Summary of Presentations
EPRI Advanced Cooling Technology Workshop

July 8-9, 2008
Charlotte, North Carolina

Introduction

Water availability has become a paramount issue for utilities operating and planning new generation. The need to develop and deploy technologies and strategies to increase power plant water use efficiency, decrease the consumptive use of water, and apply watershed management tools has become more and more important. EPRI conducted a two-day workshop for its members and industry organizations to discuss and identify the research, development and demonstration (RD&D) opportunities and needs to enable the deployment of advanced thermoelectric cooling technologies.

Dr. Joe Turnage, vice president of Unistar Nuclear, opened the workshop by summing up the concerns of many of the more than 100 participants representing more than 40 companies and organizations. He noted they are under increasing pressure to reduce water consumption at electricity generating stations, not only due to regional droughts and growing demand from other water users, but also due to pressures from power plant opponents and the general public.

Turnage talked about how policy issues surrounding water scarcity and the requirements for electricity generation are becoming more and more tightly interconnected. Both existing and proposed new generation units are affected, he said, with the most serious challenges facing new nuclear plants. New technologies are needed, focused on improving the performance and lowering the costs of both current and new cooling options.

Turnage said that agricultural consumption might lead to one of several new cooling options – wastewater and runoff that is not otherwise usable due to pesticides and other chemicals. "As you think about advanced cooling technologies, I would encourage you to not just think about power plants, but also new complexes involving synergies between agriculture, water, land, transmission and other energy centers," he said. "We need to think in new ways about the infrastructure surrounding these new technologies."

The Energy-Water Nexus

Mike Hightower of Sandia National Laboratories led off this session with a presentation on U.S. issues and challenges. Hightower is one of the leaders of a U.S. Department of Energy project to develop a science and technology roadmap for energy and water R&D.

He noted that competition for water resources is expected to increase rapidly in the next two decades. Increased electricity demand overall, combined with alternative fuels production, could more than triple water use for energy production by 2025. (More background information on the interdependency of energy and water issues is available at www. sandia.gov/energy-water).

"We're also seeing a lot of emphasis in the future on water treatment, water distribution, moving water around, and the energy it takes to do that," Hightower said. "About half of the water withdrawn on a daily basis in the U.S. is for energy development – electric power and transportation fuels production. Energy accounts for about 27 percent of all fresh water consumption.

"When you look at the expected growth in energy production over the long term, can we do business as usual, as we have done in the last 30 years? We need to look at what the water availability will be, and at some non-traditional resources. We haven't built any major dams in the United States since the 1980s; because of that, if you look at the trends in water withdrawals, we're essentially at capacity and have been since about 1980. There are no new fresh water resources available."

A recent heat wave and drought in France resulted in a loss of 7 to 15 percent of available nuclear power and as much as 20 percent of the hydropower, Hightower said. "This is the issue we're beginning to see … and the way they handled it was, they shut off power transmission to Italy. Then you start thinking about how the Southwest and Northwest are major energy suppliers to California, how the Southeast is a major energy supplier to the Eastern U.S. … and you wonder if we're going to have those kinds of problems. People are going to want to keep their water resources, and the power that's generated with it, in their own areas.

"This is not just a U.S. issue," he added. "It's becoming a big concern internationally as well. People are trying to figure out how you handle the tradeoff between the needs for power and the needs for water, and how that affects economic development. You need water for growth, but you can't have growth without power."

Hightower said recent regional workshops highlighted several needs:

- Better resource planning and management, especially in infrastructure
- Improved water and energy use efficiency
- Development of alternative water resources

"If it looks wet, we're probably going to have to look at it as a resource," he said. "According to current projections, we are going to go from (using) about 6 billion gallons of water a day in the U.S. … to anywhere from 8 to 11 billion gallons with carbon sequestration. And production of biofuels is anywhere from 3 to 5 times more water-intensive than traditional fuels."

Eric Evanson of the U.S. Geologic Survey talked about the proposed "Water for America Initiative," a 10-year project to assess U.S. water availability and develop tools for water management. The last major assessment of national water resources was in 1978. The initiative will cost an estimated $9.5 million per year and include data from 21 water resource regions.

Living with the Issue

This session addressed a range of water availability, water quality, and potential climate change-related impacts on power plant operations. Sujoy Roy with Tetra Tech summarized some findings of a national assessment of water availability, focused on whether or not water sustainability can be evaluated on a national scale. Using a multi-variable analysis that considers population trends, precipitation data, water use and electricity generation projections, the national assessment can provide county-level mapping of various metrics of water impacts and use, such as freshwater withdrawal divided by precipitation. The assessment also enables county-level comparisons of water use trends in a business-as-usual scenario versus an improved-efficiency scenario. Tetra Tech is developing a water sustainability index to capture the effects of various forces in one metric.

Bill Mills with Tetra Tech discussed the potential impacts of climate change on water resources and implications for power plant operations. Water issues can impact siting, in terms of water availability and flooding susceptibility; cooling system design and operation, through required water flow rates and turbidity; and power plant generation, through water temperature increases that can reduce output. Because water issues are predominantly local or regional in nature, global climate models need much finer resolution to enable more effective local analyses.

Terry Cheek with Geosyntec discussed water-related impacts at several southeastern power plants in recent years and the actions taken to mitigate impacts. At Plant Branch, thermal discharge from the once-through-cooled facility in the 1990s was implicated in number of fish kills. To reduce heat load impacts, the plant installed conventional mechanical draft, counterflow cooling towers in 2002. The towers, which only are operational in the summer months, helped avoid the need for a fully closed loop cooling system.

At Plants Yates and McDonough, the water discharge couldn’t achieve the 90F requirement, plus dissolved oxygen levels in the Chattahoochee River dropped below regulated levels. In response to a consent order, the plants performed thermal impact modeling, which indicated that the assimilative capacity of the river had been reached. While reduced heat load would provide some benefit, closed loop cooling was required at each. Cooling towers entered operation at Yates in 2004, and at McDonough in 2008. At Plant Hammond, thermal impacts on the assimilative capacity of the river, coupled with record lower water flows in 2007, compelled the installation of portable cooling towers.

Dan Casiraro with the Salt River Project described the zero liquid discharge (ZLD) system at the Navajo Generating Station, which has been in use since the plant opened in

1974. “ZLD systems are gaining interest because of water constraints, NPDES permitting difficulties, discharge liability issues, and air quality issues,” said Casiraro.

Casiraro said that while the systems definitely work, there are many considerations:

- Cost: A brine concentrator can cost $2 to $5 per thousand gallons, so it’s advisable to “look at other options first;” and crystallizer costs are about 10 times those of brine concentrators.
- Design: Concentrators and crystallizers can be arranged in many configurations, so find the best one for your plant, said Casiraro.
- Operations and Maintenance: Brine concentrators and crystallizers do what they’re supposed to do, but they are difficult to maintain, particularly in terms of corrosion, which places great importance on materials of construction. Solids disposal also is a concern because it can be regarded as hazardous.

Operating Plant Challenges and Solutions

Bob Lotts with Arizona Public Service described Palo Verde’s unique position as the only nuclear plant in the world not located on a large body of water. The plant uses 100% reclaimed water for cooling from Phoenix, Scottsdale, Glendale, and surrounding cities. The plant has a 90 MGD water treatment facility on site to treat the reclaimed “gray” water. Lotts discussed a number of considerations in using gray water, including source water, water transport, treatment plant, storage reservoirs, solids disposal, and environmental issues. For example, adequate feed storage capacity is required to accommodate plant outages, and piping redundancy is needed in case certain pipes are out of service.

Kent Zammit with EPRI profiled the use of brackish water as makeup for the cooling towers at Jacksonville Electric Authority’s St. John’s Power Plant. Concrete corrosion and spalling in the cooling tower structure due to chlorine migration compelled JEA to implement a cathodic protection system that would redirect the corrosion away from the rebar steel in the concrete. Removal of loose material began in February 2008. As part of the LifeJacket system, a zinc mesh overlay was installed to serve as the sacrificial anode. Lessons learned from the application include:

- Careful control over original concrete specifications to ensure it can withstand brackish water quality;
- Use of a dense mix concrete with additives, plus a cathodic protection system;
- Tower internals construction using high-grade alloy steel rather than fiberglass;
- Use of biocides other than chlorine; and easy access to internals.

Consultant Mike DiFilippo described the use of saline groundwater at the Mountain View Combined-Cycle Plant. The plant uses a combination of reclaimed/treated municipal effluent water and contaminated saline groundwater. The saline groundwater is contaminated with perchlorate from rocket research activities. Perchlorate is a very stable compound that can’t be reduced chemically and typically passes completely through the plant. Careful operation and monitoring of the treatment plant is important, DiFilippo said, because the plant is limited in the amount of water it can discharge.

Preparing for a Water-Constained Future

Duke Power's Bob Mohr talked about the challenges of siting two new AP1000 nuclear units with mechanical draft wet cooling towers at Duke's Lee Station in South Carolina. Because the design already has been certified, newer technologies aren't considered an option. And the site presented some water resource issues, such as limited space and available flow in the Broad River, and limited effectiveness of existing technologies during hot weather.

Duke "did a lot more than is typical during the design phase to determine the consumptive water use," Mohr said. That included incorporating design information from Westinghouse, operating experiences from the Catwaba Nuclear Station, data from the Cliffside Station, and cooling tower software models. The result was a plan to limit downstream impacts during low water conditions by supplementing or replacing river withdrawals with water from on-site impoundments.

Mick Greeson of Progress Energy Carolinas said his company came up with a different solution for providing cooling water for the two new AP 1000 nuclear units in its expansion of the Harris Plant near Raleigh. To provide water for the proposed wet hyperbolic natural draft cooling towers, Progress Energy plans to raise the level of nearby Lake Harris by 20 feet and build a new intake from the Cape Fear River.

David Lee of We Energies (WEC) talked about his company's recent experience in seeking approvals for new coal-fired plants at its Oak Creek Power Plant (OCPP), adjacent to Lake Michigan in Wisconsin. The plant already has four units with a combined capacity of about 1,140 MW. WEC is building two 615-MW advanced coal units, expected to go into service in 2009 and 2010. WEC was able to permit a once-through cooling system, which offers thermal efficiency, low emissions (including CO_2, as less coal is used per MW), reduced costs and eliminates the need for cooling towers. To obtain this permit, WEC had to demonstrate that it could obtain fish protection performance equivalent to using wet cooling towers by tunneling out to an offshore intake and installing wedgewire screens.

During a vendor technology overview, Peter Demakos of Niagara Blower Company discussed the advantages of closed-loop evaporative coolers, also known as wet surface air coolers (WSACs). He compared them to other heat transfer technologies and said they provide the lowest outlet temperatures and impose lower parasitic loads, which results in reduced carbon emissions. They also can use poor-quality water and serve as a first-stage evaporator upstream of ZLD systems.

Dr. Luc Debacher of GEA Power Cooling Systems shared information about hybrid cooling systems and air-cooled condensers. Tom Dendy of SPX Thermal Equipment & Services provided an update on a long-term project, partially funded by the DOE, researching the Air2Air™ technology for recovering fresh water from power plant evaporative cooling systems. Dendy said the technology could reduce water consumption by 10 to 25 percent and also has possible application for water purification, desalination and cooling tower plume reduction. He said the performance of a test unit at the San Juan Generating Station in New Mexico, which began operation in December 2007, is exceeding expectations. Testing is to be completed in 2009.

The Heller indirect dry cooling system was the subject of a presentation by András Balough and Zoltán Szabó of GEA EGI. They said the natural draft system, which uses stack-in-tower or FGD-in-tower units, offers emissions and economic advantages over many wet cooling systems. Some case studies also have shown the addition of a Heller system can extend the operating viability of existing wet-cooled plants.

Technology Solutions Being Proposed Today

John Waddill shared Dominion's experience in selecting a cooling technology for its proposed North Anna Unit 3 nuclear plant. Although the existing two units use once-through cooling technology, low lake levels in recent years forced consideration of alternatives for Unit 3. Unit 3 originally was designed as a once-through unit, just like Units 1 and 2, but the state of Virginia determined that the water impact would be too great, particularly in light of low lake levels in recent years. Dominion compared closed-cycle conventional cooling with a hybrid wet/dry system in two modes: energy conservation and water conservation. While closed-cycle cooling would address thermal discharge issues, it would increase water use. The wet/dry hybrid system, on the other hand, could address both issues.

In the energy conservation mode, if the lake level is at "full pond" (250 feet), the dry portion of the hybrid system can be turned off, with all cooling accomplished with the wet hybrid towers. In the water conservation mode, if the water level falls below 250, the dry towers are turned on to save water. While the hybrid system clearly is more expensive than the once-through system, it will enable North Anna to continue operating during severe drought conditions with a reduced impact on water use. "When you really need to save water, the system performs," said Waddill. "We should be able to achieve a 70 percent reduction in water use in the water conservation mode."

Steve Scroggs described the evaluation process under way at Florida Power & Light (FPL) to select a water source for the two proposed nuclear reactors at the Turkey Point facility in south Florida. Although the site is surrounded by water, there are limited water supply options. The two new units will need up to 130 MGD of water if saline source is selected, and somewhat less if a higher-quality source was available. Existing Turkey Point nuclear units 3 and 4 originally were supposed to use open-loop cooling from Biscayne Bay. Because of thermal discharge concerns, however, the plant changed to a closed-loop cooling canal system (12 square miles). "While this was a good environmental solution back in 1970, it's evolved into a bad solution today," said Scroggs. The state wants to recover all agricultural lands into wetlands and restore the natural flow to Biscayne Bay. FPL is considering three source options:

- Gray reclaimed municipal effluent from Miami-Dade County, which produces about 350 MGD (250 MGD of which currently goes to an outfall, 100 MGD to deepwell injection). The Florida legislature has passed a law outlawing use of outfalls for wastewater disposal.
- Saline groundwater 2500-3000 feet directly below plant. Stable supply and relatively low temperature (hi 60s/low 70s).
- Saline marine water from Card Sound of Biscayne Bay.

Review of EPRI Research

Consultant John Maulbetsch began the second day of sessions with a presentation on key research advances and opportunities related to power plant cooling. “While there are things that can be done to use less water, they usually cost more, use more power, and hurt plant performance,” said Maulbetsch. Determining absolute costs of cooling are elusive because they’re changing very fast; ratios can provide better perspective, but are tricky to develop. Capital cost ratios comparing dry systems to wet systems are in range of 3.0-3.5. On an annualized cost basis, ratios are in the range of 3-4 for a water cost of $1 per thousand gallons, but if the cost of water is doubled, the cost ratios approach 1. “The bottom line is that the cost differences are still big,” said Maulbetsch, “and one of the jokers in the deck is how much water costs.”

Because retrofit of once-through to closed-loop cooling is extremely expensive, there is a large window available for alternatives that can reduce entrainment/impingement in ways other than converting to closed-cycle cooling. “Utilities can spend an awful lot of money on some type of intake protection device that will meet regulatory requirements and potentially cost considerably less than closed-cycle retrofits,” said Maulbetsch. One research opportunity for wet cooling towers is lowering auxiliary power requirements by changing the delivery location to the cooling tower with respect to the rain zone to reduce pumping head. For air-cooled condensers, research opportunities include finned tube surfaces with higher heat transfer and lower pressure drop (such as perforated fins), and modified air flow patters to mitigate wind effects. For hybrid systems, all of the things done to improve air-cooled condensers and wet cooling towers also will accrue to the benefit of the hybrid system, but incremental gains might be available through novel configurations and the allocation of water over the course of the year.

Non-traditional water sources provide a promising water-saving alternative in certain cases. Sujoy Roy with Tetra Tech described general guidelines for performing a quick assessment of non-traditional sources of water, including treated wastewater, agricultural drain water, saline groundwater, produced water from oil and gas operations, industrial waste streams, and water from mining operations. Factors that must be incorporated into such an assessment include water quality, water quantity, treatment system, water transport, water acquisition/contracting, and regulatory concerns. A key point to keep in mind is that non-traditional water sources are not free; there is a cost associated with acquiring them.

Consultant Mike DeFillipo described a study performed by the San Juan Power Plant in New Mexico to examine the viability of using water produced from oil production operations to supplement cooling water makeup. For every barrel of oil, 8-10 barrels of water are produced, but this water is dispersed. Collecting and transporting the water to a central location can be cost and labor-intensive. The study determined that significant produced water could be acquired from New Mexico oil production, but an economic analysis revealed that it would cost about $75 million in 2004 dollars for the treatment system, delivery network and additional infrastructure.

Air-Cooled Condenser Research

EPRI's Chuck McGowin discussed how wind effects challenge the operation of air-cooled condensers. Tests at the Bighorn Plant (a natural gas combined-cycle plant in Nevada) analyzed two main factors: recirculation on leeward (trailing) cells, and fan performance degradation on windward (leading) cells. The test results and broader experience indicate that recirculation is not as impactful as fan performance degradation. Mitigation options include installing a skirt around the air-cooled condenser to reduce air separation and provide more uniform velocity through the fan. Wind screens also can be installed below the wind deck to reduce the effect of gusty winds. Anecdotal information says they can help smooth effects of gusts.

Ongoing Research and Future Opportunities

Barbara Carney led off with a discussion of the DOE/NETL's Power Plant-Water R&D program. A recent DOE/NETL analysis suggests that in 2005, the thermoelectric power sector used 3.3 billion gallons per day of freshwater. The DOE's Energy Information Agency (EIA) projects that freshwater consumption will increase through 2030, despite retirement and replacement of older cooling systems with new recirculating technologies, due to increased production and demands of CO_2 capture.

Carney said the power generation accounts for about 39 percent of total U.S. daily freshwater withdrawals, about the same as is used for irrigation, but only about 2 percent of the consumption. In the existing coal-fired fleet, 48 percent of plants use wet cooling, 39 percent use a once-through system, 13 percent use a cooling pond and less than 1 percent have dry cooling systems. A 500-MW pulverized coal (PC) plant with once-through cooling uses about 456 million gallons per day (mgd), as compared to wet cooling towers on PC (13 mgd), IGCC (10 mgd) and NGCC (6 mgd).

DOE/NETL's Innovations for Existing Plants Program includes R&D into minimizing the impact of fossil-fueled power generation on freshwater resources and quality. The program includes research into advanced cooling, water recovery and re-use, use of non-traditional water, and advanced water treatment and detection. The goal of the program is to reduce withdrawal and consumption of freshwater for thermoelectric power generation and to minimize the impact of coal-fired generation on water quality. More information about NETL's Energy-Water R&D is available at http://www.netl.doe.gov/technologies/coalpower/ewr/water/index.html

Franck David of EdF talked about 1980s research on dry cooling systems conducted by EdF and EPRI, including a 22-MWe CYBIAM (binary cycle with ammonia) bottoming-cycle project. The aim of the R&D was to reduce turbine size by creating steam with a more dense vapor in the lowest pressure stages. It offered the advantages of increased power supply and dry cooling, and the technology appeared promising. But market conditions changed, other technologies appeared, and the technology never was scaled up. David said the CYBIAM mockup has been dismantled and technical know-how has partially disappeared. However, the experiments are well-documented, and with today's greater interest in new cooling methods, the concept could be viable again.

EPRI's Ron Schoff detailed the water demands of advanced coal plants. He noted traditional pulverized coal plants use about 800 gallons per megawatt-hour produced, while supercritical and ultrasupercritical plants use about 600 gallons and new IGCC plants are expected to use about 400 gallons. In plants using CO_2 capture technologies, flue gas needs to be cooled prior to capture, which normally results in installation of a direct contact cooler, and additional cooling demand is imposed by the capture system, primarily for solvent cooling. Water use overall is much higher than in non-capture plants due to high levels of power loss. Actual water use might go up 10 to 20 percent.

NREL's Dr. Chuck Kutscher discussed studies on improving the cooling of geothermal power plants and on reducing water consumption in concentrating solar plants (CSPs). He talked about work at the Mammoth Lakes Geothermal Power Plant on use of evaporative pre-cooling of air-cooled condensers, to boost power output on hot summer days. Kutscher said hybrid, parallel cooling systems show promise for reducing water consumption (compared to a water-cooled plant) with modest performance penalties on CSPs. "Renewables are going to be an important part of our energy future," Kutscher said. "If you've been waiting for renewables to take off, stop waiting. And many of them will have their own impacts on water and cooling."

Mike Hightower of Sandia National Laboratories reviewed research trends in desalination and treatment of wastewater, brackish groundwater, and seawater for domestic and industrial applications. Use of these resources is growing at about 10 to 15 percent a year, he said.

Conclusions

EPRI's Chuck McGowin and Kent Zammit wrapped up the workshop with a discussion and question-and-answer session on EPRI's Advanced Cooling Technology Roadmap. A number of the workshop participants had offered their views on R&D projects and priorities in a presentation at dinner the previous evening. Now, after hearing a second day of information, there was more to discuss.

The objectives of the EPRI research are to reduce the environmental impacts of once-through cooling; increase the performance and reduce water consumption of existing and new wet cooling systems; reduce the capital and operating costs of cooling systems; and develop advanced cooling technology using bottoming cycles for the next generation of power plants.

The once-through cooling research focuses on measures to reduce impingement and entrainment: barrier nets; fish impingement, capture and return; subsurface water intakes, flow reduction, and fish-friendly hydro turbine designs.

For closed-cycle wet cooling, the emphasis is on reducing freshwater and power consumption and use of degraded water for tower makeup. Research includes water recovery from cooling tower plumes; tradeoffs between degraded water treatment and cooling tower design; and rain zone head recovery and environmental effects reduction. For natural-draft cooling towers, the primary research focuses on re-establishing design and cost basis through a review of international data.

The research for closed-cycle dry cooling is on improved fin designs and wind tolerance for air-cooled condensers. The scope includes review of compact heat exchanger data and preliminary fin design analyses; attached and detached wind barriers; forced-draft fan design modifications; and wind-enhanced designs for air-cooled condensers. Additional work on spray enhancement of dry systems will concentrate on advanced spray/mist generators to improve water use efficiency.

Hybrid systems of all types (parallel, series, direct and indirect) will benefit from the advances made for the wet and dry systems. In addition, research will focus on the development of rigorous design and operating algorithms and guidelines for system selection and optimization.