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EPRI JOURNAL

On a Mission to Protect Workers from Heat

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Cultivating Expertise in Risk and Probability

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EPRI JOURNAL

On a Mission to Protect Workers from Heat

EPRI Research Yields Valuable Insights on Managing Heat Stress in the Electric Power Industry

By Mary Beckman

Utility Innovation: Heat Stress Management

Los Angeles Department of Water and Power (LADWP) has incorporated insights from EPRI heat stress research into its employee safety training and heat illness prevention training for supervisors. "Crew members are more likely to relate to their safety training and implement safe work practices if materials are credible and relevant to their industry," said LADWP Industrial Hygienist Marc Hendon. "EPRI offers this relevance, and its research reinforces the safe work practices recommended by our health and safety professionals."

On a midsummer evening a few years ago in Richland, Washington, the Toxic Avengers co-ed softball team faced the prospect of playing in 107°F heat. Some players were rarin' to take the field. Others thought it was too hot even to be outside, much less play, even though it was the proverbial "dry heat." For the health and safety of the players, the Battelle Summer League allowed teams to delay games without penalty until temperatures fell below a more reasonable 100°F.

Compared to softball players, electric utility workers perform far more demanding tasks in hot weather, such as climbing poles, running wires, and repairing equipment. In addition, their work time is more than nine innings; it is a full day and repeated over successive shifts. In response to sustained, strenuous work as well as heat stress and heat strain, workers can experience heat rashes, heat cramps, heat exhaustion, or heat stroke. Heat is generated by physical activity, and an increase in work intensity increases the rate at which the body must dissipate this heat.

Similar to the softball league's cutoff temperature, the electric power industry has guidelines to protect workers from heat illness. Recent research, however, suggests that some workers could continue to work safely beyond certain cutoffs in these guidelines while others should have already taken a break.

A five-year EPRI-funded research project concluded that people react to heat stress differently depending on factors such as age, sex, health, and the number of days in a row of strenuous work. Based on the results of this study and other research, EPRI is informing the power industry on best practices for preventing heat-related illnesses in workers.

“We want to keep workers safe,” said EPRI Principal Technical Leader Eric Bauman. “EPRI research is pointing the way to enhance worker health while also maintaining productivity.”

EXPERIMENTS ON HOW UTILITY WORKERS RESPOND TO HEAT

While the federal Occupational Safety and Health Administration (OSHA) does not have a specific heat stress standard, federal law requires employers to provide a workplace “free from recognizable hazards that are causing or likely to cause death or serious harm to employees.” The National Institute of Occupational Health and Safety, OSHA, and other organizations have offered some guidance on heat stress management and heat-illness prevention programs. The electric power industry relies on heat exposure guidelines based on recommendations from the American Conference of Governmental and Industrial Hygienists. These indicate how long someone can work before heat stress presents a health risk. “Threshold limit values” prescribe temperatures at which someone can work based on clothing and the number of breaks taken, but not on duration of work. To prevent workers’ body temperatures from reaching 100.4°F (38°C), the guidelines recommend a certain number of breaks in the shade, depending on weather. The underlying assumption is that a body temperature of 100.4°F or above indicates unhealthy heat stress for all workers.

Threshold values are defined in general terms. For example: During tasks requiring effort comparable to walking, a worker wearing a long-sleeve cotton shirt and pants can work safely in 82.4°F weather as long as he or she spends up to 25% of the work period resting. When wearing polyolefin coveralls, the same worker should spend twice as much time taking breaks. (This example is based on information provided in Tables 2–5 in this OSHA Technical Manual.)

Since 2013, EPRI and University of Ottawa Physiology Professor Glen Kenny have collaborated on studies to test various threshold values’ efficacy. In laboratory and field tests, they have measured utility workers’ physiological responses to hot conditions.

“These included studies of utility workers doing real utility work,” said Bauman.

In the field, researchers observed workers and measured their core body temperature, cardiovascular strain, and the intensity of the tasks they performed.

“We wanted to monitor workers in conditions they typically encounter in their jobs, whether they’re installing equipment on the ground or working on power lines in a bucket truck,” said Kenny. “We also recorded the clothing they wore and the equipment they carry. All of these affect the level of heat stress.”

In the laboratory, researchers used a calorimeter to measure the heat stored in workers’ bodies. The team used the data to determine the level of heat stress that would compromise a worker’s performance, health, and safety.

Key findings:

- Even in cool, temperate environments, workers experienced elevated heat strain that compromised safety and productivity. This results from both the work’s physical demands and protective uniforms that restrict heat dissipation.
- Workers were not always aware of the elevated risk of heat-related injuries during work shifts.
- Risk of heat-related injuries was greater in individuals who worked in the heat on consecutive days.
- The level of heat strain varied among workers, depending on age, sex, physical fitness, and the presence of chronic diseases such as hypertension. It was also influenced by fitness, hydration, and acclimation.
- Three-quarters of the workers did not drink enough water during the work day, and many started the day dehydrated.

The results suggest that the threshold values are not accurate predictors of when a person's core temperature will reach the 100.4°F cutoff—and that a 100.4°F core temperature is not an accurate indicator of whether a person is at risk for a heat-related illness.

"Our research has shown that factors such as age, sex, disease, medication use, fitness, and hydration impact physiological heat tolerance and risk of heat-related injury, and the existing guidelines don't adequately consider these factors," said Kenny. "A one-size-fits-all exposure limit may lead to over- or under-protection of workers. Over-protection may reduce productivity in workers who develop less physiological strain in response to a given level of heat stress, while under-protection may compromise safety in less heat-tolerant workers who develop heat-related illness even in temperate conditions."

"An eye-opener for us was that young people were getting overheated doing work that wasn't particularly strenuous when it wasn't particularly hot," said Jason Parker, an industrial hygienist at American Electric Power, one of the study's participating utilities.

Researchers also found that the core temperature can remain elevated after workers ceased strenuous activity. The longer a person's core temperature remains elevated, the greater the risk of heat-related illness.

"A worker might rest for 30 minutes and start feeling cooler," said Bauman. "But this cool feeling is superficial. Our findings show that the core temperature remains elevated during the break."

HOW TO AVOID HEAT-RELATED ILLNESS

In 2018 and 2019, Bauman and Kenny conducted webinars to provide utilities with suggestions for heat stress management based on the research results. Bauman points to the importance of a team effort in preventing heat-related illness. A foreman can think of a crew of workers as a team of athletes. Like an athletic coach, the foreman needs to know each person's strengths, weaknesses, and limits. Workers should stay hydrated.

EPRI research—along with Kenny's experience with workers in the electric power and other industries—reveals that workers often are not the best judge of their condition. For that reason, workers should adopt a "buddy system"—watching each other for symptoms such as profuse sweating or slurred speech. American Electric Power's Parker said that his company is implementing a peer-monitoring system based on EPRI's recommendations.

"Traditionally, we've been taught that when a person stops sweating, that's a sign of heat stroke," said Parker. "Through our work with EPRI, we've learned that people can already be in heat stroke even though they're still sweating."

In addition, just as athletes need conditioning, utility workers need to acclimate to hot conditions before performing strenuous tasks. "You don't send an athlete to compete without training," said Bauman. "They have to get adjusted to the level of activity in the competition."

Kenny's "common sense" guidance includes heat acclimation protocols for season changes and new hires who have moved from different climates.

Los Angeles Department of Water and Power (LADWP) recommends that supervisors conduct "tailgate briefings" for every assignment. These short meetings review potential hazards along with the safe work practices necessary to mitigate those hazards. LADWP has incorporated insights from EPRI heat stress research into its employee safety training and heat illness prevention training for supervisors.

"Crew members are more likely to relate to their safety training and implement safe work practices if materials are credible and relevant to their industry," said LADWP Industrial Hygienist Marc Hendon. "EPRI offers this relevance, and its research reinforces the safe work practices recommended by our health and safety professionals."

Bauman and Kenny caution against over-cooling after a work period. While using air-conditioned cabs or "cooling chairs" (which have water reservoirs built into the armrests) may make an overheated worker feel cooler, they are not effective at reducing the body's core temperature. This is because they reduce sweating and blood flow to the skin, which are important processes in cooling the body. Rather, workers should move to shaded, cooler areas with good air flow—keeping the body's heat dissipation mechanisms active.

"If someone starts to look really tired, is dragging, and not speaking well—those are all signs of high levels of heat stress," Bauman said. "They need to sit down in a shaded area and put wet towels or compresses around their neck for gradual cooling of the body's core."

TAKING OUT THE GUESSWORK

In 2016, the National Institute of Occupational Safety and Health at the Centers for Disease Control and Prevention pointed to the benefits of physiological monitoring of workers: "An advantage of physiological monitoring is that it measures the individual's responses to the environmental and metabolic heat load rather than extrapolating from the environmental conditions and the estimated work load."

"Heat-stress monitoring offers a more effective way to manage workers' health and safety," said Kenny. "It can quantify how various individual factors contribute to heat strain and provide real-time guidance to workers on prevention of excessive heat strain."

Bauman and Kenny have examined several wearable sensors that track heart rate, sweat, and body temperature and found that they all have drawbacks for use with electric utility workers. For example, a vest that monitors heart rate could potentially make a worker hotter, and its wire-mesh design has not been tested for work near high-voltage equipment. None of the devices has been tested for utility or other industrial applications.

EPRI's next five-year project plans include integrating new heat stress management approaches with wearable sensors suitable for the electric power industry. "These studies will be in the laboratory and the field," said Bauman. "We will be seeking power companies who can take monitors in the field along with new management approaches."

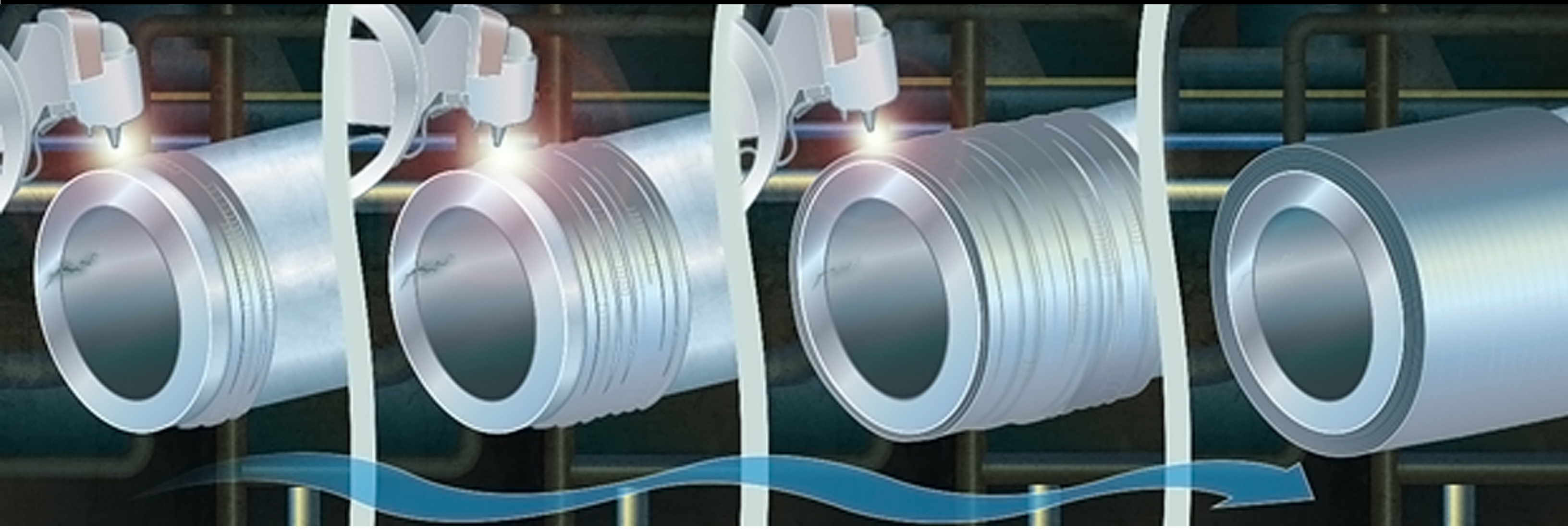
University of Ottawa's Kenny envisions a system that would include workers' age, physical characteristics, clothing, environmental conditions, work demands, and other information. Physiological sensors connected to a mobile phone or computer could provide individualized, real-time alerts and guidance.

"The system could predict the onset of heat-related illness 10 to 20 minutes in advance," Kenny said. "This gives workers another layer of protection."

KEY EPRI TECHNICAL EXPERTS

Eric Bauman

EPRI JOURNAL



EPRI Supports Transfer of Weld Overlay Technology to the Czech Republic

By Brent Barker

ČEZ Executes Weld Overlay at Dukovany Nuclear Power Station

"We started collaborating with EPRI to address the need to repair welded joints, especially in places that cannot be repaired by standard methods," said ČEZ Welding Engineer Marek Palan. "EPRI's experts provided materials, welding, and nondestructive evaluation know-how…. The technical support from EPRI's experts equipped us to defend the weld overlay technology with the State Office for Nuclear Safety."

New technologies can lead to surprising benefits. In the nuclear power industry, the weld overlay offers a case in point. This repair procedure is used when there is stress corrosion cracking along or near a weld connection joining two pipes. A weld metal is applied over the weld connection, restoring the pipes' structural integrity and resisting further stress corrosion cracking.

In the early 1980s in the United States, stress corrosion cracking in welds and piping had become such a pervasive problem in boiling water nuclear reactors that the U.S. Nuclear Regulatory Commission shut them down until the problem was under control. "The industry was faced with the prospect of wholesale piping replacement, but there wasn't enough material or manpower to do that, so they had to come up with an alternative," said EPRI Senior Technical Leader Bret Flesner. Plant operators turned to weld overlays.

"The first weld overlays were considered a temporary fix, with the assumption that they would need to be replaced within a year," said Flesner. "However, after a year and a half, then three years, then five years, plant operators found no problems. So they kept extending the life of the overlays, and EPRI and other welding experts began investigating the practicality of using weld overlays as a permanent repair."

In the late 1980s, Argonne National Laboratory and EPRI's welding research center in Charlotte removed and examined overlays and underlying welds, gaining a deeper understanding of this phenomenon: When a weld overlay is installed, the weld metal solidifies and shrinks, exerting compressive forces on the underlying pipe. The overlay not only stops crack propagation in the underlying material, but also provides the structural integrity needed to support all loads specified in the plant's design.

"In fact, the weld overlay is structurally superior to the pipe underneath," said EPRI Principal Technical Leader Steve McCracken.

Over time, weld overlays became a long-term, industrywide solution to stop the progression of stress corrosion cracking in U.S. boiling water reactors and pressurized water reactors. Today, there are more than a thousand overlays in operating nuclear plants.

Europe is a different story. "Although weld overlays are now routinely installed in the U.S., they are rarely used in Europe," said McCracken. "It's very exacting work, and the plant operators there didn't have the same level of experience with the overlay technology needed to satisfy their regulators' inquiries."

This is changing. In 2018, the Czech Republic power company ČEZ—with technical assistance from EPRI—became the first European nuclear plant operator to execute a weld overlay at a WWER type pressurized water reactor. The Institute of Applied Mechanics Brno collaborated with EPRI and provided technical support throughout the project. ČEZ Energoservis (ČEZ's welding services subsidiary) also provided technical support and applied the overlay.

During routine inspections in 2014, ČEZ technicians discovered stress corrosion cracking in the dissimilar metal welds of a super emergency feedwater pipe in one of the four WWER-440/213 reactors at Dukovany Nuclear Power Station. They attempted weld repairs, but the cracking continued. Faced with similar cracking in the other units—each has six steam generators equipped with a super emergency feedwater pipe—ČEZ and EPRI in 2015 explored options to address the problem.

"We started collaborating with EPRI to address the need to repair welded joints, especially in places that cannot be repaired by standard methods," said ČEZ Welding Engineer Marek Palan. "EPRI's experts provided materials, welding, and nondestructive evaluation know-how."

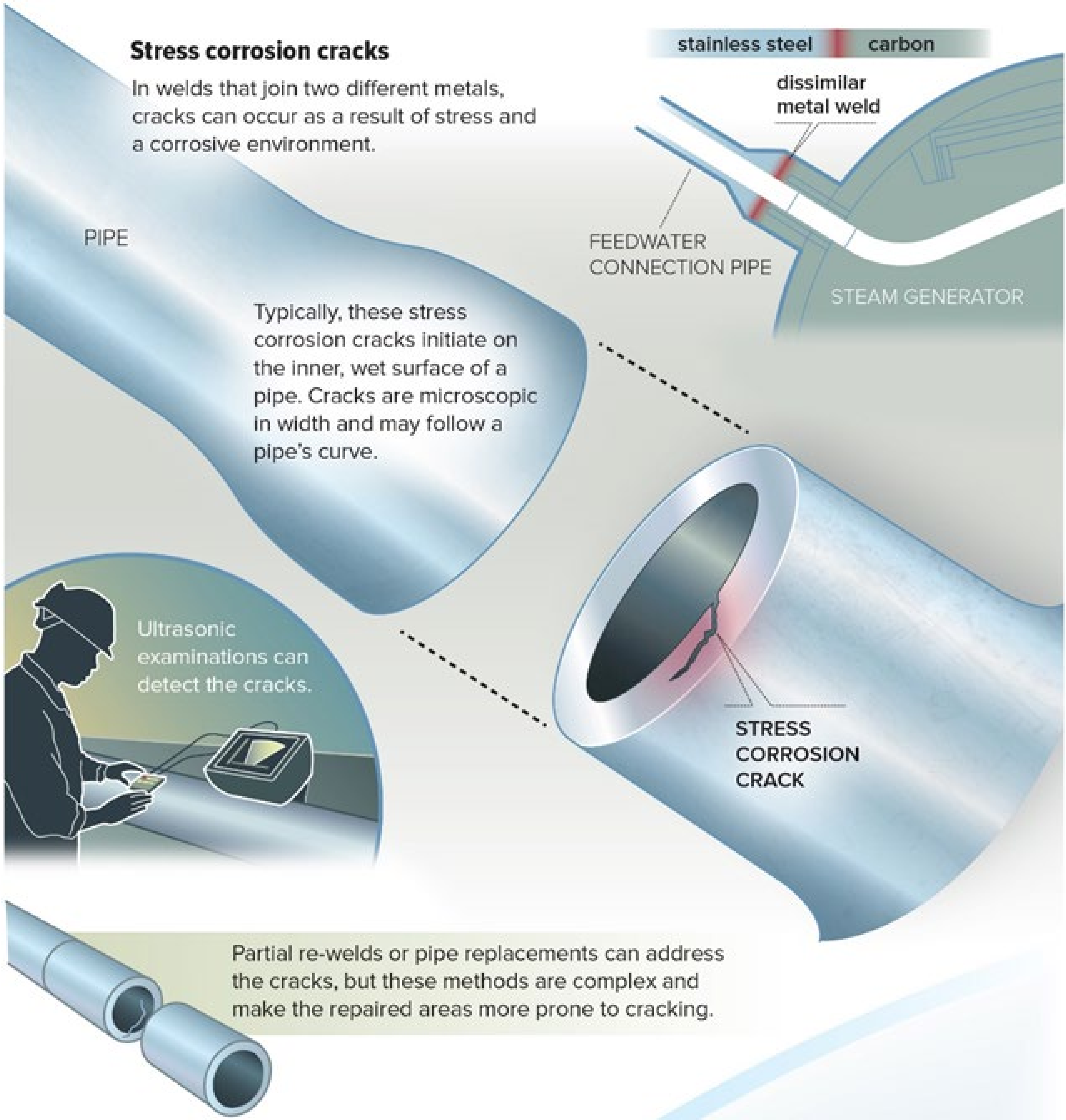
ČEZ had three options. The first was to cut out and replace the piping. "Because of the super emergency feedwater nozzle configuration, this is a very complex and risky undertaking," said McCracken.

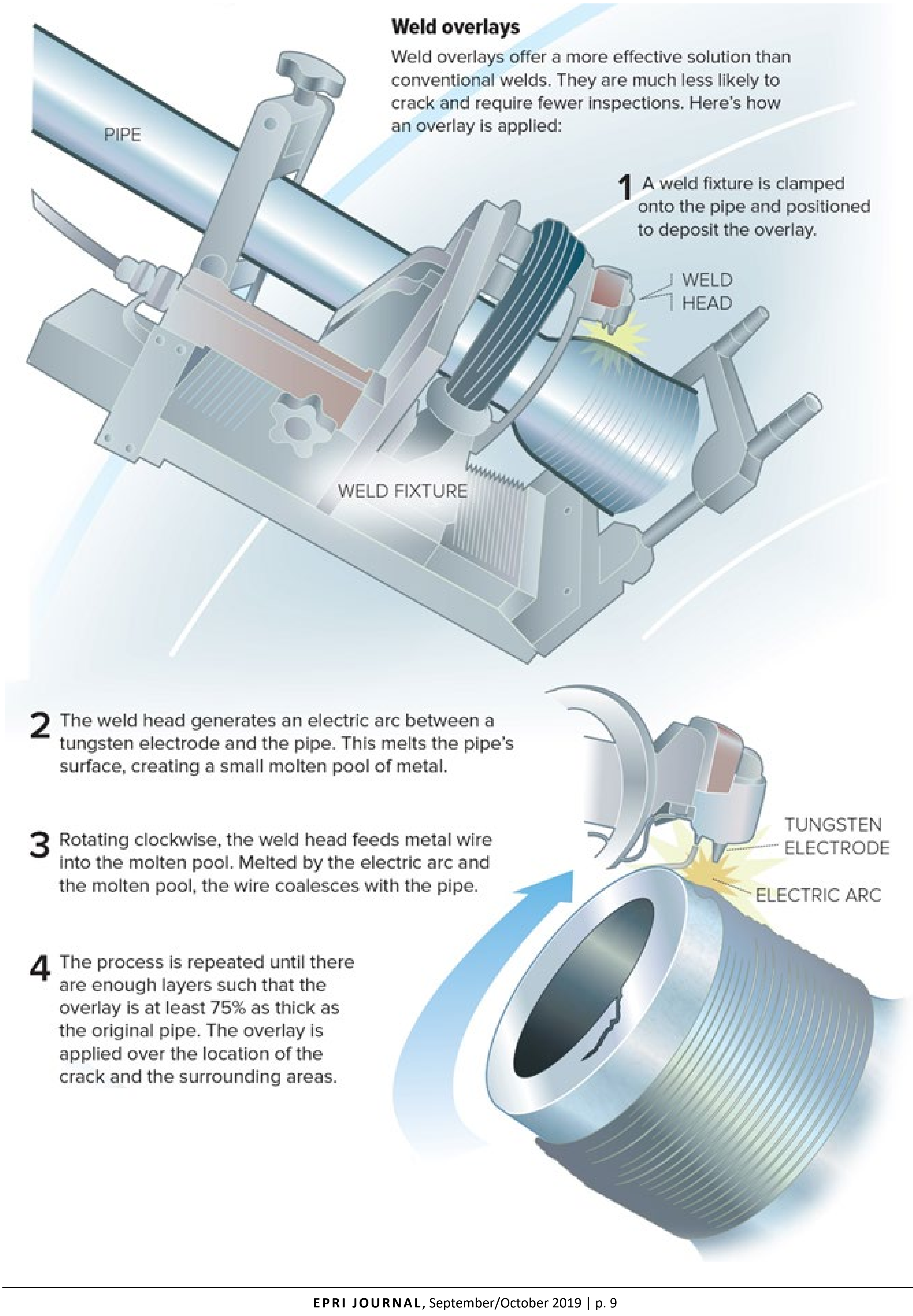
The second option—partially excavating the welds to remove the outer portion of the cracks and then re-welding—was done previously, but the stress corrosion cracks continued to grow.

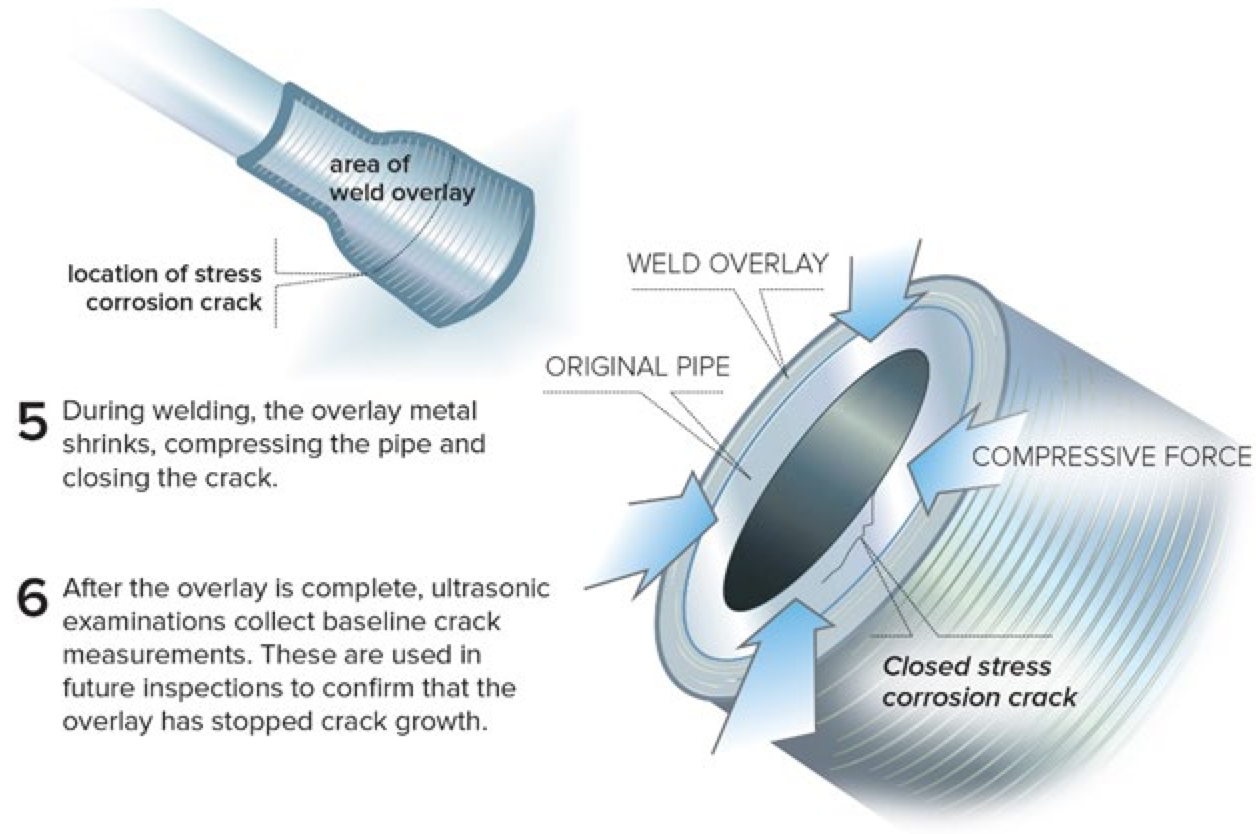
The third option was a structural weld overlay—one designed to add strength at the joint as well as stop crack growth. "This was entirely new ground," said McCracken. "Such an overlay had never been attempted on a WWER-440 reactor. Some Western European nuclear plants with designs similar to those in the U.S. fleet had recently applied overlays. But the materials and piping configurations in ČEZ's WWER reactors differ from plants in the U.S. and Western Europe. Its operators could not take full advantage of the knowledge and operating experience of those fleets."

Weld overlay technology: A superior fix

For years, nuclear power plants in the United States have used weld overlays to reinforce and strengthen pipes. EPRI supported the transfer of the overlay technology to the Czech Republic power company ČEZ.




Weld overlays
Weld overlays offer a more effective solution than conventional welds. They are much less likely to crack and require fewer inspections. Here's how an overlay is applied:
PIPE
1 A weld fixture is clamped onto the pipe and positioned to deposit the overlay.
WELD HEAD
WELD FIXTURE
2 The weld head generates an electric arc between a tungsten electrode and the pipe. This melts the pipe's surface, creating a small molten pool of metal.
3 Rotating clockwise, the weld head feeds metal wire into the molten pool. Melted by the electric arc and the molten pool, the wire coalesces with the pipe.
4 The process is repeated until there are enough layers such that the overlay is at least 75% as thick as the original pipe. The overlay is applied over the location of the crack and the surrounding areas.
TUNGSTEN ELECTRODE
ELECTRIC ARC



In 2016, a ČEZ team visited EPRI's Welding and Repair Technology Center and Nondestructive Evaluation Center in Charlotte (see box at end of article) and briefed EPRI researchers on the unique design and materials of the WWER-440 reactors. EPRI discussed the overlay technology and its three decades of U.S. experience and described the successful overlay installation in 2012 at KKL's Leibstadt Nuclear Power Plant in Switzerland.

"In 2017, we began intensive work to deploy the overlay technology to repair the welded joints of the super emergency feedwater pipes," said Palan. "We met with EPRI experts in Charlotte to establish a roadmap for the overlay application."

"ČEZ asked us to demonstrate a weld overlay on a mockup—a replica of the components with simulated cracks," said McCracken. "This involved acquiring a super emergency feedwater pipe and nozzle from a WWER nuclear plant in Germany that had never been put into service."

The mockup was shipped to Charlotte along with welding materials specific to WWER-440 reactors. "We introduced artificial flaws into the pipe welds and applied a weld overlay, demonstrating what ČEZ would be doing to repair cracking at the Dukovany units," said McCracken. Six ČEZ staff observed and participated.

These activities demonstrated the welding procedures and the associated nondestructive evaluation techniques. "Using the artificial flaws in the pipe, we demonstrated that the phased array ultrasonic examination procedures used to inspect overlays in the U.S. can be applied also to overlays fabricated with materials used for WWER reactors," said Flesner. "This enabled us to train the ČEZ staff to conduct the phased array examination. We provided them with guided practice and qualification testing for the procedures."

"ČEZ experts attended more than a month of training at EPRI's Charlotte office to perform nondestructive testing on weld overlays," said Palan.

The hands-on experience for ČEZ staff at the EPRI labs was critical to the success of this effort. "ČEZ staff acquired a comprehensive understanding of the procedures and techniques to move forward with weld overlays at their nuclear power plants," said McCracken. "The technology transfer also helped ČEZ provide the Czech Republic's nuclear regulators with the technical information needed for approval of the overlay technology."

"The technical support from EPRI's experts equipped us to defend the weld overlay technology with the State Office for Nuclear Safety," said Palan.

Another key aspect was the precision of the work. "I've been involved with welding mockups for more than two decades, and the precision of this mockup was the best I've ever seen," said McCracken. "We documented all the welding parameters, measured all the weld layers, built a map of the weld, and used all the data to validate a structural analysis model. ČEZ staff used the data to support regulatory approval."

In April 2018, ČEZ successfully installed a structural weld overlay on a dissimilar metal weld joining a super emergency feedwater pipe to a steam generator at Dukovany's Unit #2. "We appreciated the support provided on-site by Steve McCracken and Bret Flesner during the repair procedure," said Palan.

"ČEZ did all the right technical procedures in the right sequence," said McCracken. The overlay approach was accepted by ČEZ, the nuclear industry regulator, and two Czech inspection agencies.

A completed weld overlay at Dukovany Nuclear Power Station.

RADIATION REDUCTION AND EASE OF INSPECTION

In addition to providing structural integrity and controlling stress corrosion cracking, weld overlays can reduce radiation dose to workers. Before overlays were introduced in the United States, plant operators often addressed stress corrosion cracking by cutting and replacing pipe sections. "Whenever you breach the system like this, you have to drain it first, removing water's shielding effect on radiation," said McCracken. "Radiation exposure to workers can be 3–5 times higher when the system is drained. With overlays, you avoid the need to breach the system."

Pressurized water reactors have extremely thick pipes to handle pressures as high as 2,300 pounds per square inch. It's very expensive to cut and replace these pipes. Overlays provide an effective solution at a fraction of the time and cost. The majority of overlays in pressurized water reactors in the U.S. are now performed preemptively to reduce the likelihood of cracks in susceptible materials.

Overlays also can enhance inspection capabilities. The location and geometry of traditional welds often make them difficult to examine with ultrasonic and other inspection tools. Overlays can change the geometry to make weld configurations more accessible. "Overlays have made pipe welds more inspectable," said Flesner. "Since the overlay structurally replaces the weld underneath, you only have to examine the overlay, which offers a smooth surface you can scan along. You can use phased array ultrasonics to inspect the entire volume of the overlay."

NEXT STEPS

After the successful, first-of-its-kind structural weld overlay application at Dukovany Unit #2, ČEZ installed 7 more overlays on super emergency feedwater nozzles in other Dukovany units. "An additional 8 overlays are scheduled for Dukovany in 2019, with the remaining 8 scheduled for 2020," said McCracken.

"We believe the weld overlays installed in the Czech Republic represent a significant step toward further acceptance of this proven repair technology in Europe," said McCracken. "This is a great opportunity to showcase and transfer the technology."

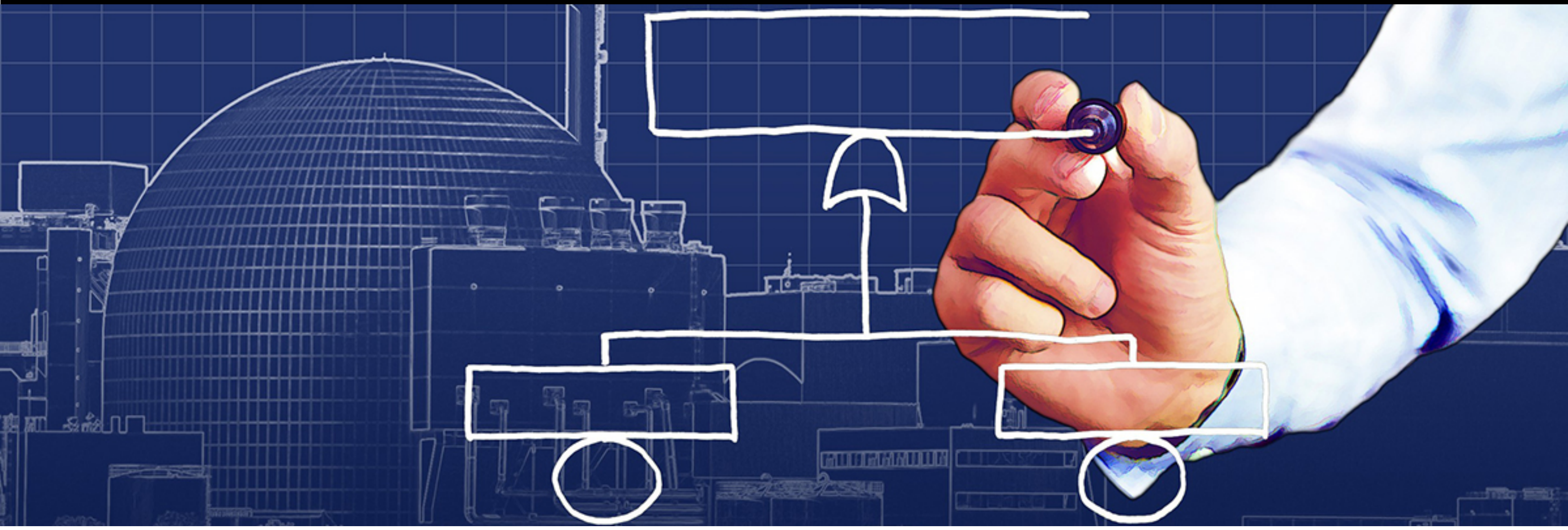
Two Critical Research Centers for Nuclear Plant Maintenance

EPRI's Welding and Repair Technology Center develops and tests advanced materials, welding, joining, and other repair technologies for nuclear plant applications. It supports technology transfer and safe, effective field implementation through guidance documents, training, and forums for information exchange. The center also provides technical input to code and regulatory entities to inform the development and modification of welding and joining requirements.

EPRI's Nondestructive Evaluation Center is among the world's leading facilities dedicated to developing and qualifying nondestructive evaluation techniques and equipment for the nuclear power industry. It promotes technology transfer by training technicians to work with these specialized techniques.

KEY EPRI TECHNICAL EXPERTS

Bret Flesner, Steve McCracken



Cultivating Expertise in Risk and Probability

EPRI Trains Nuclear Power Industry on How to Identify and Assess Risks That May Affect Plant Operations

By Chris Warren

When a nuclear power plant gets licensed, the regulator typically requires owners to demonstrate the plant's ability to withstand various design-basis accidents, such as a loss of coolant as a result of a pipe break or a loss of offsite power supply for critical equipment. Such events can create situations in which the plant is unable to maintain the nuclear fuel in a safe condition.

In the United States, these requirements are the foundation for the safe operation of the nation's nearly 100 reactors. It's an approach that begins during the design phase, long before a plant begins generating electricity. And it's an approach embraced by car and airplane manufacturers and other industries that require high levels of safety in engineering and construction.

"To establish engineering specifications for equipment, you need to consider the worst-case conditions and then establish the requirements for the equipment," said Kelli Voelsing, EPRI program manager for risk and safety management. "The design-basis accident approach does that and does it very well. It results in a very robust design."

Building Risk Expertise in Japan

Staff from all Japanese nuclear utilities have attended EPRI's six-week training on probabilistic risk assessment, a process to more effectively understand and incorporate risk into nuclear plant design and operation. "Our company has enhanced its risk-informed approach for plant operations and maintenance, and my vision is to engage every part of our nuclear business to implement this approach," said Mr. Masayuki Yamamoto, Deputy Chief Nuclear Officer of Tokyo Electric Power Company (TEPCO) and General Manager of the Nuclear Asset Management department. "EPRI has been supporting our efforts through probabilistic risk assessment courses and workshops, and I expect continued collaboration with EPRI to expand the benefits of a risk-informed approach."

Even the most robust designs, however, involve some level of risk when they encounter real-world conditions. To bolster the safety of the nuclear fleet, the U.S. industry in the 2000s supplemented its existing design-basis approach with a process known as *probabilistic risk assessment*, or PRA, to more effectively understand and incorporate risk into plant design and operation. EPRI has played a critical role in this effort.

"With PRA, we look at the entire range of things that could go wrong instead of just worst-case conditions," said Voelsing. "This draws on enormous amounts of data. For U.S. nuclear reactors, which have operated about 30 years on average, we have thousands of years of operational data. This data shows us, for example, the probability that an important backup pump will not start or will fail at random when it is needed to move water in response to an event at a plant."

PRA can enable nuclear power plant operators to identify and effectively respond to the most likely risks as well as provide sufficient protection for unlikely events. For example, one risk might be the loss of a plant's offsite power supply as a result of severe weather (such as a hurricane). Once operators identify and assess this risk, they might decide to shut down a plant in advance of extreme weather or prepare backup power sources to keep the plant safe.

PRA models can also provide insights about how scheduled equipment maintenance impacts the risk to a plant and about which human actions are most important to reduce risk. "Armed with these insights, operators can focus their training on the most important actions," said Voelsing.

Recognizing the need for consistent, effective PRA training, EPRI developed a course for nuclear plant operators in 2007. The six-week course, *Education of Risk Practitioners*, provides the knowledge to put PRA into action. It begins with an introduction to PRA and its major elements:

- Nuclear plant system analysis
- Initiating event analysis
- Event sequence analysis
- Success criteria
- Data analysis and statistics
- Human reliability analysis
- Quantification of risk and interpretation of results

Subsequent course modules provide detailed instruction about these elements, and students build their own PRA models based on a simplified plant. "They draw conclusions about the probabilities of their systems failing and about the combination of equipment failures that presents the highest risk," said Voelsing. "Students learn from each other by working together. They present their results to the class and discuss their ideas about how to model complex processes."

Over the past decade, the course has been taught to students from all U.S. nuclear utilities, as well as to participants from Japan, Korea, Canada, Mexico, Brazil, the United Kingdom, Spain, South Africa, and the United Arab Emirates.

The Fukushima Daiichi nuclear accident in 2011 provides an example of a series of events—an earthquake and subsequent tsunami—beyond those considered in the plant's design process. Since the accident, Japanese policymakers, regulators, and nuclear utilities have recognized the benefits that PRA can provide. In a 2017 strategic plan establishing how risk can inform decision making, the 11 Japanese nuclear utilities put it this way: "As a result of the Fukushima Daiichi accident, Japanese utilities have decided to face squarely the risks of nuclear power generation and started to improve their risk assessment and management capability."

To implement a risk-informed approach and realize the benefits of PRA, all Japanese nuclear utilities decided to send staff to EPRI's training. Since 2014, EPRI has led four 6-week courses in Japan, and more than 140 utility and regulatory staff have completed the training. In addition, all Japanese nuclear utilities have joined EPRI's Risk and Safety Management Program and have been using the program's research results to inform their post-Fukushima safety efforts.

Expertise in PRA will likely become even more important in Japan. The Japanese regulator and the Federation of Electric Power Companies, an industry trade group, have expressed their intent to adopt a risk-informed approach by 2020.

"Our company has enhanced its risk-informed approach for plant operations and maintenance, and my vision is to engage every part of our nuclear business to implement this approach," said Mr. Masayuki Yamamoto, Deputy Chief Nuclear Officer of Tokyo Electric Power Company (TEPCO) and General Manager of the Nuclear Asset Management department. "EPRI has been supporting our efforts through PRA courses and workshops, and I expect continued collaboration with EPRI to expand the benefits of a risk-informed approach."

KEY EPRI TECHNICAL EXPERTS

Kelli Voelsing

EPRI JOURNAL

Technology At Work

The Host with the Most

EPRI Tool Helps Utilities Assess 'Hosting Capacity' on Distribution Systems

By Chris Warren

Utility Innovation: Streamlining Solar Interconnection

New York investor-owned utilities are using EPRI's Distribution Resource Integration and Value Estimation (DRIVE) software to develop distribution system maps to indicate where it is less costly to interconnect distributed energy resources. "Now we can refer developers to the map, which may indicate that one feeder has the potential to handle six megawatts while another may be able to handle only one megawatt. This gives developers guidance on which locations may be better suited to proceed with an interconnection project," said Stephanie Genesee, associate engineer for electric distribution planning at Central Hudson. "We have received feedback from developers who say they use the maps and find them beneficial.".

It was crunch time for Central Hudson Gas & Electric. On March 9, 2017, the New York Public Service Commission required the Poughkeepsie-based power company (along with other investor-owned utilities in New York) to create publicly available maps showing the hosting capacity of all distribution system feeders operating at 12 kilovolts and above, with a deadline of October 1, 2017. The commission wanted to clearly identify for the public the locations that could more readily host distributed energy resources (DER) without adverse grid impacts. For Central Hudson, new stand-alone solar projects of 2–5 megawatts were considered most likely to have significant impacts.

Central Hudson and the other investor-owned utilities in New York joined with EPRI to develop the maps. Using EPRI's Distribution Resource Integration and Value Estimation (DRIVE) software, Central Hudson was able to calculate the hosting capacity of its approximately 230 distribution feeders operating at 12 kilovolts and above and completed the maps before the deadline. Released in 2016, DRIVE analyzes a distribution system's hosting capacity at specific locations on individual feeders and provides detailed information on DER's potential grid impacts, particularly related to grid reliability and power quality.

"Because New York's investor-owned utilities all use different power flow modeling tools, it would have been difficult to develop a standardized methodology to compute the hosting capacity," said Stephanie Genesee, associate engineer for electric distribution planning at Central Hudson. "We were pleased with the tool and grateful that EPRI was able to help us."

Since then, Central Hudson has used DRIVE to update the maps annually. This year, they will include information on smaller areas on feeders known as nodes. In fact, all New York investor-owned utilities are using DRIVE to develop distribution system maps to indicate where it should be less costly to interconnect DER.

"Using DRIVE to compute hosting capacity is straightforward, and I can quickly train new engineers to use the tool," said Genesee. "We also took the time to learn how the tool processes the data to better understand its functioning."

The maps make business more efficient for New York's solar developers as well. In the past, the utility was unable to provide applicants with insights on feeder hosting capacity without performing a detailed impact study. "Now we can refer developers to the map, which may indicate that one feeder has the potential to handle six megawatts while another may be able to handle only one megawatt. This gives developers guidance on which locations may be better suited to proceed with an interconnection project," said Genesee. "We have received feedback from developers who say they use the maps and find them beneficial."

FASTER INTERCONNECTION, INTEGRATION WITH OTHER UTILITY TOOLS

Historically, solar installers and developers across the United States seeking to build new systems have had to submit applications to the utility for extensive reviews.

"It's a time-consuming and expensive process," said EPRI Technical Leader Matthew Rylander.

DRIVE is helping to change this by enabling utilities to quickly provide an approximation of whether new DER interconnections would result in distribution grid problems. This capability is particularly important as more regulators seek to streamline DER integration. New York's Reforming the Energy Vision initiative aims to integrate DER into distribution planning and operations and includes a requirement that utilities identify where DER can best be accommodated. Regulators in Minnesota and California are pursuing similar efforts.

Through a feature called *Connect*, DRIVE helps utilities speed interconnection screening by linking to the utility websites that developers use to submit applications. The application data—including details on the size and type of DER—feed into DRIVE, which

New York's investor-owned utilities are using EPRI's DRIVE tool to develop distribution system maps to indicate where it should be less costly to interconnect solar. Photo courtesy of U.S. Department of Energy.

quickly determines if hosting capacity is available at the proposed location. “It will come back and indicate whether there is hosting capacity and how much,” said EPRI Senior Project Manager Lindsey Rogers. “If there’s no capacity, a utility engineer steps in and does a manual analysis to determine what upgrades are feasible, then contacts the developer who submitted the application.”

DRIVE can integrate data from other utility planning tools—such as power flow and generation of existing DER—to estimate potential voltage and thermal impacts of different sizes and types of additional DER at specific locations. “DRIVE was developed to work with different tools,” said Rylander. “Utilities have different distribution analysis software, and we wanted to create something that could work well on its own and with those tools.”

The tool can calculate hosting capacity feeder by feeder as well as location by location within a feeder—for current and future grid configurations. Utilities can use this capability to identify distribution system locations where DER can be interconnected without significant additional cost for infrastructure upgrades. This is valuable market information that can inform the planning of developers, regulators, and policymakers. Distribution planners can use DRIVE’s location-specific hosting capacity data along with load and DER deployment forecasts to assess necessary grid infrastructure upgrades.

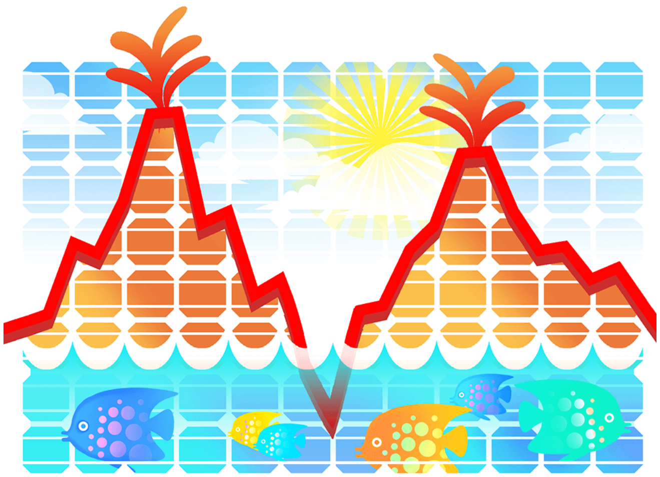
“DRIVE enables users to input various parameters such as whether energy resources are solar or wind, how rapid are output fluctuations, and what additional fault current will come out of the system,” said Rogers. “Based on these analyses, the tool can inform users on impacts from various resources.”

While today DRIVE is used primarily to assess hosting capacity and DER’s grid impacts, EPRI plans to incorporate features to help planners estimate the grid benefits and values of siting and integrating new DER.

KEY EPRI TECHNICAL EXPERTS

Matthew Rylander, Lindsey Rogers

Paying for Solar: Power *and* Grid Flexibility



According to an EPRI Quick Insights paper, a new approach for purchasing solar power generation in Hawaii offers potential to enhance grid flexibility while reducing financial risks for plant owners.

With many solar power purchase agreements (PPAs) today, utilities pay plant owners per kilowatt-hour of output, which can result in reduced payments for owners when the utility needs to curtail output for grid balancing.

As part of its plans for eight solar facilities totaling 275 megawatts coupled with battery energy storage, Hawaiian Electric has developed a new PPA structure in which it pays plant owners a monthly lump sum (regardless of energy output) in return for utility control. This enables the utility to dispatch the solar and storage as needed for flexible, reliable grid operations while reducing the owner's financial uncertainty associated with curtailment. The agreement also provides financial incentives to keep plants well-maintained and available for dispatch, based on performance metrics. If these are not met, the monthly payment is reduced. Six of the facilities have been approved by the Hawaii Public Utilities Commission.

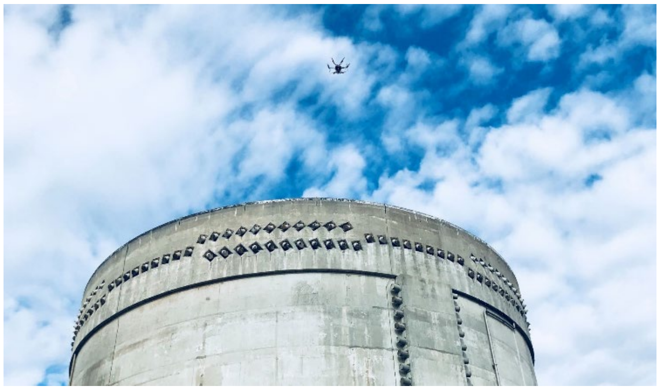
Hawaii's power prices are relatively high because the islands rely to a significant extent on imported petroleum for power generation. These solar-plus-storage projects are anticipated to decrease petroleum- and coal-based electricity consumption and stabilize prices for customers. The PPA prices (based on the lump sum payment divided by the plant's expected output) range from 8 to 12 cents per kilowatt-hour—significantly lower than the cost of fossil fuel generation on the islands (about 15 cents per kilowatt-hour).

"As solar and storage costs decline, the experience gained from these power plants and innovative PPA structures is likely to carry into other projects around the world," said Robin Bedilion, EPRI senior project manager and the paper's author. "We expect to see a continued shift toward novel PPA structures as renewables become larger contributors to the grid."

KEY EPRI TECHNICAL EXPERTS

Robin Bedilion

Flying Inspectors at Nuclear Plants



Drone-mounted technology can be used to inspect concrete structures at nuclear power plants with the same degree of accuracy as traditional inspection methods, an EPRI field demonstration showed.

Historically, when nuclear plant technicians inspect containment buildings, cooling towers, and other large concrete structures, they may use scaffolding, hanging platforms, or personnel baskets to gain access—or even rappel from the top. These approaches increase risk of worker injury. The use of drones can reduce risk, costs, and disruption of plant operations.

EPRI field-tested the use of drones equipped with various payloads to inspect a containment building at a nuclear plant in the United States. Inspectors used the drones to collect photos, thermal images, and videos, then analyzed them to locate areas of degradation. The results were compared with those from traditional visual inspections performed a few months earlier, and the accuracy of defect detection was comparable.

In a separate lab study of various camera systems, EPRI found that image sharpness varied widely, pointing to the importance of considering specific inspection needs when selecting a drone.

In related research, EPRI is investigating:

- Automated drone flight paths for recurring nuclear plant inspections
- Drone payloads such as thermal sensors, microwave transducers, and radiation detectors to provide more information on nuclear plant conditions
- Automated analysis of data from drone inspections to provide actionable insights on plant maintenance needs

KEY EPRI TECHNICAL EXPERTS

Sam Johnson, Tony Cinson

EPRI JOURNAL

R&D Quick Hits

How Much Renewable Energy Can a Power Transmission System Accommodate?

A new EPRI tool can help utilities answer this question.

Transmission planning increasingly is driven by needs associated with grid-connected variable renewable energy resources. Transmission infrastructure, particularly in remote areas suitable for large wind and solar capacity, may nevertheless be limited with respect to the amount of new generation that can be accommodated without exceeding thermal or voltage limits.

EPRI's Transmission Hosting Capacity Tool builds on similar EPRI software for distribution systems. It enables utilities to screen various scenarios for generation, load, dispatch, and grid conditions and to gauge where and how new generation could impact the system's thermal and voltage performance. The tool can inform utility decisions on grid upgrades and optimal locations for renewables, although it's not intended to replace detailed system impact studies necessary for investment decisions.

In 2018, EPRI and Salt River Project (SRP) tested the tool on the utility's transmission system. They determined that it provides a useful "first cut" in assessing the maximum renewable generation that can be accommodated without system upgrades. By automating the analysis, the tool enabled substantial savings in work hours.

"EPRI's newly developed Transmission Hosting Capacity Tool has allowed SRP to easily understand how the development of solar photovoltaic resources will impact transmission system reliability," said Justin Lee, SRP manager of transmission system planning. "The work done by this team allowed SRP to demonstrate the tool in a real-world environment, showing how this new automatic assessment capability can benefit system planning."

EPRI plans to test the tool with other utilities to develop its application to larger systems.

KEY EPRI TECHNICAL EXPERTS

Vikas Singhvi, Deepak Ramasubramanian

ELECTRIC POWER RESEARCH INSTITUTE

The Electric Power Research Institute, Inc. (EPRI, www.epri.com) conducts research and development relating to the generation, delivery and use of electricity for the benefit of the public. An independent, nonprofit organization, EPRI brings together its scientists and engineers as well as experts from academia and industry to help address challenges in electricity, including reliability, efficiency, affordability, health, safety and the environment. EPRI also provides technology, policy and economic analyses to drive long-range research and development planning, and supports research in emerging technologies. EPRI members represent 90% of the electricity generated and delivered in the United States with international participation extending to 40 countries. EPRI's principal offices and laboratories are located in Palo Alto, Calif.; Charlotte, N.C.; Knoxville, Tenn.; Dallas, Texas; Lenox, Mass., and Washington, District of Columbia.

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