Management of Stress Corrosion Cracking in Pressurized Water Reactor Alloy 82/182 Dissimilar Metal Butt Welds

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Introduction

• Stress corrosion cracking has been present for over 30 years in the US nuclear industry
  ❖ Boiling Water Reactors (BWR) experienced IGSCC for many years
  ❖ Pressurized Water Reactors (PWR) did not experience SCC since the mid 1980s
• Over past 8 years PWSCC of Alloy 600, 182 and 82 has caused cracking and leakage
  ❖ RPV head penetrations (heads replaced)
  ❖ Dissimilar metal butt welds (DMW)
DM Butt Welds

- PWR Industry and US NRC initiated work to understand and manage PWR SCC
- Requirements, guidelines and recommendations established to support continued safe operation of PWRs
  - Includes augmented inspection, beyond ASME requirements
  - Proactive mitigation of susceptible welds and preparation for contingency repair before an outage
- Significant challenge is that many locations not inspectable to required standards
Degraded DMW Example
Plant Life Management

- Three main aspects of plant life management
  - Understanding active degradation mechanisms
  - Monitoring of critical components and parameters
  - Development of forward looking repair programs for rapid disposition of cracking
- Implementation of a PLM program necessary to minimize impact of SCC on plant safety and reliability
Plant Life Management

• PWSCC is an active mechanism and will occur if not mitigated
• Experience, both BWR and PWR, shows plant availability can be impacted
• Emergency repairs have occurred
  ♦ Very expensive
  ♦ Design, fabrication, installation of repair and critical path time
  ♦ With better planning, repairs can be implemented more efficiently, possibly reducing cost and schedule of repair
Plant Life Management

- Proactive Analysis
- Repair/Replacement Contingency Planning
- Mitigation
- Inspection/Monitoring
Understanding Active Degradation Mechanisms

• Extensive experience in studying and evaluating PWSCC
• Repairs must be performed with understanding of active mechanism
  ♦ PWSCC
  ♦ Fatigue crack growth
• Design and materials of US plants similar to other PWRs
• PWSCC is function of temperature
  ♦ Consistent with US plant experience
  ♦ Pressurizer and hot leg nozzles
• Presence of weld repairs important
• Environmental mitigation technique not yet available
Monitoring/Inspection of Critical Components and Parameters

- Inspection of DMWs and selection of appropriate inspection interval is challenging
  - Inspection per ASME Code Section XI
  - Inspection interval needed reevaluation due to recent cracking incidences: some through-wall
  - Previous inspections performed without current inspection standards
- Cracking incidences and potential for high crack growth rates raised concern regarding adequacy of ASME Code Section XI inspection frequency
Monitoring/Inspection of Critical Components and Parameters

• PWR industry issued augmented inspection requirements
  ♦ In addition to the ASME Code required inspections
  ♦ Depends on inspection history, susceptibility to SCC and mitigation condition of each DMW

• Development of plan to identify all susceptible locations and inspection interval to adequately detect degradation prior to it challenging integrity absolutely necessary
  ♦ Inspection of higher temperature locations a priority
  ♦ Weld repairs

• Not always possible to develop such a plan due to inspection challenges, therefore......
Development of Forward Looking Programs for Proactive Mitigation

• Due to inspection challenges, proactive mitigation necessary in many cases
• Must be performed on a case-by-case basis
• Because of the inability to perform qualified inspections, many US plants have implemented proactive mitigation
  ♦ Inability to inspect due to geometric features of DMW
  ♦ Weld overlay has been mitigation option choice
Development of Forward Looking Programs for Proactive Mitigation

- Weld overlays used past 30 years to repair power plant piping
  - BWR piping and nozzles
  - Recently, PWR DMWs have implemented weld overlays
- PWR weld overlays applied for 3 reasons:
  - Repair of flawed piping detected by volumetric inspection
  - Through-wall cracking found by leakage
  - Inability to inspect in the original condition
- Attractive feature of a weld overlay is that it can make the location inspectable
Development of Forward Looking Programs for Proactive Mitigation: Weld Overlay

- Weld overlay is designed to produce compressive stress on inside surface to mitigate against SCC
- Weld overlay adds additional material to outside surface that maintains required safety factors
- Weld overlay is made using PWSCC resistant material
- Weld overlay provides significant margin against degradation
Preemptive Mitigation: Preemptive Weld Overlays

- Mitigate potential future PWSCC in susceptible locations:
  - Favorable residual stress
  - Structural reinforcement with PWSCC resistant material
- Improve inspection intervals and inspectability
  - Can make DMW inspectable
  - Extend reinspection interval
- Restores leak-before-break status of PWSCC susceptible locations
- Currently under evaluation by industry and regulator
Example of Pressurizer Spray Nozzle Finite Element Model

A82/182 Butterfly
A82/182 Butt Weld
Assumed ID Repair
SS Butt Weld

FMDL Spray Nozzle, Twol=0.3 inches, Long
Residual Stress after ID Weld Repair for Pressurizer Spray Nozzle

Long FWCL Spray Nozzle (tk = 0.3"), Post Repair at 650°F - Axial Stress
Residual Stress after Application of Weld Overlay for Pressurizer Spray Nozzle

Long FWOL Spray Nozzle (tk = 0.3”). Post WOL3_9 at 650°F - Axial Stress
Example: Repaired & Mitigated
Example: First Overlay Applied to a PWR
Summary

• PWSCC will occur
• Implementation of proactive programs to address PWSCC can be effective in reducing impact of cracking on plant availability and safety
• Integrated approach with analysis, mitigation, repair/replacement and inspection/monitoring is recommended approach
• Proactive approach has been successful in managing cracking in US PWRs
• Integrated program supports plant life extension
• Proactive evaluations are cost-effective