Boiling Water Reactor Vessel and Internals

Program Overview

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

Industry Needs and Issues Addressed
- 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, cases of poor materials performance have been addressed by analyses focused 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 is needed to address a broader range of factors impacting pressure vessel internals.

Impact
- Increased capacity factors (less unplanned or extended outages)
- Cost-effective options for replacing or repairing reactor components
- Reduced inspection requirements and outage critical path times
- Reduced personnel radiation exposure
- Reduced regulatory scrutiny

Key Accomplishments
- Guidelines for inspecting boiling water reactor safety-related internal components for degradation indications
- Elimination of reactor pressure vessel circumferential weld inspections
- Integrated surveillance program for boiling water reactors
- Demonstration of noble metal chemical addition as a mitigation technique for stress corrosion cracking

Current Year Objectives
- Crack growth and fracture toughness evaluations of highly irradiated materials
- Advanced mitigation techniques for stress corrosion cracking
- Steam dryer and jet pump evaluations

Industry Involvement
- Estimated 2009 funding: $6.9

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Summary of Projects

Project Number	Project Title	Value
	BWRVIP Integration	Provide overall Boiling Water Reactor Vessels and Internals Project (BWRVIP) program management and regulatory interface, as well as coordinate and prioritize the various task activities within the BWRVIP and with other industry activities.
	BWRVIP Assessment	Provide guidelines to ensure prompt detection of material degradation and a variety of solutions for addressing observed problems. In addition, the guideline will offer cost-effective solutions to reduce damage related to stress corrosion cracking.
	BWRVIP Mitigation	Provide BWRVIP members with cost-effective means to implement techniques to mitigate stress corrosion cracking of reactor internal components. The benefits from this program are cost savings due to reduced inspection scope, extended intervals between inspections, and improved operating characteristics.
	BWRVIP Inspection	Develop techniques that will allow for unique solutions to internals inspection needs such that BWRVIP participants are not limited to vendors' nondestructive evaluation offerings. In many cases, vendors are applying techniques that were pioneered by the BWRVIP. In addition to performing inspections that might not otherwise be possible, the greatest member benefits from this program are achieved through reduced inspection and outage critical path times as well as reduced personnel radiation exposure.
	BWRVIP Repair	Provide design criteria and unique solutions to repair or replace reactor internals and piping. The benefits from this program are realized through cost-effective solutions to repair or replace reactor components.
	BWRVIA RAD/ECP	Develop modeling techniques to better characterize the mitigation of internals components.
	BWRVIP Improved Materials Performance	Provide the industry with improved understanding of materials performance in the areas of fracture toughness of stainless steel exposed to high fluence levels, weldability of irradiated materials, and crack growth rates of internal components subjected to irradiation-assisted stress corrosion cracking and intergranular stress corrosion cracking.

Project Descriptions

BWRVIP Integration (062248)

Issue
Maintain alignment of the Boiling Water Reactor Vessel and Internals Program (BWRVIP) Integration Committee with current industry internals integrity concerns. Manage, develop, and modify, as appropriate, the overall BWRVIP issue management strategy. Assist the Integration Committee in ensuring that BWRVIP task activities are coordinated and that work priorities reflect the best industry information.

Description
Electric Power Research Institute (EPRI) activities in this task include overall BWRVIP technical and administrative program management to support the Integration Committee; costs for conducting and attending BWRVIP meetings; interface with the Nuclear Regulatory Commission (NRC) on all associated BWRVIP matters; coordination and interface with international BWRVIP members and potential members; BWRVIP report licensing and distribution; contract management with BWRVIP contractors; and coordination and interface regarding EPRI contracts with all U. S. and international BWRVIP members. This task includes preparing materials for BWRVIP training sessions and conducting domestic and international training sessions. The task also includes participating in Institute of Nuclear Power Operations' review visits and developing and documenting interpretations and implementation issues associated with BWRVIP products.

Value
- Successful overall BWRVIP program management and regulatory interface
- Close coordination and prioritization of the various task activities within the BWRVIP

How to Apply Results
The work performed under this task provides the information necessary for members to better manage the BWRVIP program nuclear power plants. Program results enable nuclear plants to apply the operating experience and lessons learned from other plants, respond to emerging industry issues, and better understand the regulatory aspects of the program.

BWRVIP Assessment (052371)

Issue
Maintenance and repairs at boiling water rectors entail significant costs. Through improved inspection techniques, new results from materials research and development, and plant operating experiences, best practices can be deployed to make cost-effective decisions. To best serve the industry, these best practices should be communicated fleet-wide such that they are consistently applied and continually updated as new information is available.

Description
The BWRVIP continues to research and develop solutions to provide utilities with the necessary information to make cost-effective decisions for managing degradation of boiling water reactor vessel and internal components.

Value
- Standardized and regulator-approved methodology for fluence evaluation
- *Inspection and Evaluation Guidelines* to ensure prompt detection of degradation, reduce outage time due to unanticipated degradation, and provide cost-effective solutions for reducing inspections and damage related to stress corrosion cracking

- Eliminated testing of some surveillance program capsules of low value to the industry
- Improved data and information on changes in reactor pressure vessel material properties due to neutron irradiation

How to Apply Results

The products that come from this task are directly applied at nuclear power plants through inspection, maintenance, and repair programs. The inspection and evaluation guidelines provide the scope for what needs to be inspected and a methodology for evaluating or repairing any indications that are found. Other products such as the Radiation Analysis Modeling Application (RAMA) fluence methodology, integrated surveillance, and Distributed Ligament Length (DLL) provide tools that plants can use to evaluate their material condition. In addition, research examining irradiation effects on materials provides valuable information for managing license renewal activities.

2009 Products

Product Title & Description	Planned Completion Date	Product Type
Integrated Surveillance Program: Regulatory requirements dictate that boiling water reactors have a vessel materials surveillance program to monitor the changes in vessel material properties resulting from neutron irradiation damage. The 2009 product will incorporate the Monticello capsule test results into BWRVIP-135, Rev. 1.	12/31/2009	
Evaluate and Trend Inspection Data: The purpose this project is to assemble and analyze reinspection data on core internals and to use this information to justify a relaxation in reinspection frequencies.	12/31/2009	
Steam Dryer Evaluation Methodologies: BWRVIP guidelines addressing steam dryer evaluation methodologies will be revised to address 1) Nuclear Regulatory Commission comments via Requests for Additional Information or Safety Evaluation, 2) reinspection frequencies, 3) approaches for developing loads for structural analysis, and 4) general lessons learned. The goal of this effort is to provide the technical basis for Nuclear Regulatory Commission approval of the steam dryer inspection and evaluation guidelines.	12/31/2009	
Evaluation of EAC in BWRs: The fatigue crack growth rates for ferritic steels in water environments given in A-4300 of Appendix A, Section XI, the American Society of Mechanical Engineers (ASME) Code, were developed from data obtained prior to 1980. While ASME Code Case N-643 was developed for pressurized water reactor primary system applications, it has limitations for boiling water reactor conditions. A similar Code Case for the boiling water environment is needed for both the normal water chemistry and hydrogen water chemistry/noble metal chemical addition.	12/31/2009	
Testing of X-750 Materials: Service experience shows that X-750 materials can be susceptible to degradation by intergranular stress corrosion cracking (IGSCC). Another issue concerns the long-term viability of X-750 materials used in components such as boiling water reactor jet pump beams and repair hardware for core shrouds where a high-strength material is required. Recent cracking in the upper portion of a core shroud tie rod repair has reinforced concerns about the crack initiation behavior of X-750 materials. This project is aimed at addressing key knowledge gaps.	12/31/2009	

Product Title & Description	Planned Completion Date	Product Type
Bottom Head Drain Line I&E Guideline and Repair Criteria Technical analysis has shown that the bottom head drain line in boiling water reactors is susceptible to flow-assisted corrosion. A break in this line due to flow-accelerated corrosion could not be isolated and would release a large amount of reactor coolant into the drywell. A number of industry activities are underway to address the issue: The CHECWORKS User Group funded a project to perform plant-specific analyses of the bottom head drain lines in all U.S. boiling water reactors and the EPRI Nondestructive Evaluation Center coordinated a project to design and manufacture a prototype inspection tool. The tool is applicable to BWR/5-6 designs and has been successfully tested at a nuclear power plant. The BWRVIP Repair Focus Group evaluated the need for repair tooling that could be used by plants that perform inspections and find unacceptable damage. This task integrates and enhances these industry efforts under a single BWRVIP project.	12/31/2009	

BWRVIP Mitigation (052372)

Issue
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.

Description
This program will provide guidance for implementing effective countermeasures for stress corrosion cracking of reactor internal components. Research results and guidelines will enable members to effectively implement techniques for mitigating stress corrosion cracking such as hydrogen water chemistry and noble metal chemical application. Work also will be conducted to demonstrate the effectiveness of mitigation techniques and the effect of noble metal chemical application on fuel.

Value
- Cost-effective techniques to mitigate stress corrosion cracking of reactor internal components; economic evaluations conducted for five plants indicate that cost savings for implementing hydrogen water chemistry or noble metal chemical application exceed $40 million per plant.
- Cost savings due to reduced inspection scope, extended intervals between inspections, and improved operating characteristics.
- Savings also expected in optimized use of costly chemicals.

How to Apply Results
Members would use the results from this project to optimize water chemistry programs, allowing plants to mitigate stress corrosion cracking of reactor internals and recirculation piping without affecting other plant parameters (for example, dose and fuel).

2009 Products

Product Title & Description	Planned Completion Date	Product Type
BWR Chemistry Guidelines and HWC / NMCA / OLNC Experience Report: The *EPRI Boiling Water Reactor Water Chemistry Guidelines* are reviewed biennially, with fully revised guidelines issued every four years. The next revision of these guidelines will be completed in 2008. During 2009, BWRVIP will collect and analyze water chemistry experience for the 2010 interim guidelines review. Issues identified over the period of 2009-2010 will be addressed in this review.		
Online NMCA Deposition and ECP Study: The on-line noble metal chemical addition process can mitigate crack growth caused by lack of noble metal on new crack surfaces coated during off-hydrogen periods. BWRVIP participated in the demonstration of this process at an international boiling water reactor to monitor technical progress and to ensure timely availability of the results to BWRVIP members. While the demonstration was successful and the process has been implemented at several U.S. plants, several technical challenges remain.		
Generic Safety Evaluation and Demonstration of Alternate Reductant Injection to Mitigate IGSCC at Low Temperatures (Plant Startup): In recent years, boiling water reactors have practiced hydrogen injection (typically combined with noble metal chemical addition) to reduce intergranular stress corrosion cracking of reactor internal components. However, hydrogen injection is typically not started until the plant is at 20% power or higher. During plant startup, when hydrogen cannot be injected, major plant components are susceptible to intergranular stress corrosion cracking, especially at lower temperatures (less than 400°F).		

BWRVIP Inspection (061776)

Issue
As boiling water reactors have aged, various forms of operation-limiting stress corrosion cracking have appeared. Advanced nondestructive evaluation techniques can improve detection of indications in internals' components so they can be assessed and repaired/mitigated to maintain safety margin.

Description
This program develops or refines nondestructive evaluation techniques to address emerging issues in internals inspection. Past examples of inspection programs developed under this activity include creeping wave ultrasonic testing; phased-array ultrasonic and eddy current testing for the shroud; core plate bolt nondestructive evaluation from the annulus; ultrasonic testing for shroud support legs; and alternative ultrasonic testing for jet pump beams.

Value
- Develops technical solutions to internals inspection needs
- Provides unique solutions such that BWRVIP participants are not limited to vendors' nondestructive evaluation offerings
- Reduces inspection and outage critical path times and personal radiation exposure
- Results in an estimated $25,000 to $100,000 savings per member per year

How to Apply Results
This project will provide members with the latest technology necessary to inspect reactor internals. The results of this project are demonstration techniques that members can use to determine which vendor and which inspection technique should be used for specific inspection needs.

2009 Products

Product Title & Description	Planned Completion Date	Product Type
NDE Maintenance: This task includes design and fabrication of any new mockups necessary to support field configurations not addressed by the existing mockups and to support nondestructive examination (NDE) techniques for which the existing mockups are not applicable. The task also includes administering, monitoring, and documenting the new demonstrations for inclusion in *Reactor Pressure Vessel and Internals Examination Guidelines (BWRVIP-03)*.		
NDE Development: Respond to emerging NDE issues by using existing BWRVIP and EPRI mockups, equipment, and personnel resources, plus acquiring any necessary additional mockups and NDE equipment to develop or refine NDE techniques as appropriate.		

BWRVIP Repair (065840)

Issue
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. As these components have continued to degrade, repair and replacement options have become necessary for continued operation.

Description
BWRVIP provides repair and replacement options and the associated design requirements that must be met.

Value

- Generic design criteria approved by NRC
- Generic repair and replacement options

How to Apply Results
Indications continue to be found in boiling water reactor internals. Some indications are beyond critical flaw sizes and must be repaired. This project provides the tools necessary to make decisions on which repair and replacements should be performed at a given plant. Members can better evaluate options and determine the most cost-effective solution.

2009 Products

Product Title & Description	Planned Completion Date	Product Type
Irradiated Weld Modeling and Revision to BWRVIP-97: The project will evaluate the conservatism in the BWRVIP's irradiation weld model by systematically varying model parameters and adjusting them appropriately. Once the level of conservatism has been reduced, the model will be benchmarked against underwater thermal test data and used to evaluate or adjust the applicability of BWRVIP guidelines to underwater welding and non-flat configurations. The resulting model will be a general tool for predicting weldability and for establishing acceptable welding parameters for a wide range of configurations and welding conditions.		
Alternative High Strength Materials for BWR Repairs: BWRVIP is conducting a literature search and survey of material experts to identify material alternatives to X-750. Subsequent evaluation and testing in 2009 and 2010 will have to demonstrate that the candidate materials maintain high-strength properties in a boiling water environment and show adequate resistance to intergranular stress corrosion cracking. The evaluation report will describe the selected materials as well as criteria for their use in boiling water reactor repairs. These criteria will be incorporated into a future revision of BWRVIP-84.		
Repair Design Criteria for Top Guide Grid Beams: This project will develop repair design criteria for top guide grid beams, including guidance on material selection, design considerations, fabrication processes, inspection and testing, and potential design concepts. The resulting criteria may be published as a separate report or incorporated into the existing *Top Guide Repair Design Criteria*.		

BWRVIA RAD/ECP (061429)

Issue
Improved water chemistry enables plants to better manage reactor internals. The Boiling Water Reactor Vessel and Internals Application (BWRVIA) model is used to monitor mitigation areas within the reactor.

Description
The BWRVIA code is used to monitor vessel protection for plants with hydrogen water chemistry and noble metal chemical addition and to support plants in optimizing hydrogen addition to protect vessel internals.

Value
- The BWRVIA model allows boiling water reactors to verify protection under moderate hydrogen water chemistry and noble metal chemical addition schemes in regions not directly monitored with electrochemical potential probes.
- The BWRVIA model is an integral part of the methodology proposed in BWRVIP-62 to ensure an effective mitigation program.

How to Apply Results
Plants apply the BWRVIA model to verify the effectiveness of the reactor's mitigation program.

BWRVIP Improved Materials Performance (052368)

Issue
Utilities must manage current and potential future degradation of boiling water reactor internal components.

Description
This program provides members with improved understanding of materials performance in the areas of fracture toughness of stainless steel exposed to high fluence levels, weldability of irradiated materials, and crack growth rates of internal components subjected to irradiation-assisted stress corrosion cracking and intergranular stress corrosion cracking.

Value
- This program will provide cost-effective tools to enable members to identify and manage this degradation for current license terms and for the license renewal period.
- The NRC approval of many of the products allows members to effectively address regulatory issues.
- The direct benefit from this program will be due to reduced inspection scope, extended intervals between inspections, and improved operating characteristics.

How to Apply Results
This program will be delivered through a combination of guidance documents and technical reports throughout its duration. Many of the guidance documents will be submitted to the NRC by the BWRVIP for approval, which will result in effective member implementation of regulatory-approved guidance.