**IN USE: WELDING OF IRRADIATED MATERIALS FOR PWR AND BWR INTERNALS**

**ISSUE STATEMENT**

The continued operation of light water reactors will require that repairs or replacement of reactor internal components be performed as degradation occurs. Welding plays an important role in the repair or replacement of degraded reactor internals. When reactor internals are subjected to irradiation, however, the weldability of the materials is altered by the formation of helium and can result in helium-induced cracking when these irradiated materials are welded. Most of the research performed to-date has been on irradiated stainless steel. A large gap exists in the understanding related to the weldability of irradiated nickel alloys and reactor pressure vessel steel as well as the ability to utilize special welding techniques to repair high fluence materials.

**DRivers**

There are a number of factors that drive the need for a comprehensive plan to weld irradiated material:

**Operational Impacts**

In both PWR and BWR reactor designs, there are key structural components that support internal components. If the structural integrity of these components – such as the core support lugs and the jet pump riser leaves - is compromised by degradation, the reactor could be rendered inoperable. No mechanical repair technology currently exists for repairing these components and welded repair or replacements are the only viable option.

**Limitations of Existing Welding Technology**

Current laser welding technology is only capable of successfully welding material with about 10 atom-part-per-million (appm) helium concentration. This level of helium will be generated in many of the reactor internals locations after about 40 years of operation. New welding technology needs to be developed to extend the weldability of irradiated materials out to 80 years of operation. Hybrid welding technologies such as multiple laser beams that alter the residual stress show significant promise for extending the weldability range of irradiated material, but extensive process development and testing is needed to implement these new technologies.

**Cost**

The replacement of reactor internals is a costly undertaking. This activity not only involves component removal and replacement, but cut-up and disposal as well. The welded repair is a cost effective alternative to the repair or replacement option. In some cases, welding is also required to perform replacement of reactor internals.

**Coordinated Research Approach**

Researching the weldability of irradiated material is difficult for any single EPRI issue management group to fund. It requires the use of hot cell facilities for the experiments and examination of irradiated test specimens. The data produced from these experiments is not unique to one reactor design and can be used by all EPRI issue management groups if the experiments are designed appropriately.

**Regulatory**

The U.S. Nuclear Regulatory Commission has stated that engineering guidance is required before welding can be performed on irradiated reactor internals. Such guidance has been provided for BWR designs in the form of BWRVIP-97, which has received a safety evaluation review by the NRC. A similar document needs to be produced for PWR designs.

**RESULTS IMPLEMENTATION**

The improved data and degradation models developed under this program will be incorporated into industry guidance for managing internals degradation in BWRs and PWRs. The goal is to provide all necessary data and models to support light water reactor operation through 80 years. Examples include:

- Improved crack growth rate models and disposition curves for BWR (e.g. BWRVIP-99-A) and PWR internals based on an enhanced database and input from an expert panel. These models will support utility decisions on inspection frequency, repair and replacements
- Improved IASCC initiation models for PWR internals will be developed based on data from crack initiation tests on materials removed from the retired PWR plants such as Zorita and in-reactor crack initiation tests with periodic dynamic loading in the Halden reactor. MRP will also perform crack initiation tests in autoclaves to study the effect of lithium and investigate the effect of dynamic loading on (with EDF). The materials include stainless steel base metal, welds and heat affected zones.
• Improved fracture toughness models for BWR (e.g. BWRVIP- 100, Rev. 1) and PWR internals to support structural margin and integrity analyses.
• Improved void swelling model for PWRs based on results from the Gondole project.
• Radiation-resistant materials for future replacements of internals or for new plants.

PROJECT PLAN
A comprehensive plan has been developed between EPRI and the Department of Energy to address the weldability of irradiated material. The technology developed through this program will be transferred to industry in two forms:
• Topical reports that contain thermal neutron fluence assessments and weldability maps for each reactor design. These documents will be submitted to the NRC for a safety evaluation.
• Topical reports that document the development of new welding technology that can be used for applications on highly irradiated materials.
• Transfer of newly developed welding technology to vendors for commercialization

This work is divided into short-term and long-term R&D activities. The short-term activities address research needs out to 40 years of operation for welded repairs or replacement to reactor internals. Long-term research activities focus on the development of tools to address degradation that may exist in reactors with 40 or more years of operation, such as the development of models and advanced welding processes for highly irradiated material.

Short-term activities:
• Develop thermal fluence map for PWR reactor designs
• Develop weldability assessment for the PWR reactor designs
• Refine conventional welding model for predicting the weldability of irradiated stainless steel
• Develop laser welding predictive model for welding irradiated stainless steel
• Develop techniques for applying laser welding to reactor internal repairs
• Refine BWR weldability assessment

Long-term activities:
• Develop a predictive model for the weldability of nickel base materials
• Research advanced welding process for application on highly irradiated material
• Develop a process model for advanced welding technologies
• Test advanced welding processes on irradiated stainless steel and nickel base alloys

RISKS
• Regulatory approval of a topical report on the weldability of irradiated PWR reactor internals will take the same level of effort as was required for the BWRs. The schedule for the NRC review and issuance of a safety evaluation on the topical report is difficult to predict. Inspection of the reactor internals for the PWRs is planned to begin in 2011. If degradation is found in the internals it may be multiple years before NRC approval may be granted to make welded repairs or replacements. Information is being generated to support relief request for specific plant application, but generic approval for the PWR fleet will not be available until 2014.
• Significant uncertainty currently exists in the boron levels present in the materials used to construct reactor internals. A large level of engineering conservatism is currently used when predicting the weldability, which may cause some components to be evaluated as unweldable prematurely. The commitment from PWR plants to donate representative reactor internals materials has not been confirmed.
• Development of new welding technology beyond current capabilities is required to address joining processes necessary for repair and replacement applications addressing highly irradiated reactor internals.
• Commercial application of new welding technologies for the repair or replacement of highly irradiated reactor internals will require approval by ASME and NRC prior to implementation. The schedule for the review and approval by the ASME and NRC is difficult to determine.
This record of revision will provide a high level summary of the major changes in the document and identify the Roadmap Owner.

<table>
<thead>
<tr>
<th>REVISION</th>
<th>DESCRIPTION OF CHANGE</th>
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| 0        | Original Issue: August 2011  
Roadmap Owner: Greg Frederick |
| 1        | Revision Issued: August 2012  
Roadmap Owner: Greg Frederick  
Changes: Milestones added for topical reports within the flowchart. Irradiation of Sample Seat at HFIR under Government extended through the end of 2013. |
| 2        | Revision Issued: August 2013  
Roadmap Owner: Greg Frederick  
Changes: Updated flow chart. |
| 3        | Revision Issued: January 2014  
Roadmap Owner: Greg Frederick  
Changes: Added milestones legend and added milestone 14, VIP97R1-A. 9 milestones completed. |