The Embedded Flaw Process for Repair of Reactor Vessel Head Penetrations

Westinghouse Electric Company

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Introduction

On December 12, 2001, Westinghouse submitted a generic relief request for an embedded flaw repair that could be applied to CRDM/CEDM J-weld surfaces.

There have been several follow-up meetings and phone calls held with the staff where additional information was submitted and discussed.

An objective of this meeting is to discuss recent experience with this repair technique and determine if there are any questions from the staff.

Introduction (Continued)

- In 2001, Westinghouse applied the embedded flaw weld repair process on the J-weld surfaces for 3 CRDM penetrations on the North Anna 2 reactor vessel head
- This was a first time site application on J-weld surfaces
- The welding process had been qualified previously
  - The weld process was qualified per ASME Section IX
  - The tooling and personnel were certified on mockups

Introduction (Continued)

No rejectable indications were observed in the post repair dye penetrant exam

It appeared that the implementation was successful

Introduction (Continued)

As a result of observed leakage on one of these penetrations in 2002, all three penetrations were re-examined. Evidence of flaws was observed

An evaluation of these three repairs has been completed, with the following conclusions:

- The weld repairs did not achieve full coverage of the Alloy 82/182 wetted surface
- These exposed 82/182 surfaces are the location of indications found in 2002

Lessons learned and corrective actions have been identified and are being implemented.

Basis for Embedded Flaw Concept

Basis for the Embedded Flaw Concept WOG Weld Repair Program Summary

Investigate and provide a local and 360° weld repair on both flawed and unflawed material.

Provide a design that is consistent with rules of ASME Section XI

Provide a weld process specification and repair design package

Depth of Weldment for Embedded Flaw

Section XI requirement for a flaw to be considered embedded: $S > 0.4a$

where S = distance from flaw to surface

a = half width of embedded flaw

Set width of flaw (2a) equal to penetration thickness (0.625 in.)

Weld thickness (S) is then 0.125 inches

For smaller flaws the weld thickness can be smaller

WOG Program/Qualification Summary

Local Repair

- Performed with both uphill and downhill repairs
- Residual stress levels of welded tube compared to unrepaired
- Weld overlay on an EDM notch showed no cracks or indications generated in the surrounding area

360° repair - range of weld depths produced acceptable dimension change in the penetration tubes

Penetration Repair via Embedded Flaw

Conclusions

- Embedded flaw repair isolates the cracking from the RCS environment and stops further propagation of existing cracks
- Minimizes examination and repair time
- Leaves acceptable surface for post repair NDE
- Previous WOG experimental work demonstrates qualification of the methodology

Basis for Selection of Alloy 52 for Repair Weld

Alloy 52

Alloy 52 is the weld metal analog of Alloy 690; it is used for gas metal arc and gas tungsten arc deposition processes [Alloy 152 = shielded metal arc coated electrode version].

The composition is very similar to that of Alloy 690 with slightly higher Cr [28-31.5 wt %] and controlled additions of Al and Ti [to 1.1-1.5 max combined]

Developed to minimize issues related to hot cracking and SCC susceptibility of Alloys 182 and 82

Alloy 52 - SCC Resistance

Owing primarily to high Cr content, Alloys 52/152 and 690 exhibit apparent immunity to primary water stress corrosion cracking (PWSCC)

Service experience with Alloy 690 in SG heat transfer tubing applications, and Alloys 52/152 as buttering, cladding and weld filler materials has been exemplary, with no reported degradation, after more than 12 years of service

Laboratory testing of each of these materials emphasizes the corrosion resistance - no known incidence of crack initiation or crack propagation in primary water environments

Alloy 52: Service Experience D C Cook Unit 2

Pen. 75 found to have ID surface flaw in 1994

Depth approx. 40 percent of wall thickness

Embedded Flaw Repair implemented in 1996

Repair re-inspected in Jan. 2002: No Indications on the weld repair

Alloy 52 - Conclusion

There is adequate technical basis that Alloy 52 provides a fully reliable barrier to preclude the occurrence or continuation of environmental degradation in PWR primary water environments

Process, Tooling and Personnel Certifications

Process, Tooling and Personnel Certifications

Equipment and Personnel Qualification

Equipment and Personnel were qualified under the W-PCI Nuclear Quality Assurance Program that meets the requirements of 10CFR50 Appendix B.

Project Instructions were used to document step by step instructions and define the acceptance criteria for the qualification process.

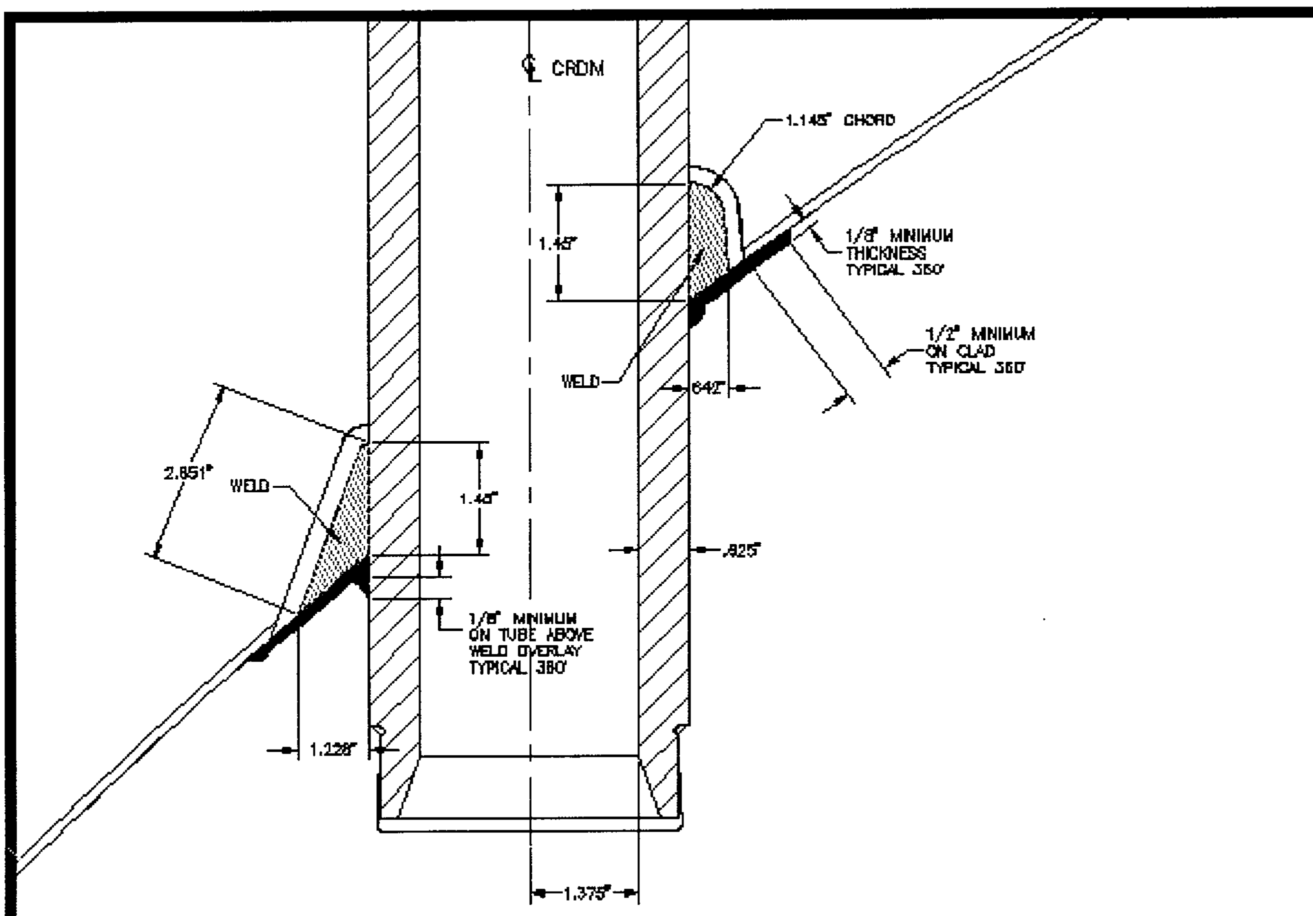
Personnel were trained on each specific tool and associated equipment and completed a certification form.

Embedded Flaw Repair Process

Welding Procedure Specification and Procedure Qualification Record Machine Gas Tungsten Arc Welding Process (Remote)

- WPS 3-43/F43-B MC-GTAW and PQR 603, 677 and 694A was utilized.
- ASME Section II, Part C, AWS Class. ERNiCrFe-7 (Alloy-52) was used for the overlay weld.
- Standard ASME Section IX Groove Weld Procedure.
- ASME Section IX Testing included Bends,Tensile, Hardness and ASTM-A262, Practice A Corrosion Testing.

Intended Repair Weld Geometry



Weld Geometry
Typical for 51, 62, & 63

2001 Repair Implementation

2001 Repair Implementation

2001 Site Repair Process at North Anna Unit 2

Performed the embedded flaw repair process on penetrations 51, 62 and 63.

A liquid penetrant examination prior to welding of the 2 layers of Alloy 52.

Performed layout of build up area per approved sketch

After the first layer was welded, light grinding was performed and approximately 0.015 inch to 0.020 inch removed.

Welded second layer and verified that a minimum of 0.125 inch of build up was applied.

2001 Repair Implementation

Site Repair Process (Cont'd)

- Visual 5X inspection was performed.
- Cleaning and preparation for final liquid penetrant examination was performed.
- Final solvent removal liquid penetrant testing was performed and witnessed by the Authorized Nuclear Inspector.
- No rejectable indications were observed in the post repair dye penetrant exam

2002 Inspection Findings on Previously Repaired Penetrations

2002 Inspection Sequence

- Bare metal visual examination on top of head
  - Evidence of new leakage on penetration 51
  - No evidence of leakage on penetrations 62, 63
- Subsequent dye penetrant examinations of the J welds were conducted on all three penetrations
- Penetration tube ID examinations with both ECT and UT were also conducted

LP Exam of Penetration 51, Sept. 02

LP Exam of Penetration 51, Sept. 02

Inspection Findings on Previously Repaired Penetrations

Dye penetrant examinations

Inspection results from inside the penetration tubes

Penetration 51 boat sample results

Dye Penetrant Examinations

- Prior to the September 2002 PT inspections, the surfaces of all the repair welds were conditioned with a flapper wheel
- All three penetrations had indications
- Three different locations will be discussed
  - Inner periphery of repair weld
  - In the repair weld
  - Outer periphery of repair weld

Inner Periphery of the Repair Weld

- Four indications found (62 and 63 only) after flapping
- It is speculated that these indications resulted from:
  - The exposure of subsurface indications due to flapping or
  - The weld repair was not smoothly blended, leaving a trap for penetrant
- All four indications were removed with light grinding, to a depth of approximately 1/16 inch

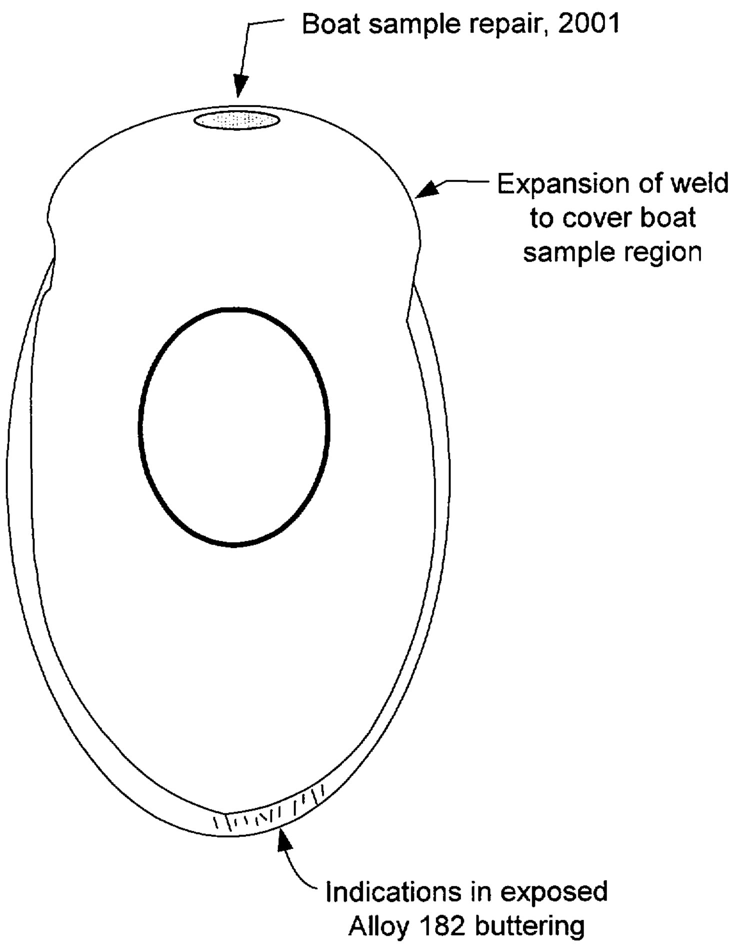
In the Repair Weld

- One rounded indication in penetration 51 from first dye penetrant examination in 2002.
  - Removed by light grinding
- Five rounded indications in penetrations 62 and 63.
  - removed by grinding

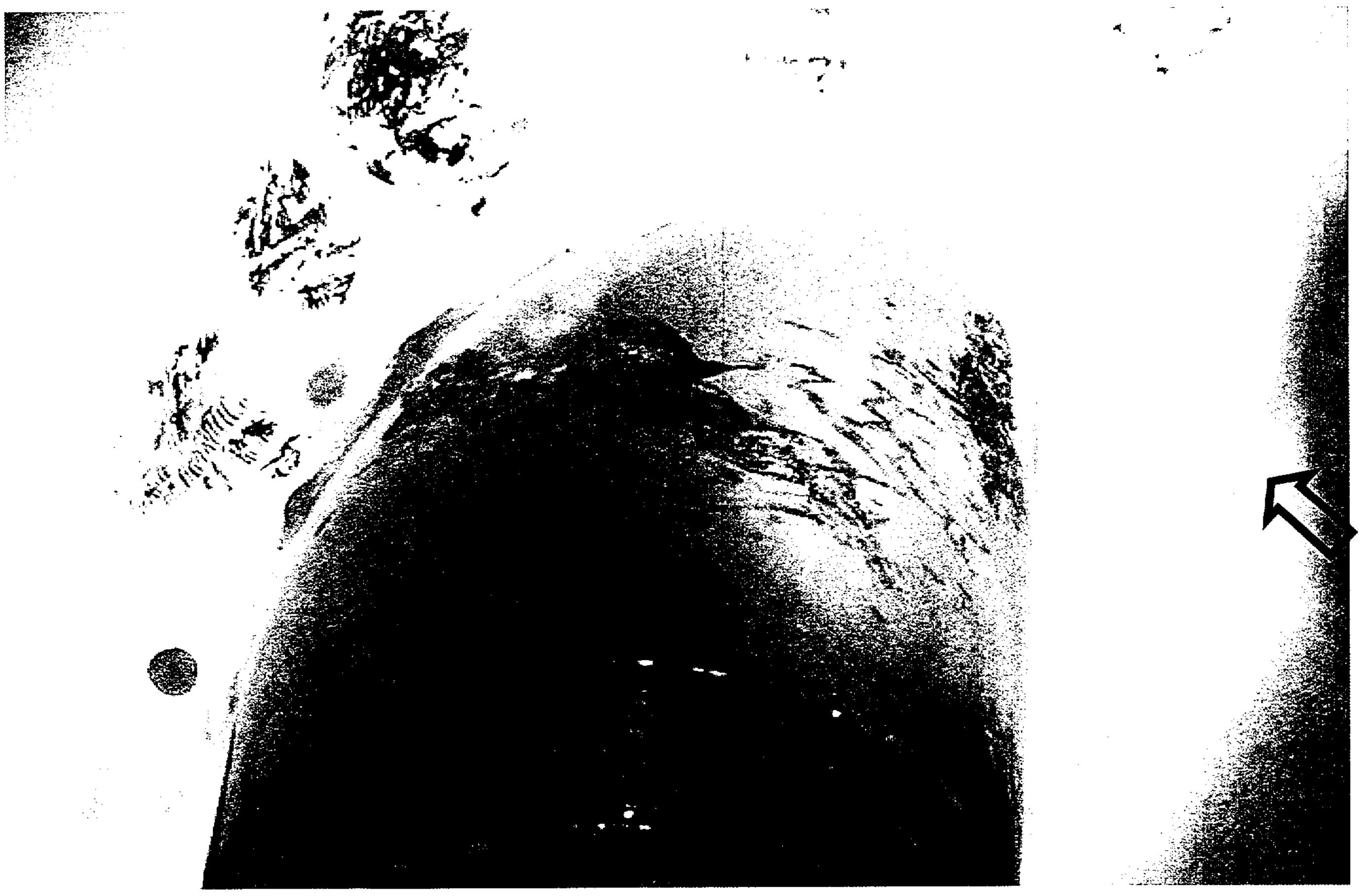
On the Periphery of the Repair Weld

- Indications found on penetration 51
  - One linear indication
  - One rounded
- After additional grinding on penetration 51, new indications were revealed
- One linear indication found on penetration 62
- Two linear indications found on penetration 63

Sketch of Weld Repair, Penetration 62, Shows the Extension to Cover Buttering



Penetrant Results of Penetration 62, September 2002



Note the Extension of the Weld Repair Region to Cover the Boat Sample Region (See Arrow)

On the Periphery of the Repair Weld

Acid etch on penetration 62 demonstrates that 82/182 surface remains exposed outboard of repair weld

Boat sample on penetration 51 demonstrates that 82/182 surface remains exposed outboard of repair weld

Etched Region of Penetration 62

The Boundary Between the Repair and the Original Weld Buttering is Shown by the Solid Arrow. The Boundary Between the Buttering and the Etched Stainless Steel (Gray) is Shown by the Small Red Arrows. The Area of PT Indications is in the Buttering Between the Two Scribe Marks, Indicated by the Large Open Arrows.

Summary of Indications

Penetration/ Indication No.	Location (Degrees)	Position	Bleed Out	Description	Comments
*51-1	190	Outer Periphery	0.31"	Linear	Blended, reduced length to 0.0625
51-2	135	Outer Periphery	0.125"	Linear	Boat sample
51-3	135	Outer Periphery	0.125"	Linear	Boat sample
51-4	125	Outer Periphery	0.10"	Rounded	
51-5	30	In Weld	0.25"	Rounded	
*51-6	240	In Weld	0.25"	Rounded	Blended to remove, depth ≤ 0.1875"
*51-7	240	Outer Periphery	0.09"	Rounded	Blended to remove, depth ≤ 0.125"
62-1	10	Inner Toe	2.5"	Linear	Blended to remove, depth ≤ 0.125
62-2	240	Inner Toe	2.25"	Linear	Blended to remove, depth ≤ 0.125
62-3	260	In Weld	0.375"	Rounded	Removed, ground to depth ≤ 0.0625
62-4	280	In Weld	0.375"	Rounded	Removed, ground to depth ≤ 0.0625
62-5	330	Outer Periphery	3.0"	Linear	
63-1	5	In Weld	0.75"	Rounded	Removed, ground to depth ≤ 0.0625
63-2	60	In Weld	0.75"	Rounded	Removed, ground to depth ≤ 0.0625
63-3	100	Outer Periphery	1.0"	Linear	
63-4	135	Inner Toe	0.10"	Linear	Blended to remove, depth ≤ 0.0625
63-5	160	Outer Periphery	0.10"	Linear	
63-6	270	Inner Toe	2.00"	Linear	Blended to remove, depth ≤ 0.0625
63-7	315	In Weld	0.75"	Rounded	Removed, Ground to depth ≤ 0.0625

Note: Indications 51-1, 51-6, and 51-7 were the only indications found in the original PT of 2002. All other indications were uncovered by subsequent grinding.

Key Take Away: Minimum grinding was required to eliminate indications

Penetration 51
Boat Sample Results

Objectives

Characterize Penetrant Test Indications Found Near Weld Outboard Edge

Determine Whether Indications may be Associated with a Potential Leakage Path

Determine the Extent of Weld Repair with respect to the Original Weld

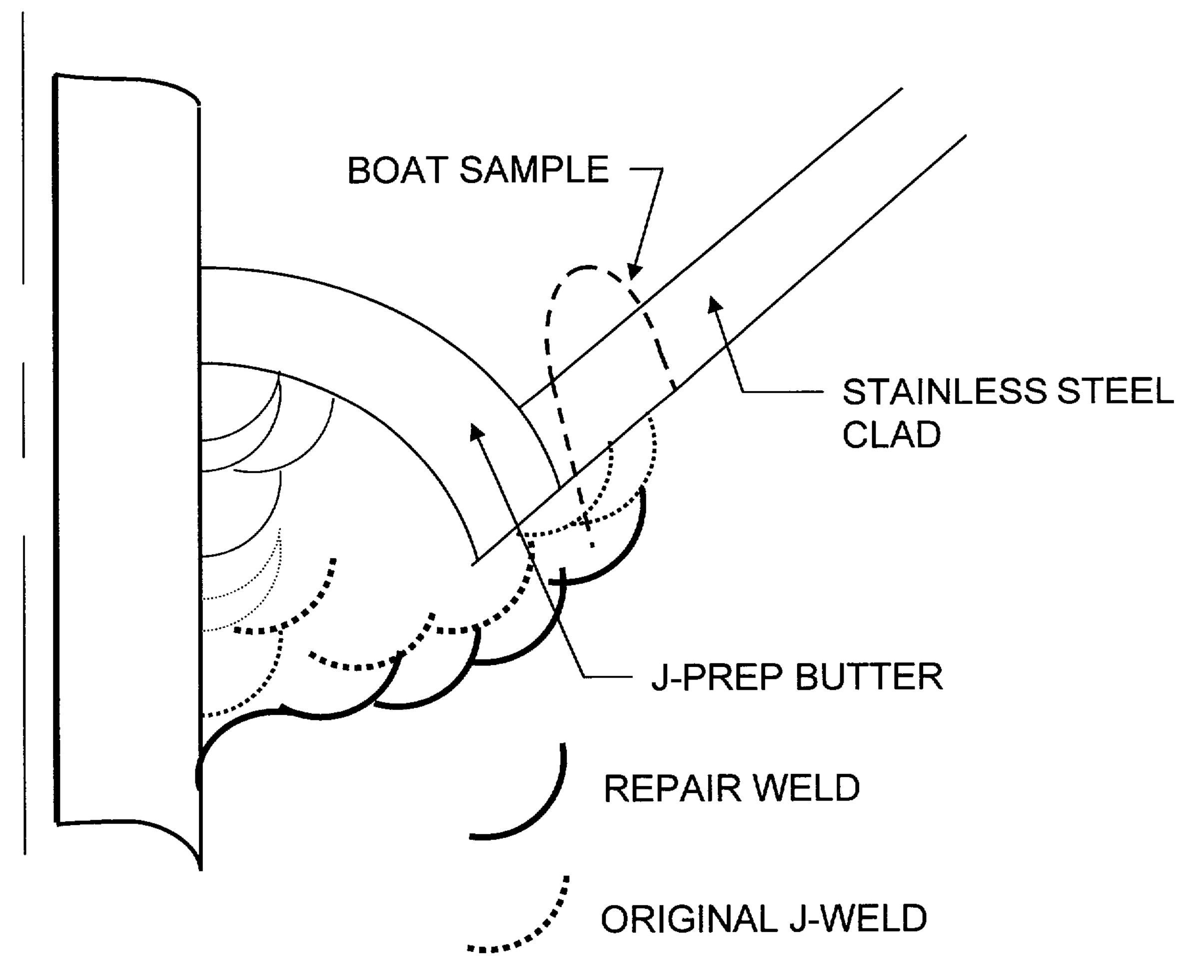
Methodology

A Boat Sample Containing Two PT Indications at 135 degrees was Removed from the J-Weld Area of the Head

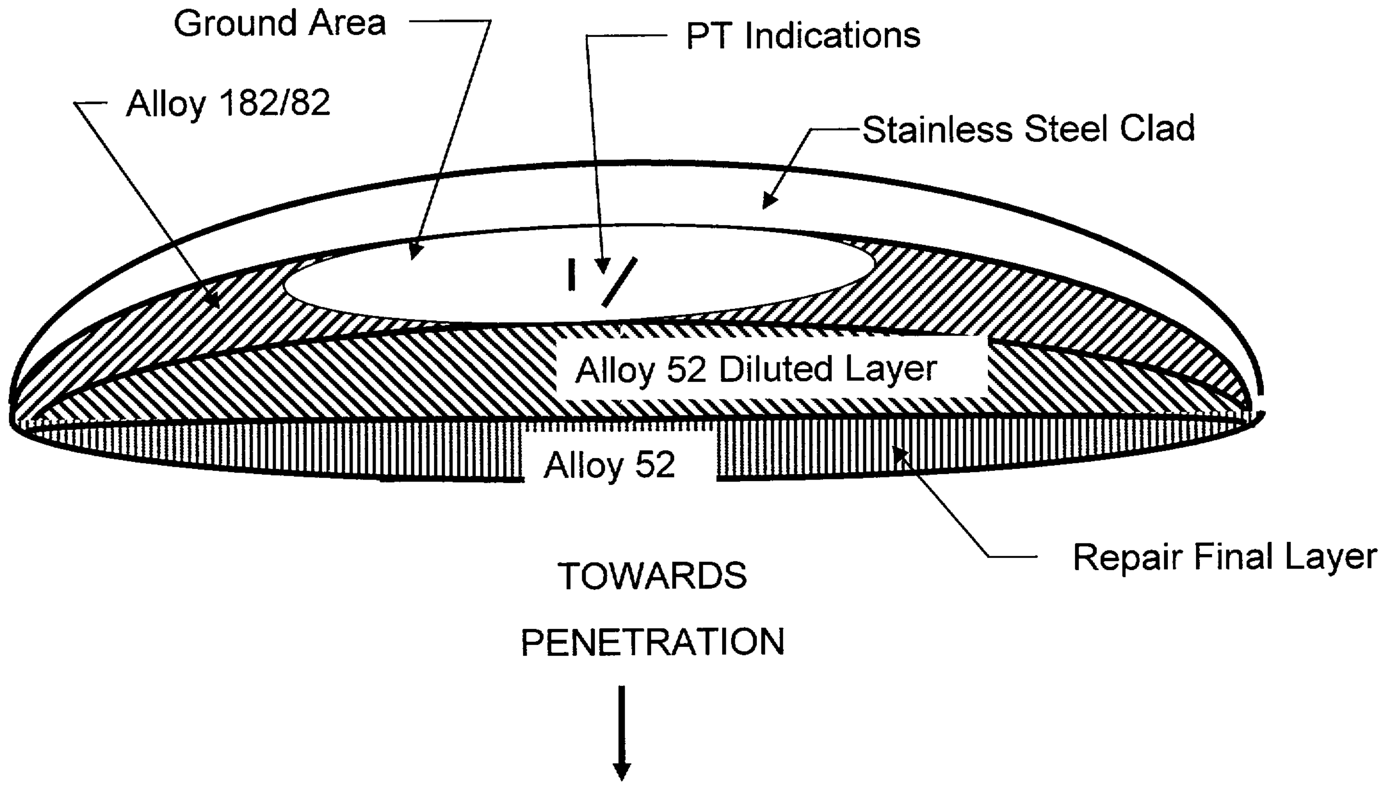
Optical and SEM Examination were used to Scan the Wetted Surface

Metallographic Exam of Sections Transverse and Longitudinal to Weld Direction

2002 Boat Sample Location



Wetted Surface Weld Bead Analysis



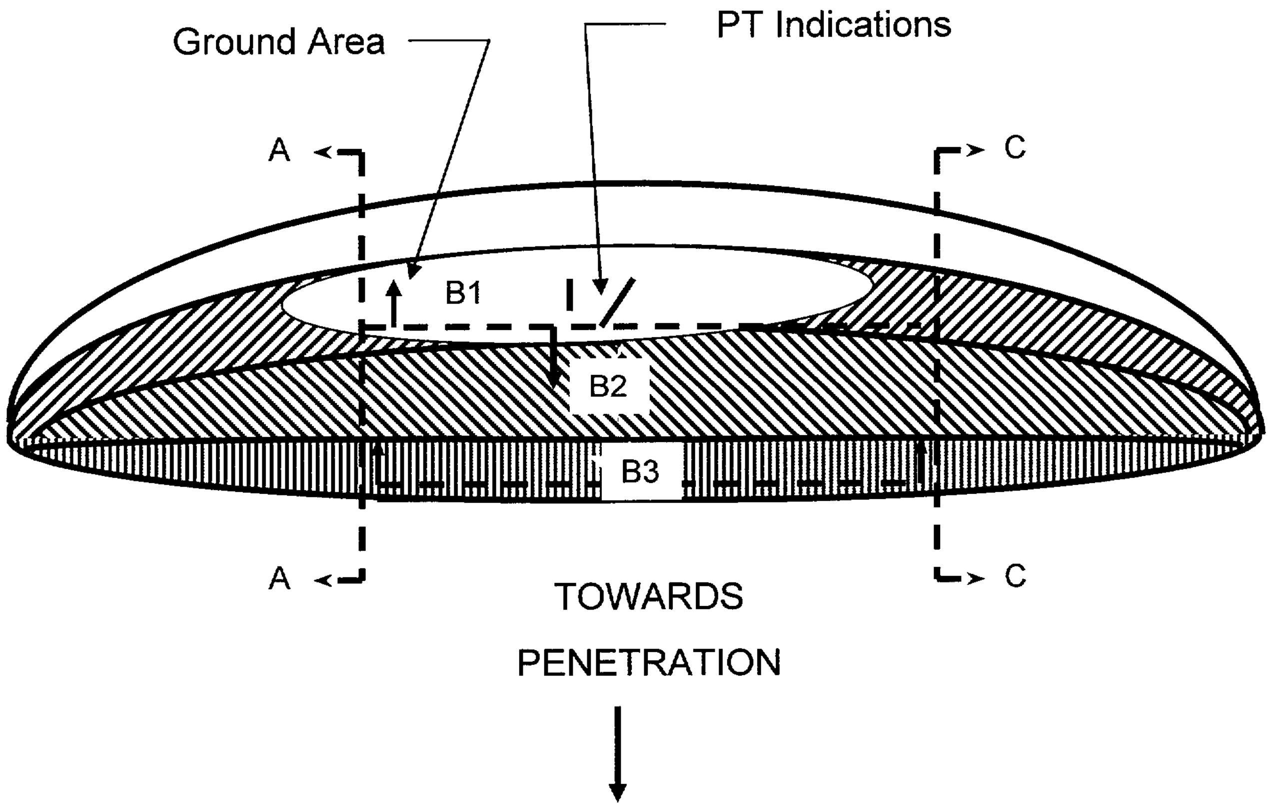
Surface Examination

Two PT Indications were evident in an area that had been recently ground

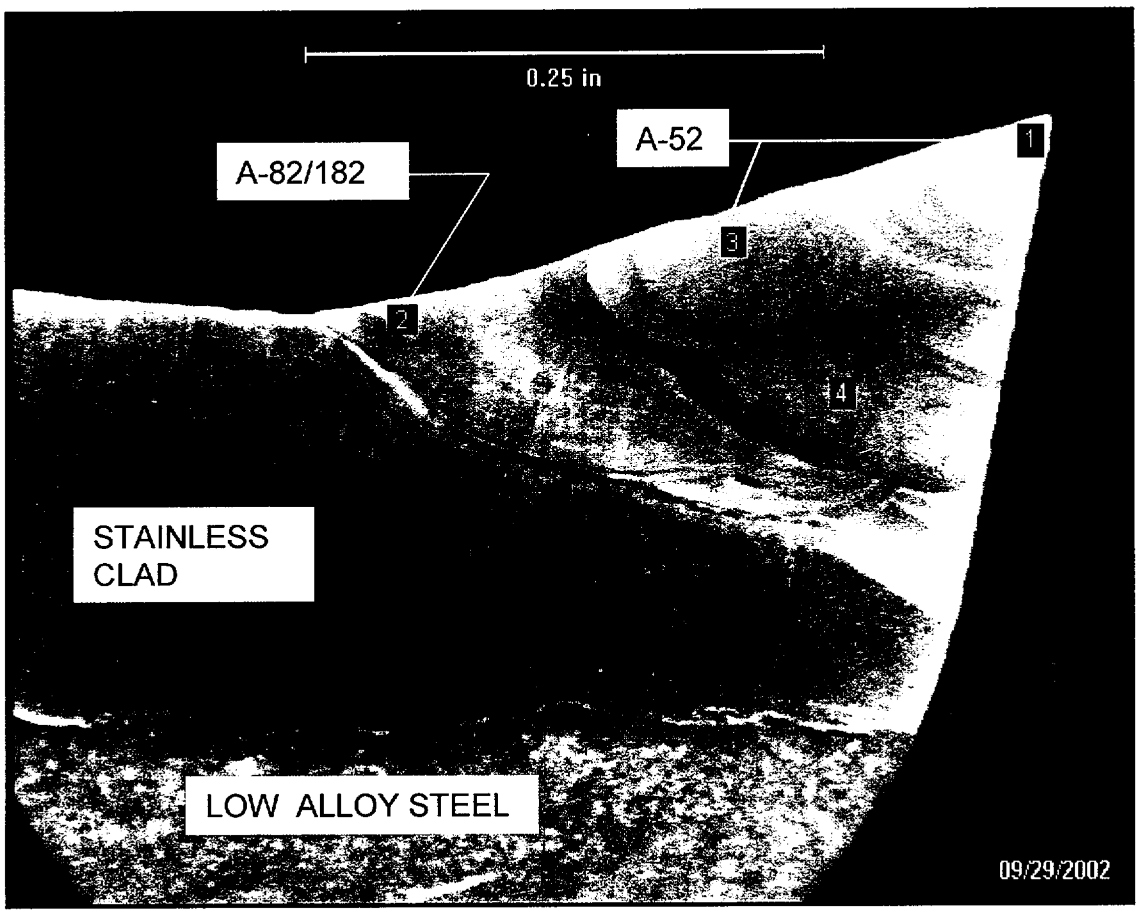
At least one other surface indication was found in the ground area of the outboard weld bead

No surface indications were evident on any other surface with optical and SEM examinations of up to 40X

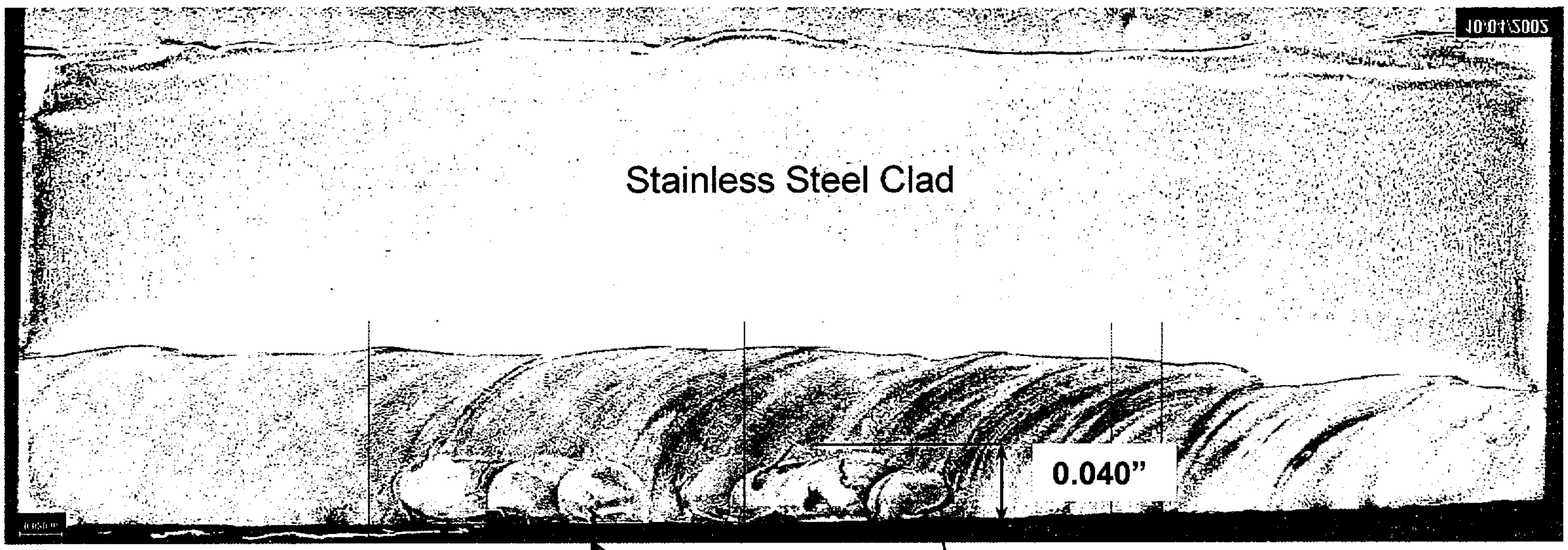
Sectioning Plan



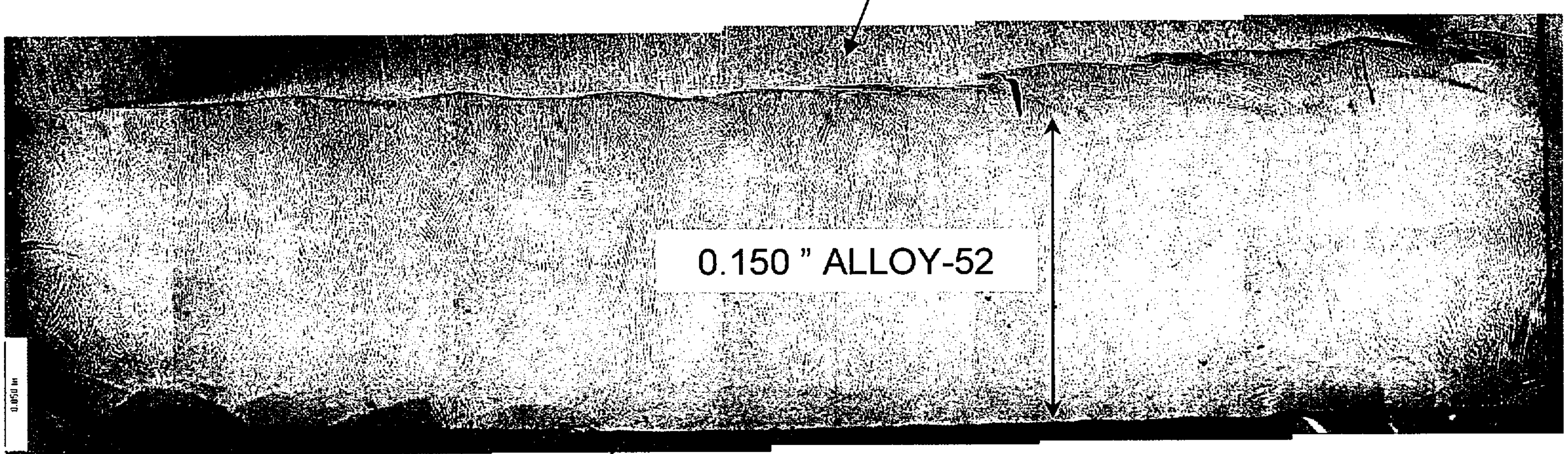
Cross Section C-C Intact Weld Beads



Longitudinal Section B1:Overall



Longitudinal Section B3: Overall



Section B
Observations

The PT Indication is Shallow and is Located at the Edge of a Diluted Weld Bead in the Ground Area

No Cracking was Identified at the Wetted Surface or within the Full-Thickness Repair

Most Hot Cracking Occurred at 308SS, Alloy-182/82 and Alloy 52 Diluted Boundaries

CONCLUSIONS

No Leakage Path was Identified on This Sample

Full Thickness Alloy 52 Repair Did Exist Beyond the Original Butter Layer at the Boat Sample Location

The Alloy 52 Repair Stopped Short of the Alloy 82/182 J-Weld Cover Pass

Dye Penetrant Indications Identified in this Area were a Result of Interdendritic Hot Cracking

Hot Cracking was observed in the Diluted Weld Beads but not in the Alloy 52 Final Layer

No Hot Cracks were Evident at the Wetted Surface or Within the Final Repair Layer

No Evidence of Environmental Degradation was Present on This Sample

Penetration #51:

Evaluation of Potential Leakage Paths

Possible Leak Paths in Penetration #51

- Penetration tube inside diameter
- Repair weld surface
- Surface outboard of repair weld
  - Toe of repair weld
  - Exposed 82/182 surface

Possible Leak Paths: Penetration 51

- Penetration tube inside diameter
  - Examined by surface exam (ECT) and volumetric (UT)
  - Minor indications found, but no leakage path exists

Possible Leak Paths: Penetration 51

- Penetration tube outside diameter UT scans
  - Time-of-Flight Diffraction optimized for identification of circumferentially oriented degradation on tube OD surface
  - Time-of-Flight Diffraction optimized for identification of axially oriented degradation on tube OD surface
  - High frequency to identify variations in tube to RV head shrink fit, which might indicate a leak path
  - Low frequency to identify degradation in the weld, parallel to the tube-to-weld interface
  - Confirmed that no leakage path exists along the tube OD

Possible Leak Paths in Penetration #51 Evaluation and Conclusions (continued)

Repair weld surface

- No rejectable indications from 2001 dye penetrant exam
- Rounded indication observed after flapping and dye penetrant exam in 2002
- Rounded indications are categorized as inclusions or porosity, not PWSCC
- Rounded indications eliminated quickly with subsequent grinding

Possible Leak Paths in Penetration #51 Evaluation and Conclusions (Continued)

- Surface outboard of repair weld
  - Toe of repair weld boat sample results indicate no cracking at toe of weld
  - Exposed 82/182 surface
    - Acid etch on penetration #62 demonstrates exposed Alloy 82/182 surface between weld repair and stainless clad
    - Boat sample from penetration #51 demonstrates exposed Alloy 82/182 surface between weld repair and stainless clad

Possible Leak Paths in Penetration #51 Conclusions

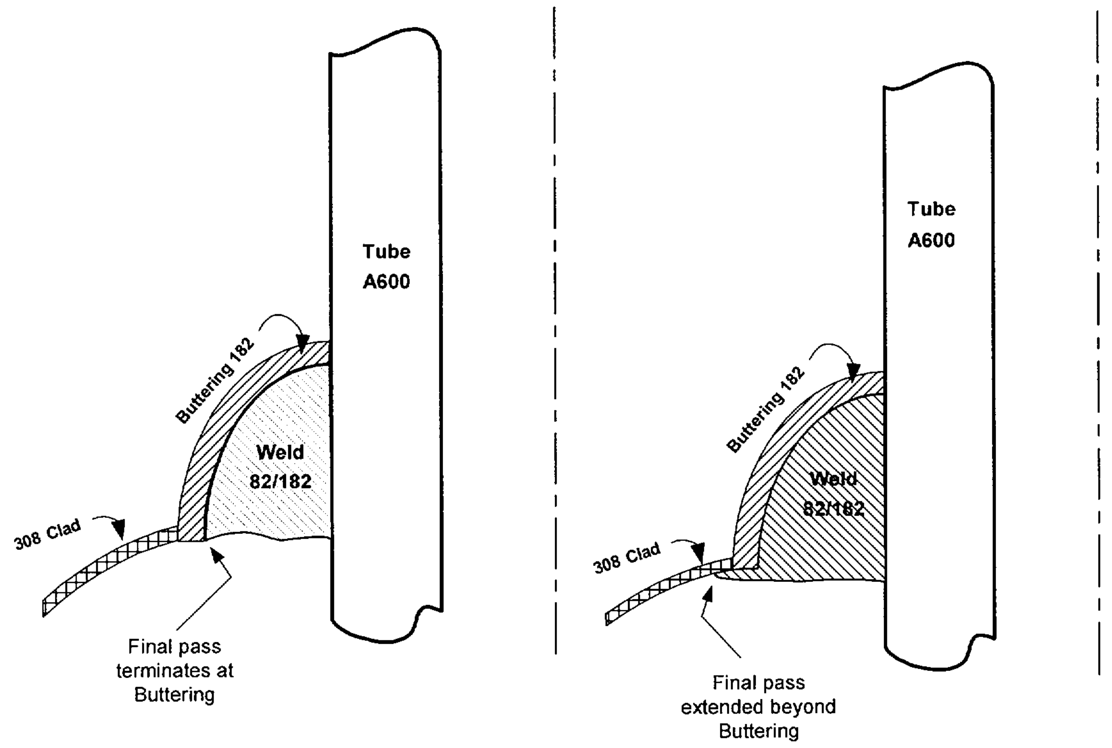
- No leak path identified in weld repair and inner periphery of weld repair
- Outer periphery investigation:
  - There are exposed indications beyond the overlay repair
  - 2002 indication location consistent with original flaws at 190 degrees from 2001
  - A boat sample was taken in an attempt to characterize the indications
  - The boat sample confirmed that an 82/182 surface was left exposed
  - Through this process, plausible leak paths outboard of the repair weld can be concluded

Incorrect Application of the Repair Weld: How did it Happen?

Visual identification of J-groove weld toe was incorrectly interpreted as the Alloy 600 to Stainless Steel interface

Poor communication: Information that was developed to define the interface was not adequately communicated to proper personnel.

J-Weld Final Pass Configurations



Lessons Learned

There are uncertainties in the location of the interface between the stainless steel clad and the Alloy 82/182 material

Review of manufacturing records indicates latitude in application of weld that could vary the interface location

Corrective Actions

Two approaches considered to assure complete coverage of Alloy 182/82 buttering & J-weld

For future applications, both manufacture record reviews and on-site inspections will be performed to locate this interface

Technique	Advantages	Disadvantages
Conservatively Extend Overlay Boundary Out from Nozzle based on Design Information	Simple	• Extra Weld Deposit • Larger Area for PT Exam • Personnel exposure
Eddy Current Test to /define Material Boundaries by Conductivity & Permeability Change	• Principle Proven at three sites plus laboratory • Minimize Area of Overlay & PT Exam • Reduce In Process Repair	Tooling Application in Progress

Conclusions

The weld repair on penetrations 51, 62 and 63 did not cover all of the exposed Alloy 82/182 material

An evaluation of all relevant data demonstrates that this exposed Alloy 82/182 material is the only plausible leakage path in penetration 51

The boat sample analysis demonstrates that the two layer Alloy 52 weld repair material is in good condition

All open questions on the generic relief request have been addressed

Timely approval of the Westinghouse relief request is requested to support the upcoming fall outages