Construction of the Olkiluoto Unit 3 nuclear power plant in Finland. (Photo courtesy of TVO.)

Welding for New Nuclear Power Plants: Building on Experience

Lessons learned from the existing fleet of nuclear plants provide the foundation for new welding guidelines aimed at reducing the risk of degradation mechanisms

BY STEVE McCRACKEN, ERIC WILLIS, AND JEFFREY HAMEL

Pressures to meet the growing demand for reliable, around-the-clock electricity and to reduce greenhouse gas emissions have revived interest in nuclear power in the United States. Several U.S. utilities are actively planning to build advanced nuclear power plants, and these plants could come on line by 2016 or 2017. The Nuclear Regulatory Commission has received 17 applications to build 26 new U.S. nuclear reactors and expects applications for up to 7 more reactors by the end of 2010.

A key reason for the renewed interest in construction of new nuclear plants is the existing nuclear fleet's strong record of safe and reliable operation. In 2008, for example, U.S. nuclear power plants achieved an average 91% capacity factor, which indicates that plants were on line and generating electricity more than nine out of every ten hours.

The welding community has contributed to this commendable fleet performance through technically sound welding practices supported by stringent engineering codes and standards, and will continue to contribute to the success of the next generation of nuclear plants. High-quality, reliable welds are critical to safe nuclear plant operation. Because of the safety significance of welds in many critical systems, structures, and components, the nuclear power industry must be confident in the quality and integrity of welded joints.

The next generation of nuclear power plants will likely have a design life of 60 years or more. Improved welding and fabrication practices will be essential in achieving this increased life expectancy and minimizing the potential for unexpected and costly repairs and maintenance.

To ensure the reliability and longevity of future nuclear plants, the Electric Power Research Institute (EPRI) is working with utilities and equipment manufacturers to develop welding and fabrication "best practice" guidelines for new nuclear plant construction. Such guidelines will equip the welding community and utility engineers with practical tools for identifying and implementing the most efficient, timely, and cost-effective methods to reduce the risk of degradation mechanisms such as stress corrosion cracking.

As an independent, nonprofit research and development organization, EPRI

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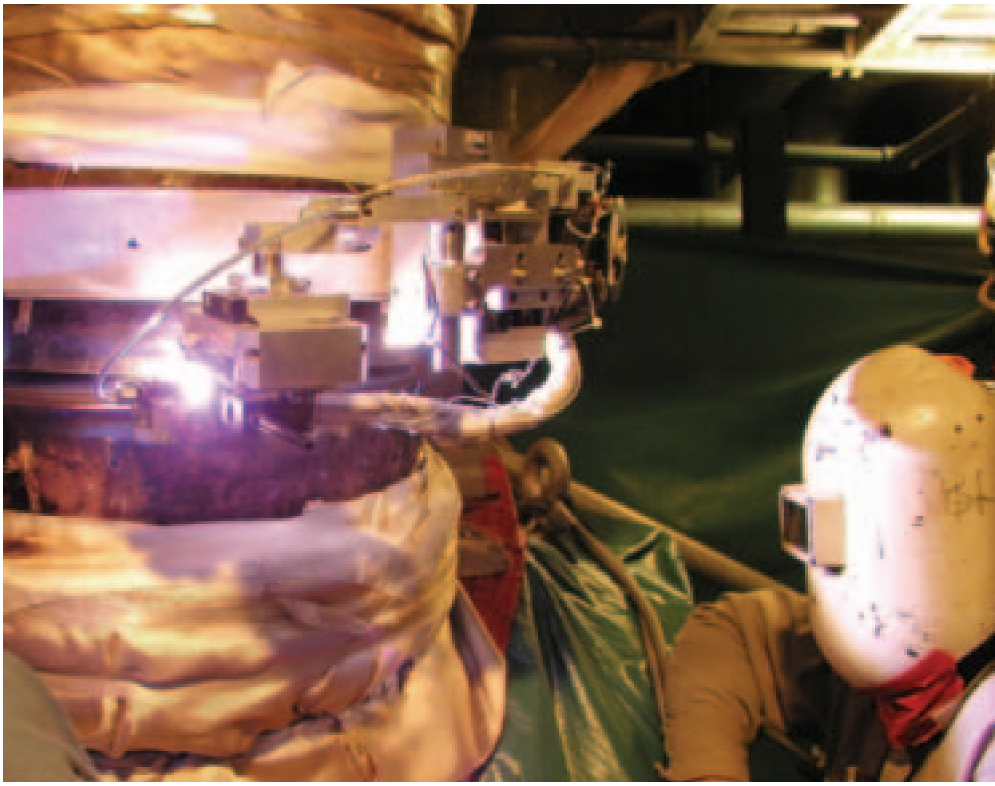

Machine gas tunsten arc welding of a closure joint on a 14-in.-diameter pipe.

Machine gas tungsten arc welding of a pipe-to-nozzle joint.

Vessel head clad welding.

does not attempt to advocate or dictate any particular process for reducing the risks inherent in welding and fabrication practices. Rather, the Welding and Fabrication Best Practices project aims to provide multiple ways of achieving risk-reduction goals, so users can choose among several options and select the most practical or cost-effective approach in a given situation.

The ongoing project includes the following key steps:

- Evaluate welding and fabrication practices in operating plants to identify lessons learned
- Identify the relative susceptibility of critical welds in new nuclear plant designs to known degradation mechanisms
- Develop a systematic process that identifies the key factors influencing the susceptibility of high-risk welds to degradation mechanisms
- Provide recommendations for reducing the propensity of welds to degradation mechanisms.

Learning from Experience

The 104 nuclear generating units now operating in the United States offer a wealth of information about welding and fabrication practices, materials failure, and component degradation. The lessons learned from the existing nuclear fleet can help the industry identify practices that contribute to failures, and apply improved practices to increase the reliability and extend the life of new nuclear plants.

In 2008, as a first step in the best practices project, EPRI assembled a team of welding and fabrication experts to survey welding and fabrication practices in nuclear plants and in other industries. The survey team reviewed and documented practices that contributed, or could contribute, to the premature failure of critical components.

The researchers confirmed that most material failures in operating plants occur in or near welds. Root cause evaluations showed that many of these failures resulted from less than optimum welding, fabrication, or surface-conditioning practices. For example, residual stresses induced by welding and uncontrolled grinding on reactor coolant piping are known contributors to stress corrosion cracking. Weld repairs in particular can induce high weld residual stresses that increase susceptibility to cracking mechanisms. However, optimized welding and fabrication processes along with properly controlled repair practices can reduce susceptibility to known cracking mechanisms.

Closing the Gaps

Operating experience from the current fleet of nuclear power plants can be analyzed to identify and manage materials performance issues for advanced light water reactor designs currently being considered for new nuclear power plants. In many cases, evaluation of operating plant issues and implementation of mitigation or management technologies can significantly reduce operating costs over the life of these new plants. Potential benefits include prevention of degraded conditions, more efficient and accurate inspections, and reductions in repair and replacement costs.

The EPRI Advanced Nuclear Technology Program has initiated a materials management matrix (MMM) initiative to meet this need. Among the key gaps identified through the MMM initiative is that currently there are no industry guidelines for new nuclear power plants plant fabrication and construction that identify practices that influence (positively or negatively) susceptibility to known degradation mechanisms.

Practical Information and Guidance

Building on the information matrix, the project team will meet with the original equipment manufacturer (OEM) for each new reactor design to review and document welding and fabrication practices. The team will then identify critical welds and assign a relative risk ranking to a known degradation mechanism. The risk ranking considers the influence of welding, machining, repair, and mitigation processes identified by the OEM and considers weld material, system service conditions, and operating experience. This information will be compiled in a Welding and Fabrication Addenda to the MMM for each new reactor design.

The team will also determine the welding, machining, repair, and mitigation factors that influence degradation mechanisms for specific materials. This information will be evaluated and documented in a Welding and Fabrication Critical Factors document. Utility engineers can use this report to identify specific processes or process parameters that can be implemented to reduce the identified susceptibility and risk. Together, these documents will enable users to identify welds with a high relative risk for degradation, and then systematically determine methods and ways to minimize and reduce susceptibility with specific welding and fabrication practices.

For example, the Welding and Fabrication Addenda to the matrix for a new pressurized water reactor design may rank the dissimilar metal nozzle-to-safe-end welds in the reactor coolant system high for relative risk to primary water stress corrosion cracking. A high relative risk ranking may be based on the critical nature of the system, materials, specific reactor design, service conditions, and on the influence of the welding, fabrication, and surface conditioning specified by the OEM.

The materials, design, and service conditions of the new reactors most likely cannot be changed. However, the welding, fabrication, or surface-conditioning processes can possibly be modified slightly or significantly to reduce the relative risk ranking of the dissimilar metal welds, which would increase the reactor coolant system life and reliability. For example, a number of processes have recently been developed to mitigate the tensile residual stresses that are produced by welding. These residual stress mitigation processes were not available during the construction of the original U.S. nuclear power plant fleet, but hold significant potential for application in the new fleet. For those cases where it is not cost effective or feasible to modify the welding process to reduce the residual tensile stresses, residual stress mitigation processes can be used to lower the propensity to degradation mechanisms. The Welding and Fabrication Critical Factors report will provide background information and specific guidelines on which processes or process parameters would effectively reduce the relative risk ranking.

The Payoff

Optimizing welding, fabrication, or surface-conditioning practices in the susceptible areas of critical components can significantly improve the life and reliability of new nuclear power plants, preventing forced shutdowns and reducing outage maintenance costs.

The best practices project is an ambitious collaborative effort to develop information and tools that will enable project participants to build reliability into new nuclear power plants. Working together, utilities, equipment manufacturers, vendors, and the welding community can seize the opportunity to apply improved welding and fabrication practices to ensure that new nuclear plants will operate reliably over their designed 60-year lifetimes.◆

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