Program Overview

Program Description
As boiling water reactors have aged, various forms of operation-limiting stress corrosion cracking have appeared, first in the recirculation piping, then in the reactor pressure vessel internals. Typically, poor materials performance has been identified and addressed by focusing on the specific component or system. This near-term, reactive approach has resulted in costly unplanned outages and expensive weld-by-weld mitigation and repair methods. A longer-term, strategic approach to materials aging management is needed to help ensure safe and reliable functionality is maintained throughout the life of the plant.

The Boiling Water Reactor Vessel and Internals Project (BWRVIP) provides an integrated approach for managing materials-related degradation issues in reactor coolant system components in boiling water reactors. The program addresses all facets of operation, maintenance, and repair to develop reliable and cost-effective detection, inspection, and mitigation techniques.

Research Value
BWRVIP maintains alignment with current industry internals integrity concerns affecting boiling water reactors. Research results lead to proven solutions for reducing damage related to stress corrosion cracking, optimized inspection scope, improved operating characteristics, reduced personnel radiation exposure, and improved models to better characterize the mitigation of internals components. Program participants gain access to the following:

- Strategic roadmaps outlining research gaps associated with key issues—such as jet pump vibration and mitigation of internals degradation—and the collaborative actions needed to address these gaps.
- Technologies and technical guidance that improve plant reliability.
- Cost-effective techniques to mitigate stress corrosion cracking of reactor internal components. For example, economic evaluations indicate that cost savings for implementing hydrogen water chemistry or noble metal chemical application exceed $40 million per plant.
- Cost-effective options for replacing or repairing reactor components.
- Technical solutions to internals inspection needs.
- Industry operating experience and technical insights to optimize inspection requirements, reduce outage critical path times, and inform regulatory decisions.

Approach
The BWRVIP Program takes an integrated approach to degradation management, encompassing assessment, mitigation, and inspection. Through improved inspection techniques, new results from materials research and development, and plant operating experiences, best practices can be deployed to enhance boiling water reactor reliability. BWRVIP closely collaborates with other Electric Power Research Institute (EPRI) programs, including Nondestructive Evaluation and Chemistry, to ensure appropriate technologies and technical guidance are effectively integrated into research activities.

There are both base and supplemental components to the BWRVIP research program. The base program focuses on improving the understanding of materials performance in areas such as fracture toughness of stainless steel exposed to high fluence levels, weldability of irradiated materials, and crack growth rates. Because these factors can all impact materials aging, enhanced understanding of their interactions and their impact on materials performance is essential. Research results are provided in the form of guidelines to ensure prompt detection of material degradation, technical reports to support materials performance assessments, and cost-effective tools to more effectively identify and manage degradation for current and extended operations.
To address strategic objectives established for each of its programs, EPRI has developed roadmaps to plan, coordinate, and execute needed research among multiple entities. For the BWRVIP Program, specific roadmaps have been developed to address flow-induced jet pump vibration and the degradation of boiling water reactor internals. The BWRVIP also collaborates on roadmaps being led by other EPRI programs that have implications relative to the BWRVIP, including roadmaps on the welding of irradiated materials and irradiated materials testing.

The supplemental portion of the BWRVIP program encompasses research related to assessment, inspection, repair and mitigation.

- **Assessment:** Develop inspection and evaluation guidelines that provide the scope for what needs to be inspected and a methodology for evaluating or repairing any indications.
- **Inspection:** Develop advanced nondestructive evaluation techniques to improve detection of indications in internal components.
- **Repair:** Develop technically based repair criteria for degraded components and compile information needed to safely plan and implement repairs.
- **Mitigation:** Provide guidance for implementing effective chemistry-based countermeasures for stress corrosion cracking of reactor internal components.

Also included is a surveillance program for monitoring changes in reactor pressure vessel materials properties due to neutron irradiation.

Nuclear plant owners can participate separately in a project aimed at maintaining and improving the BWR Vessel and Internals Application (BWRVIA) software code, which performs radiolysis analysis and electrochemical corrosion potential calculations for boiling water reactors. Continued maintenance ensures this code reflects the latest industry operating experience and is equipped to address analytical needs.

**Accomplishments**

The BWRVIP Program supports nuclear power industry efforts to assess and implement effective countermeasures for stress corrosion cracking of reactor internal components. BWRVIP research provides utilities with the information necessary to make cost-effective decisions for managing degradation of boiling water reactor vessel and internal components.

- Developed technical basis for optimizing the inspection intervals for components within the core spray system using plant inspection and laboratory data from more than 20 years of examinations.
- Constructed a full-scale jet pump facility to better understand the flow-induced vibration (FIV) phenomena in boiling water reactor jet pumps. Information obtained from this R&D activity will enable nuclear plants to better address degradation issues. The facility also allows vendors to test and demonstrate solutions designed to mitigate FIV damage.
- Published revision 15 of the examination guidelines for reactor pressure vessels and internals.
- Continued to compile data to advance understanding of the relationship between fracture toughness and neutron fluence in highly irradiated stainless steel materials.
- Developed data on crack growth of irradiated austenitic stainless steels in support of a methodology to evaluate the operability of internal components in BWRs to end-of-life fluence levels. Data will be used to extend crack growth models to higher neutron doses.
- Conducted the industry's first demonstration of early hydrogen water chemistry (EHWC) to mitigate intergranular stress corrosion cracking (IGSCC) during the startup of a boiling water reactor. EHWC helps mitigate IGSCC of boiling water reactor components.
- Issued the *Electrochemical Corrosion Potential (ECP) Sourcebook*. The sourcebook summarizes the evolution of ECP monitoring and describes currently used reference electrodes, monitoring approaches, and monitoring locations. Representative ECP data is provided from select plants.
- Issued Version 3.1 of the BWR Vessel and Internals Application (BWRVIA) model. The model calculates the ECP and the concentrations of oxidizing and reducing species around a BWR circuit, and assesses which parts of the primary circuit are protected against IGSCC.
Demonstrated the socket welded ultrasonic technique for inspecting difficult-to-access BWR drain lines.
• Continued to demonstrate online noble metal chemical addition as a mitigation technique for stress corrosion cracking. Field tests indicate that the technique is effective in reducing electrochemical corrosion potentials and has had no adverse plant impacts. Because the application is performed during operation, 60 critical path hours can be saved versus the classic noble metal application.

Current Year Activities

BWRVIP research and development for 2014 will continue to focus on the technical gaps defined in the BWR Issue Management Tables. Highest priority gaps include the impacts of fluence on the material properties of BWR materials, high-cycle fatigue in jet pump assemblies, and mitigation of intergranular stress corrosion cracking by online noble metal chemical addition. Specific efforts will include the following:
• Continue research into the jet pump flow induced vibration phenomenon and mitigation hardware testing in a full-scale jet pump facility for BWR 4 designs.
• Support technical review of the steam dryer loads methodology as it works its way through the regulatory review process.
• Continue crack growth testing, fracture toughness evaluations, and metallurgical examinations of highly irradiated materials.
• Develop advanced mitigation techniques for stress corrosion cracking.
• Optimize inspection and flaw evaluation guidelines for selected BWR internals components.
• Update the BWR Water Chemistry Guidelines.

Selected reports will be developed in whole or in part under the EPRI Quality Assurance Program that fulfills Title 10 of the Code of Federal Regulations Part 50 (10 CFR 50) Appendix B and 10 CFR 21. Additional products may be developed under 10 CFR 50 Appendix B and 10 CFR 21 at the discretion of the BWRVIP member utilities or EPRI, when such action is deemed appropriate.

Estimated 2014 Program Funding

$10.5 million

Program Manager

Andrew McGehee, 704-595-2615, amcgehee@epri.com

Summary of Projects

<table>
<thead>
<tr>
<th>Project Number</th>
<th>Project Title</th>
<th>Description</th>
</tr>
</thead>
</table>
BWR Vessel and Internals Application User Group (supplemental) (047065)

Description
Two technologies—moderate hydrogen injection, known as hydrogen water chemistry, and noble metal chemical addition—have been applied in boiling water reactors to mitigate intergranular stress corrosion cracking (IGSCC) by lowering primary water electrochemical corrosion potential. Analytical capabilities are needed to determine appropriate injection concentrations that can maintain electrochemical corrosion potential values at levels that mitigate corrosion. This user group provides information and training on the use of the radiolysis and electrochemical corrosion potential models used in EPRI’s BWR Vessel and Internals Application (BWRVIA) software program. Ongoing development of the codes also is evaluated and reported at the annual participant's meeting.

Approach
The BWRVIA User Group provides technology that operating BWRs can use to help mitigate IGSCC of reactor piping and internals. The technical project team performs comprehensive reviews of research and development in the areas of radiation chemistry and electrochemical corrosion potential modeling. Sensitivity analyses are performed to evaluate the model's response due to changes in input parameters such as chemical reaction rate constants and dose rate profiles. Adjustments are then made to these sensitive parameters to provide the best possible correlations. Finally, the results of the sensitivity analyses are compared to actual plant data to provide a technical basis for plant application of the calculated results.

Impact
By incorporating the current state of the art in radiation chemistry and electrochemical corrosion potential formulation into the BWRVIA code and benchmarking the revised code against all plant and laboratory data available, this user group ensures the availability of an accurate model for BWR plant owners. The model can then be used, for example, to predict the amount of hydrogen injection needed for IGSCC mitigation of susceptible reactor internals and piping in BWRs.

How to Apply Results
The BWRVIA User Group provides annual training workshops and ongoing support to run the software.