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, 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 can address a broader range of factors impacting pressure vessel internals.

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 assesses all facets of operation, maintenance, and repair to develop reliable and cost-effective detection, inspection, and mitigation techniques.

Research Value

The BWRVIP Program maintains alignment with current industry internals integrity concerns affecting boiling water reactors. Research results lead to cost-effective solutions to reduce damage related to stress corrosion cracking; cost savings due to reduced inspection scope, extended intervals between inspections, and improved operating characteristics; reduced personnel radiation exposure; and improved models to better characterize the mitigation of internals components. BWRVIP participants gain access to the following:

- Technologies and technical guidance that drive increased capacity factors (less unplanned or extended outages).
- Cost-effective techniques to mitigate stress corrosion cracking of reactor internal components. 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 driving reduced inspection requirements, outage critical path times, and regulatory scrutiny.

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 make cost-effective decisions.

- Develop guidelines to ensure prompt detection of material degradation and a variety of solutions for addressing observed problems
- Develop and demonstrate cost-effective means to implement techniques to mitigate stress corrosion cracking of reactor internal components
- Devise unique solutions to internals inspection needs such that boiling water reactor (BWR) plants have a wider selection of nondestructive evaluation offerings
- Formulate design criteria and develop unique solutions to repair or replace reactor internals and piping
- Improve 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

BWRVIP closely collaborates with other EPRI programs, including Nondestructive Evaluation and Chemistry, to ensure appropriate technologies and technical guidance are effectively integrated into research activities.
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.

- Issued NRC-approved guidelines on steam dryer inspection and flaw evaluation that define visual inspection requirements for BWR steam dryer assemblies. Baseline inspection results can be compared to subsequent results to assess potential effects of time and power uprates.
- Completed construction, shakedown testing, and initial operation of full-scale jet pump facility to advance understanding of observed degradation mechanisms.
- Issued guidelines for performing weld repairs on irradiated BWR internals, providing a mechanism for determining the weldability of reactor components.
- Compiled data to advance understanding of the relationship between fracture toughness and neutron fluence in highly irradiated stainless steel materials. Also conducted tests to collect crack growth rate data on irradiated stainless steels that can be used to extend EPRI’s flaw evaluation methodology to higher neutron doses.
- Designed, developed, and demonstrated a radiographic testing system to facilitate corrosion detection in difficult-to-access BWR drain lines.
- Demonstrated online noble metal chemical addition as a mitigation technique for stress corrosion cracking. Field tests indicate critical path savings of up to 60 hours.

Current Year Activities

BWRVIP research and development for 2011 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 flow-assisted corrosion of the BWR bottom head drain line. Specific efforts will include the following:

- Continue testing of the full-scale jet pump facility to better understand the operating degradation mechanism and to evaluate mitigation technologies
- Support the steam dryer loads methodology as it works its way through Nuclear Regulatory Commission review
- Continue crack growth and fracture toughness evaluations of highly irradiated materials
- Develop advanced mitigation techniques for stress corrosion cracking
- Complete inspection and evaluation guidelines for all BWR internals’ components

Selected reports will be developed in whole or in part under Title 10 of the Code of Federal Regulations Part 50 (10 CFR50) Appendix B, Quality Assurance, 10 CFR 21, and the EPRI Quality Assurance Program. 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 2011 Program Funding

$9.0 million

Program Manager

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### Summary of Projects

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<th>Project Number</th>
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<tr>
<td>P41.01.03.01</td>
<td>BWRVIP Improved Materials Performance (base)</td>
<td>Utilities must manage current and potential future degradation of boiling water reactor internal components. 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.</td>
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<td>P41.01.03.02</td>
<td>BWRVIP Integration (supplemental)</td>
<td>This task provides overall BWRVIP technical and administrative program management. Activities include oversight and attendance at BWRVIP meetings; interface with the Nuclear Regulatory Commission on all BWRVIP matters; coordination with international BWRVIP members and potential members; BWRVIP report licensing and distribution; contract management with BWRVIP contractors; and coordination regarding EPRI contracts with U. S. and international BWRVIP members. This task includes preparing materials for BWRVIP training sessions and conducting domestic and international training sessions.</td>
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| P41.01.03.03   | BWRVIP Assessment, Inspection and Repair (supplemental) | BWRVIP provides utilities with the tools and information needed to manage degradation of boiling water reactor vessel and internal components. The products that come from this task target three areas: assessment, inspection, and repair.  
- **Assessment:** 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.  
- **Inspection:** Advanced nondestructive evaluation techniques improve detection of indications in internals' components so they can be assessed and repaired/mitigated to maintain safety margins.  
- **Repair:** Technically based repair criteria for degraded components equip nuclear plants with the information needed to confidently plan and implement repairs. |
| P41.01.03.04   | BWRVIP Mitigation (supplemental)      | This program provides guidance for implementing effective chemistry-based 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. |
| P41.01.03.06   | BWRVIP Integrated Surveillance (supplemental) | Each BWR has a surveillance program for monitoring changes in reactor pressure vessel material properties due to neutron irradiation. Substantial cost savings and improvements in data quality are possible by integrating these individual surveillance programs. This program helps utilities optimize the quality of data and number of materials used to monitor embrittlement of BWR reactor vessel materials. |
### BWRVIA - BWR Vessel and Internals Application User Group (ISO 9001) (supplemental)

The BWR Vessel & Internals Application (BWRVIA) computer code, which performs radiolysis analysis and electrochemical corrosion potential calculations for BWRs, has progressed through several upgrades to enhance its value to the nuclear power industry. Continued maintenance through this project ensures the code reflects the latest industry operating experience and is equipped to address analytical needs. The BWRVIA User Group provides training and ongoing support to all BWR utilities using the model and participating in this program.

### BWRVIP Improved Materials Performance (base) (052368)

**Key Research Question**

Utilities must manage current and potential future degradation of boiling water reactor internal components. Because changes in materials, welding practices, and fluence levels can all impact materials aging issues, the industry must continually evaluate the interactions of such changes with materials performance.

**Approach**

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.

**Impact**

- Cost-effective tools to enable members to identify and manage degradation for current license terms and for the license renewal period
- Regulatory approval of many of the products allows members to effectively address regulatory issues
- 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 for approval, which will result in effective member implementation of regulatory-approved guidance.

### BWRVIP Integration (supplemental) (062248)

**Key Research Question**

The broad technical scope of materials issues impacting BWRs, coupled with the extensive regulatory interactions required to address these issues, call for an integrated coordination effort. This project ensures that the Boiling Water Reactor Vessel and Internals Project (BWRVIP) Integration Committee remains aligned with current industry internals integrity concerns. The overall BWRVIP issue management strategy is reviewed and modified as necessary, and assistance is provided to the Integration Committee to ensure that BWRVIP work priorities reflect the best industry information.

- Maintain alignment of the Boiling Water Reactor Vessel and Internals Project (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.

Approach
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.

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

How to Apply Results
The work performed under this task provides the information necessary for members to better manage BWR 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, Inspection and Repair (supplemental) (052371)

Key Research Question
As boiling water reactors have aged, various forms of operation-limiting stress corrosion cracking have appeared, first in the recirculation piping and then in the reactor pressure vessel internals. To systematically address such degradation issues—from assessment to inspection to repair—the industry developed the Boiling Water Reactor Vessels and Internals Project. Through standard guidelines for inspection and evaluation, improved inspection techniques, and detailed repair criteria, 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.

Approach
To assist utilities in properly characterizing and planning for potential materials degradation, BWRVIP develops assessment tools such as inspection and evaluation guidelines for internals components and standardized methodologies for fluence evaluation. These tools provide utilities with the necessary information to make cost-effective decisions for managing degradation.

To improve detection of indications in internals’ components so they can be assessed and repaired/mitigated to maintain safety margins, BWRVIP develops and refines nondestructive evaluation techniques. 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.

To provide the industry with the technical bases for effective repairs, BWRVIP develops detailed repair criteria that define important considerations when evaluating and planning structural or mechanical repairs to BWR vessel and internals components. Repair approaches are provided to the regulator for review and approval, increasing confidence in their application.
Impact

- 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
- Nondestructive evaluation solutions to internals inspection needs that reduce inspection and outage critical path times, reduce personal radiation exposure, and result in an estimated $25,000 to $100,000 savings per member per year
- Availability of unique nondestructive evaluation solutions such that BWRVIP participants are not limited to vendors’ nondestructive evaluation offerings
- Generic design criteria approved by the Nuclear Regulatory Commission (NRC)
- Generic repair and replacement options

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. Nondestructive evaluation results provide information that members can use to determine which vendor and which inspection technique should be used for specific inspection needs. Mitigation research results enable members 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).

BWRVIP Mitigation (supplemental) (052372)

Key Research Question

As boiling water reactors have aged, various forms of operation-limiting stress corrosion cracking have appeared, first in the recirculation piping, and then in the reactor pressure vessel internals. Chemistry-based technologies can be applied to help mitigate such corrosion, but require laboratory and field demonstration to confirm their capabilities.

Approach

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.

Impact

- 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).

BWRVIP Integrated Surveillance (supplemental) (052373)

Key Research Question

Each boiling water reactor has a surveillance program for monitoring changes in reactor pressure vessel material properties due to neutron irradiation. Substantial cost savings and improvements in data quality are possible by integrating these individual surveillance programs.

Approach

The Integrated Surveillance Program provides an integrated plan for monitoring BWR reactor pressure vessel embrittlement, resulting in significant savings compared to individual programs. Materials chosen for the Integrated Surveillance Program best represent the limiting plate and weld materials for each plant using specimens from the entire BWR fleet. The Integrated Surveillance Program is a regulatory commitment for all U.S. BWRs through the end of life.

Impact

Neutron irradiation exposure reduces the toughness of reactor vessel steel plates, welds, and forgings. Accurate methods for monitoring radiation embrittlement are important for evaluating the remaining life of reactor pressure vessel materials. The Integrated Surveillance Program will result in significant cost savings to the BWR fleet and provide more accurate monitoring of embrittlement in BWRs.

How to Apply Results

This program and sourcebook data will help member utilities optimize the quality of data and number of materials that will be used to monitor embrittlement of BWR reactor vessel materials and ensure that the Integrated Surveillance Program will comply with the requirements of 10CFR50, Appendix H.

BWRVIA - BWR Vessel and Internals Application User Group (ISO 9001) (supplemental) (047065)

Key Research Question

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 out at the annual member'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.