)
Program: Educating Risk Staff
EPRI Project Manager: Frank J. Rahn

Proceedings: 2007 Condensate Polishing Workshop
1015447 (Technical Report)
Program: Water Chemistry Control
EPRI Project Manager: Keith Paul Fruzzetti

Fuel Reliability Guidelines: PWR Fuel Cladding Corrosion and Crud
1015449 (Technical Report)
Program: Fuel Reliability and Margins
EPRI Project Manager: Kurt W. Edsinger

BWRVIP-177: BWR Vessel and Internals Project, Analysis of a Noble Metal Surface/Crack Deposition Monitoring Specimen—2007 Update
1015468 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Rajeshwar Pathania

Materials Reliability Program: Corrosion Testing of Decommissioned PWR Core Internals Material Samples (MRP-222)
1015478 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Hui-Tsung Tang

Materials Reliability Program: Corrosion and Fracture Toughness Testing of BOR-60 Irradiated Materials (MRP-223)
1015479 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Hui-Tsung Tang

Materials Reliability Program: Analysis of IASCC Initiation Data for Irradiated Stainless Steels (MRP-224)
1015480 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Hui-Tsung Tang

An Interim Review of the Cooperative Irradiation-Assisted Stress Corrosion Cracking Research (CIR) Program—Revision 1
1015493 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Rajeshwar Pathania

Rancho Seco Reactor Vessel Segmentation Experience Report
1015501 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Sean P. Bushart

CAFTA, Computer-Aided Fault Tree Analysis, Version 5.3
1015513 (Software)
Program: Educating Risk Staff
EPRI Project Manager: Frank J. Rahn

CAFTA, Computer-Aided Fault Tree Analysis, DEMO Version 5.3
1015514 (Software)
Program: Educating Risk Staff
EPRI Project Manager: Frank J. Rahn

CAFTA 5.3, Educational Version
1015515 (Software)
Program: Educating Risk Staff
EPRI Project Manager: Frank J. Rahn

A History of the Maintenance Rule 10CFR50.65
1015517 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Leonard Loflin

Nuclear Maintenance Applications Center: Preventive Maintenance Basis Database, Version 1.5—User's Manual
1015519 (Technical Report)
Program: Staff Expertise Loss
EPRI Project Manager: Martin L. Bridges, Jr.

Data Transfer Tool for ChemWorks, V4.0
1015525 (Software)
Program: Nuclear Power
EPRI Project Manager: David Perkins

Risk Impact Assessment of Extended Integrated Leak Rate Testing Intervals
1015529 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Frank J. Rahn

Materials Reliability Program: Stress Corrosion Cracking of Stainless Steel Components in Primary Water Circuit Environments of Pressurized Water Reactors (MRP-236)
1015540 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Gabriel O. Ilevbare

Program on Technology Innovation: Graphite Waste Separation
1016098 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Sean P. Bushart

Groundwater Protection Guidelines for Nuclear Power Plants
1016099 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Sean P. Bushart

Nondestructive Evaluation: Assessment of Reactor Internal Loss of Bolt Pre-Load—Feasibility
1016101 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Pedro Felipe Lara

Materials Reliability Program: Fracture Toughness Evaluation of Highly Irradiated PWR Stainless Steel Internal Components (MRP-210)
1016106 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Anne Genevieve Demma

ETTM—Instrument Uncertainty Determination, CBT Module, Version 1.0
1016108 (Software)
Program: Nuclear Power
EPRI Project Manager: Kenneth R. Caraway

An Evaluation of Alternative Classification Methods for Routine Low Level Waste From the Nuclear Power Industry
1016120 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Phung Kim Tran

BWRVIP-108NP: BWR Vessel and Internals Project, Technical Basis for the Reduction of Inspection Requirements for the Boiling Water Reactor Nozzle-to-Vessel Shell Welds and Nozzle Blend Radii
1016123 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Robert G. Carter

Experience-Based Seismic Equipment Qualification
1016125 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Robert Kassawara

Review of High Frequency Conducted Susceptibility Limits for Electromagnetic Compatibility Testing
1016158 (Technical Report)
Program: Combustion Performance and NO_x Control
EPRI Project Manager: Raymond C. Torok

BWRVIP-182: BWR Vessel and Internals Project, Guidance for Demonstration of Steam Dryer Integrity for Power Uprate
1016166 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Robert G. Carter

ETTM—Seismic Analysis, CBT Module, Version 1.0
1016238 (Software)
Program: Nuclear Power
EPRI Project Manager: Kenneth R. Caraway

ETTM—Material Properties of Metals, CBT Module, Version 1.0
1016248 (Software)
Program: Nuclear Power
EPRI Project Manager: Kenneth R. Caraway

Materials Reliability Program: Development of Preemptive Weld Overlay (PWOL) for Alloy 600 Primary Water Stress Corrosion Cracking (PWSCC) Mitigation (MRP-208)
1016252 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Kawaljit Singh Ahluwalia

Advanced Nuclear Technology (ANT) Margins and Monitoring Project Description
1016265 (Software)
Program: Nuclear Power
EPRI Project Manager: Tom J. Mulford

Program on Technology Innovation: Evaluation of Wear Characteristics of a Nanofluid in a Pressurized Water Reactor
1016281 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Heather M. Feldman

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1016322 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Randal Stark

Hot Cell Examination of AREVA Fuel Channel Coupons From Susquehanna 2006/2007
1016325 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Erik Mader

BWRVIP-34-A: BWR Vessel and Internals Project, Technical Basis for Part Circumference Weld Overlay Repair of Vessel Internal Core Spray Piping
1016377 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Robert G. Carter

Power Delivery

TFlash, Version 5.0
1012315 (Software)
Program: Overhead Transmission
EPRI Project Manager: Fabio Bologna

MSM (Motor Starting Module) Version 1.0
1013731 (Software)
Program: Power Quality
EPRI Project Manager: Bill Howe

FastFit (FFit) Version 3.0
1013735 (Software)
Program: Value and Risk in Energy Markets
EPRI Project Manager: Art M. Altman

EBS (Energy Book System) Version 6.0
1013736 (Software)
Program: Value and Risk in Energy Markets
EPRI Project Manager: Art M. Altman

OTLOT (Overhead Transmission Line Inspection—On-Line Training) Version 3.0
1013738 (Software)
Program: Overhead Transmission
EPRI Project Manager: John D. Kile

EPIC (EPRI Software for Polymer Insulators Electric Field Calculations) Version 1.0
1013740 (Software)
Program: Overhead Transmission
EPRI Project Manager: Timothy Shaw

PSTSR, Power System Transient Stability Region Version 1.0
1013744 (Software)
Program: Grid Operations
EPRI Project Manager: Pei Zhang

ESVT (Energy Storage Valuation Tool)—Modeling Stakeholder Costs and Benefits, Version 2.0
1013749 (Software)
Program: Energy Storage for DER, Renewable and T&D Applications
EPRI Project Manager: Daniel M. Rastler

DTCR (Dynamic Thermal Circuit Rating Software) Version 4.1
1013761 (Software)
Program: Increased Utilization of Transmission Corridors
EPRI Project Manager: Bernard Arthur Clairmont

Justification and Prioritization of Reliability Improvement Projects
1013767 (Technical Report)
Program: Power Quality
EPRI Project Manager: Bill Howe

Voltage Sag Direction
1013770 (Technical Report)
Program: Power Quality
EPRI Project Manager: Daniel Sabin

Mitigating the Effects of Temporary Overvoltage on Electronic Devices
1013771 (Technical Report)
Program: Power Quality
EPRI Project Manager: Brian D. Fortenbery

Plug-In Hybrid Electric Vehicle Performance Analysis
1013779 (Technical Report)
Program: Electric Transportation
EPRI Project Manager: Mark Duvall

Advanced Diagnostics
1013782 (Technical Report)
Program: Underground Distribution Systems
EPRI Project Manager: Matthew G. Olearczyk

Overhead Transmission Inspection and Assessment Guidelines—2007
1013784 (Technical Report)
Program: Overhead Transmission
EPRI Project Manager: John D. Kile

TL Workstation Tools (Tools and Software for Transmission Line Design) Version 1.0
1013785 (Software)
Program: Overhead Transmission
EPRI Project Manager: John Kar Leung Chan

EPRI Transmission Line Reference Book: 115–345-kV Compact Line Design
1013787 (Technical Report)
Program: Overhead Transmission
EPRI Project Manager: John Kar Leung Chan

Substation Ground Grid Impedance Measurement
1013793 (Technical Report)
Program: Substations
EPRI Project Manager: George Gela

Performance-Focused Maintenance Methodology for High-Voltage Circuit Breakers and Transformers—Volume I
1013795 (Technical Report)
Program: Substations
EPRI Project Manager: Bhavin Desai

Testing and Technical Issues Resolution Within IEC 61850
1013798 (Technical Report)
Program: Substations
EPRI Project Manager: Joseph William Hughes, Jr.

Solid State Load Changer
1013800 (Technical Report)
Program: Substations
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