

San Onofre Unit 3 Replacement Steam Generator

Divider Plate-to-Channel Head Weld Separation

September 15, 2009



An EDISON INTERNATIONALSM Company



Introductions

Scope of Presentation

- To present the investigation into weld separation and cracking found in the Unit 3 Replacement Steam Generators (3A/3B RSG)
- To present the plan for repair of the Unit 3 RSGs
- To present the assessment of the acceptability of the Unit 2 RSGs (2A/2B)

San Onofre Nuclear Generating Station Units 2 and 3

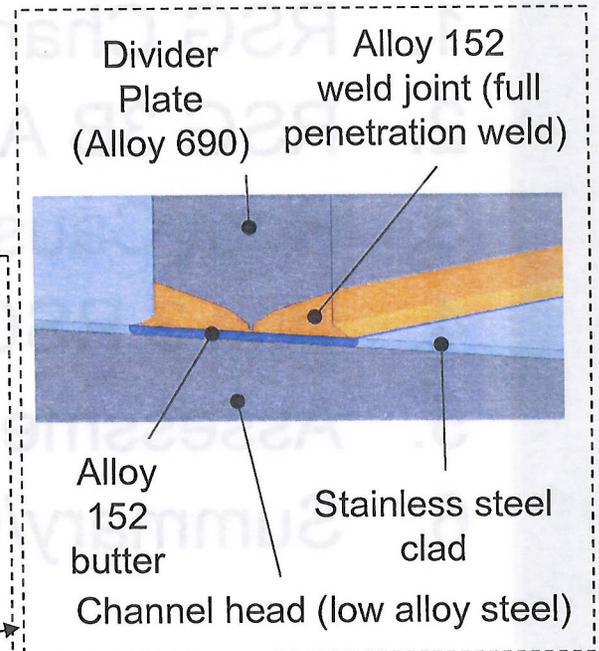
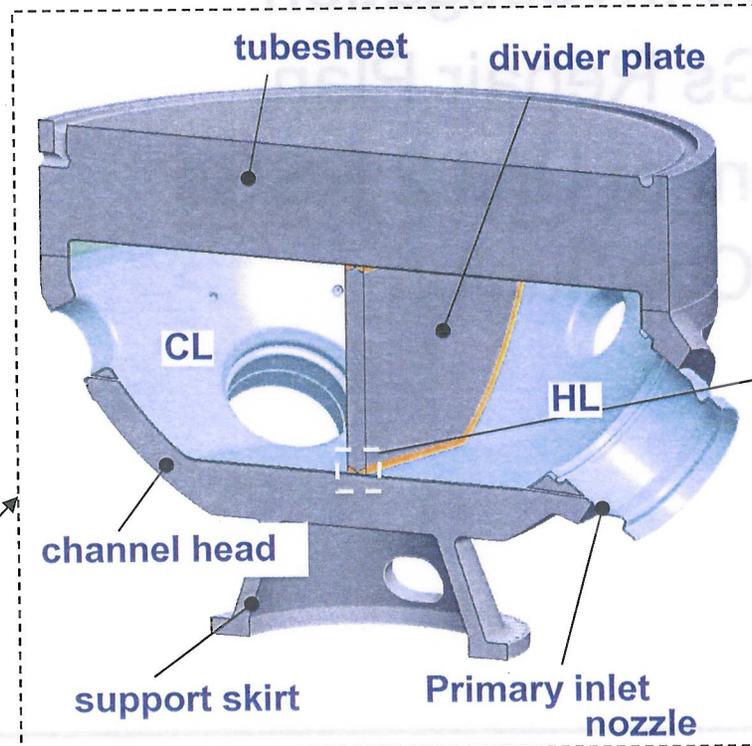
- Two CE NSSS units
- Two steam generators per unit
- SG replacement schedule
 - Unit 2 – Fall 2009
 - Unit 3 – Fall 2010

Agenda

1. RSG Channel Head and Divider Plate
2. RSG 3B As Found Condition
3. Root Cause Investigation
4. Unit 3 RSGs Repair Plan
5. Assessment of Unit 2 RSGs
6. Summary/Conclusion

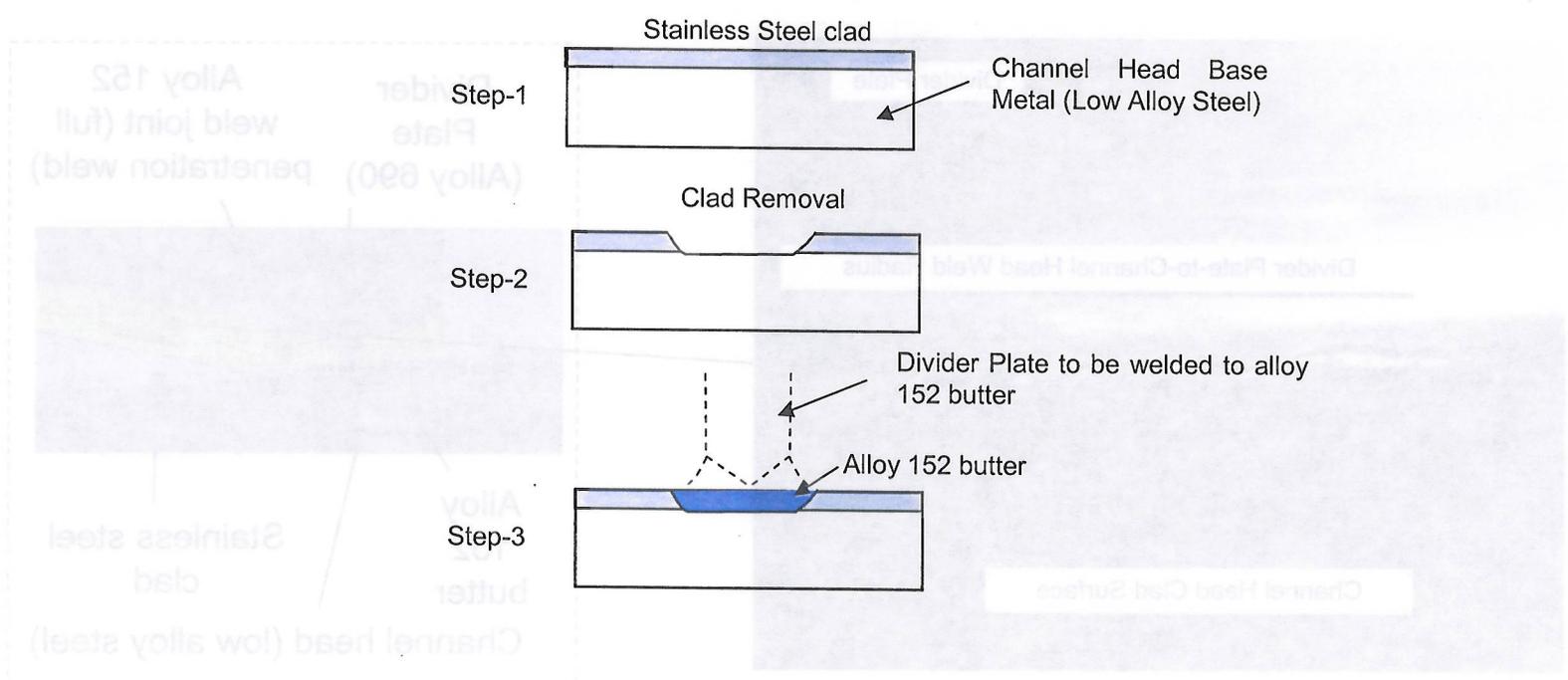


RSG Channel Head and Divider Plate



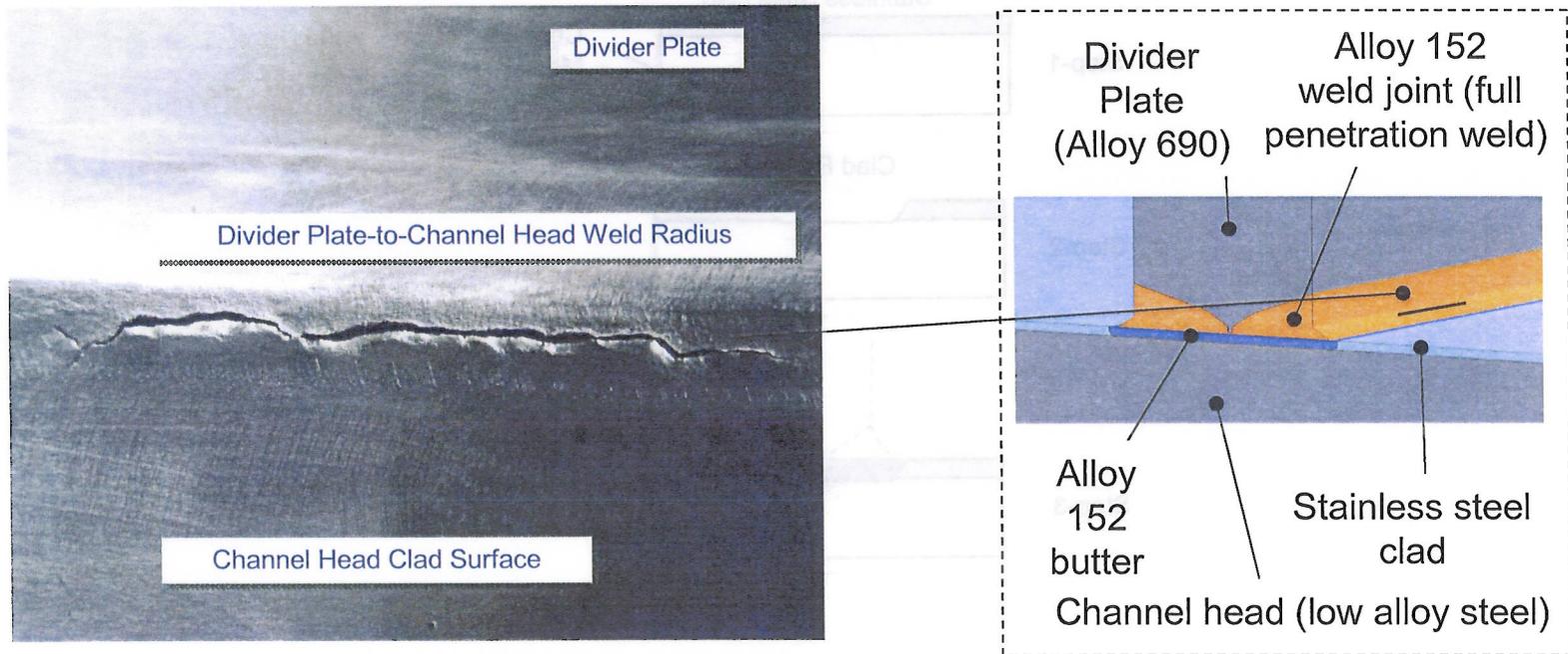
RSG Fabrication Process

A crack in the weld between the RSG 3B divider plate and the channel head was reported on March 18, 2009 after completion of the hydrostatic pressure testing.



RSG 3B As Found Condition

A crack in the weld between the RSG 3B divider plate and the channel head was reported on March 18, 2009 after completion of the hydrostatic pressure testing.



RSG 3B Cold-Side Crack in Divider Plate-to-Channel Head Weld

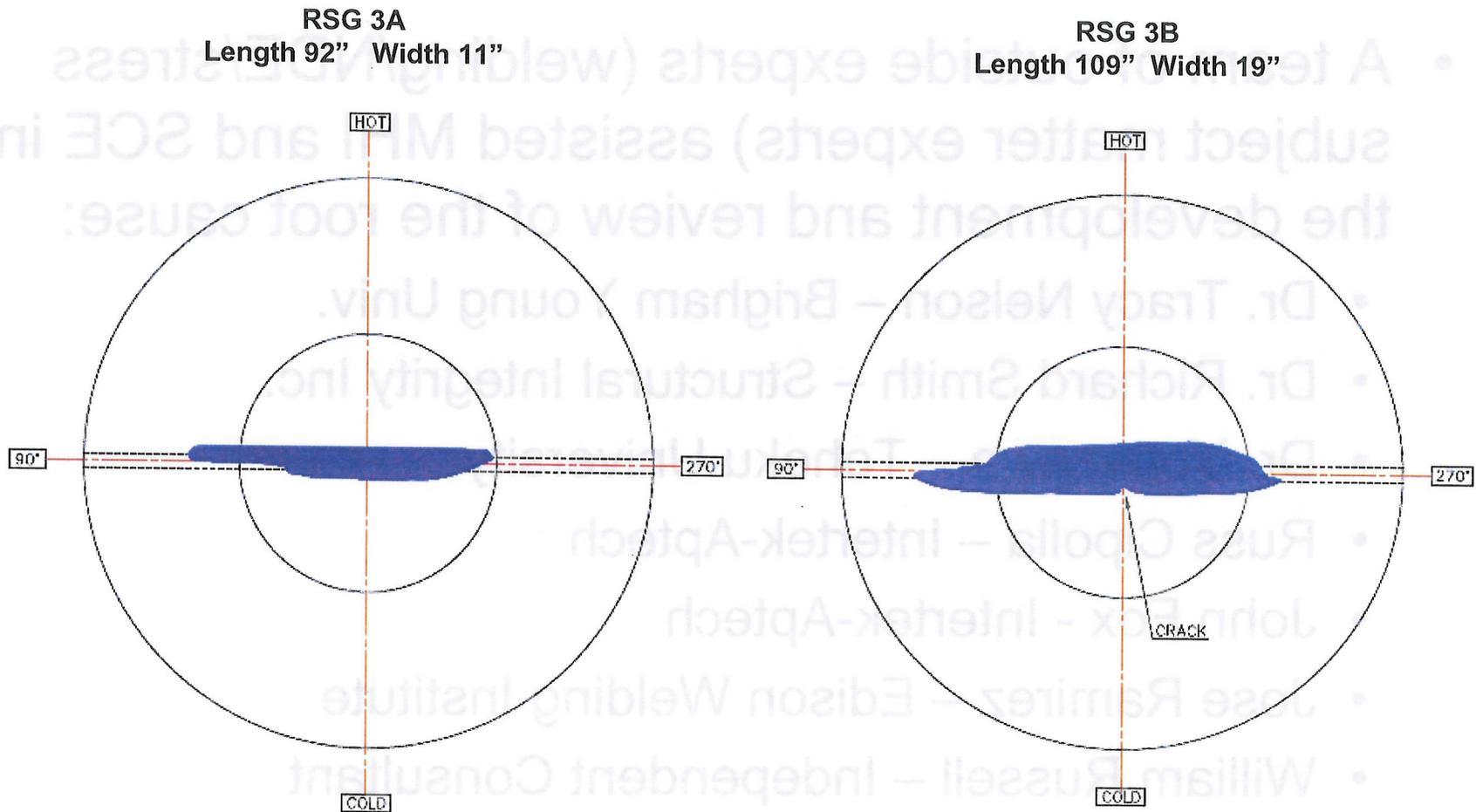
Unit 3 RSG Root Cause Investigation Inspection Findings

- Inspections of divider plate to channel head and divider plate to tubesheet welds
- Surface examinations with liquid penetrant and visual
 - 3A RSG
 - 9 small cracks - divider plate to channel head weld
 - Strain marks - divider plate to channel head weld
 - 3B RSG
 - Strain marks - divider plate to channel head weld
 - As found crack - divider plate to channel head weld

Unit 3 RSG Root Cause Investigation Inspection Findings (Continued)

- UT examinations – straight beam from accessible areas inside and outside channel head
- Inconel butter and stainless steel clad separation from channel head base material (low alloy steel)
- Affected regions – under and adjacent to divider plate to channel head weld

Unit 3 RSG Root Cause Investigation Extent of Separation



Unit 3 RSG Root Cause Investigation Team Expertise

- A team of outside experts (welding/NDE/stress subject matter experts) assisted MHI and SCE in the development and review of the root cause:
 - Dr. Tracy Nelson – Brigham Young Univ.
 - Dr. Richard Smith – Structural Integrity Inc.
 - Dr. Yonezawa – Tohoku University
 - Russ Cipolla – Intertek-Aptech
 - John Fox - Intertek-Aptech
 - Jose Ramirez – Edison Welding Institute
 - William Russell – Independent Consultant

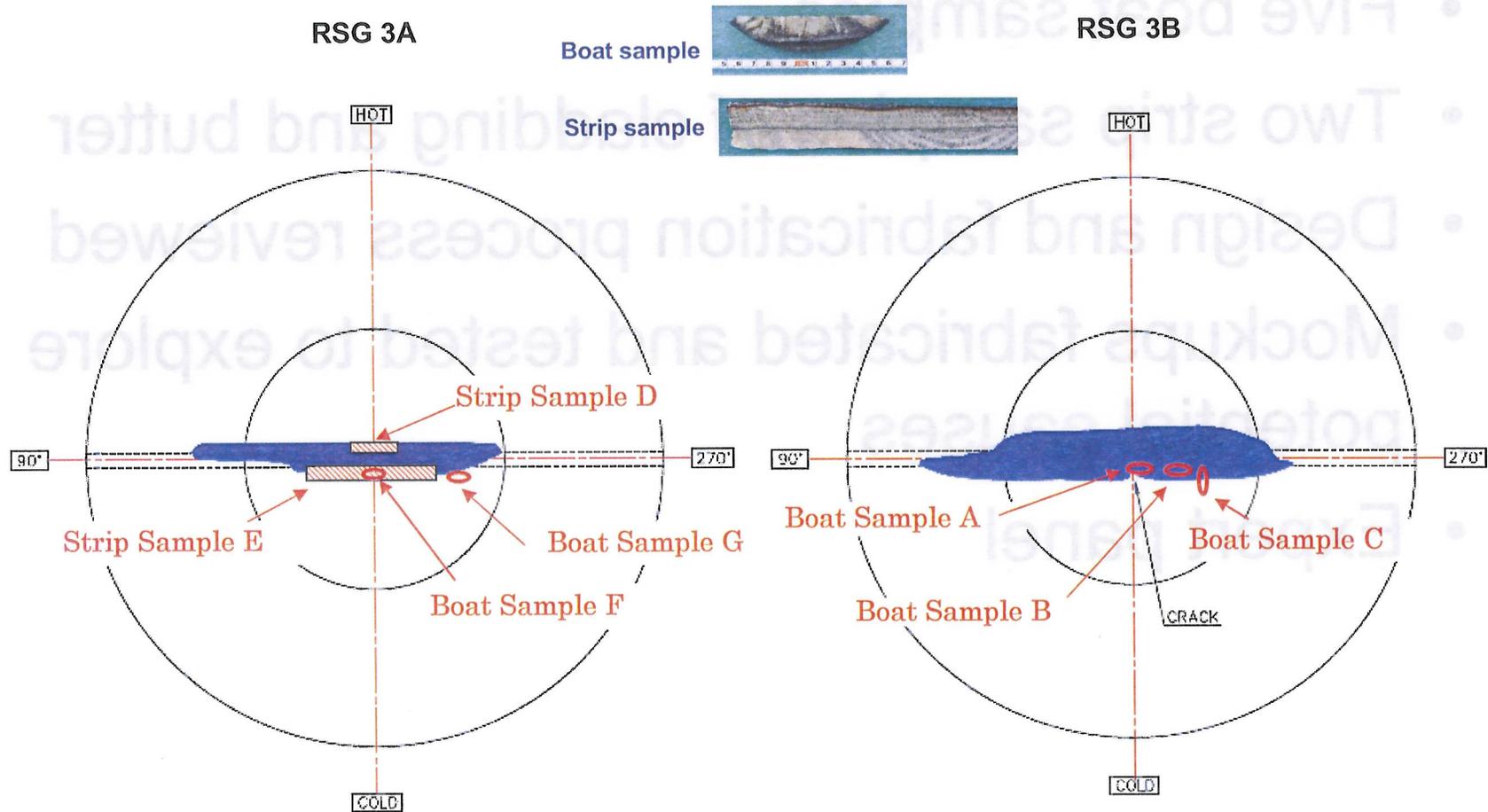
Unit 3 RSG Root Cause Investigation Overview

- Five boat samples
- Two strip samples of cladding and butter
- Design and fabrication process reviewed
- Mockups fabricated and tested to explore potential causes
- Expert panel



Unit 3 RSG Root Cause Investigation

Extent of Separation



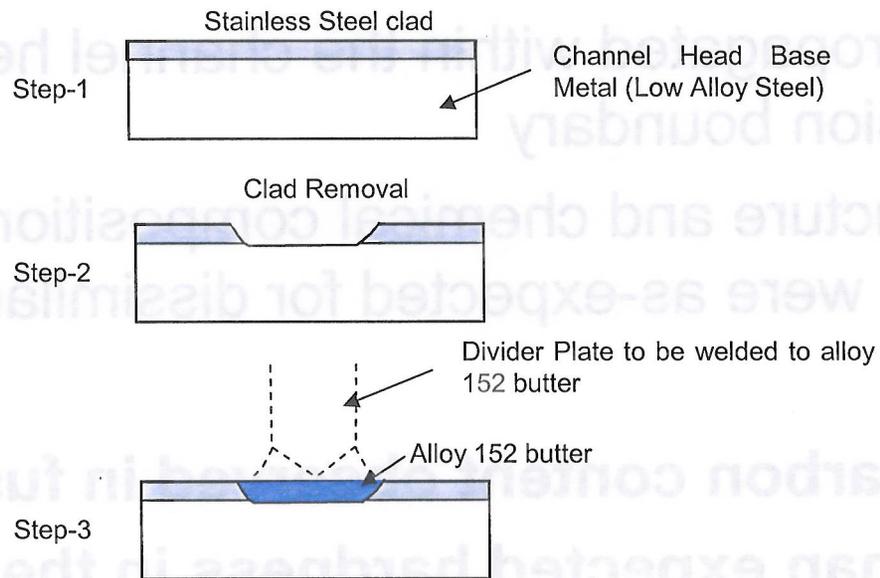
Unit 3 RSG Root Cause Investigation Boat/Strip Sample Results

- Brittle failure mode exhibited in separation region
- No micro cracking or significant weld defects
- Failure propagated within the channel head base metal along fusion boundary
- Microstructure and chemical composition of base metals and weld were as-expected for dissimilar metal welds

Higher carbon content observed in fusion zone

Higher than expected hardness in the base metal heat affected zone near fusion boundary

RSG Fabrication Process



Unit 3 RSG Root Cause Investigation Fabrication

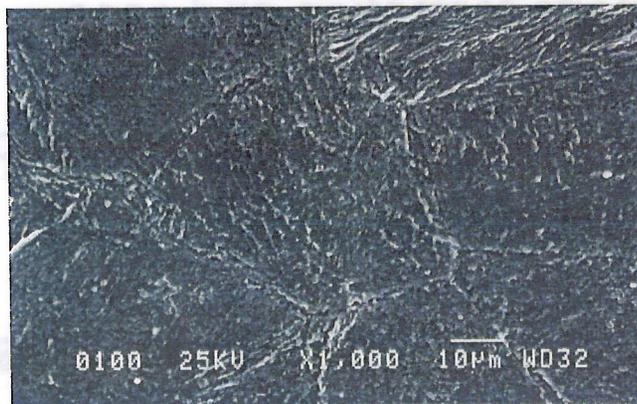
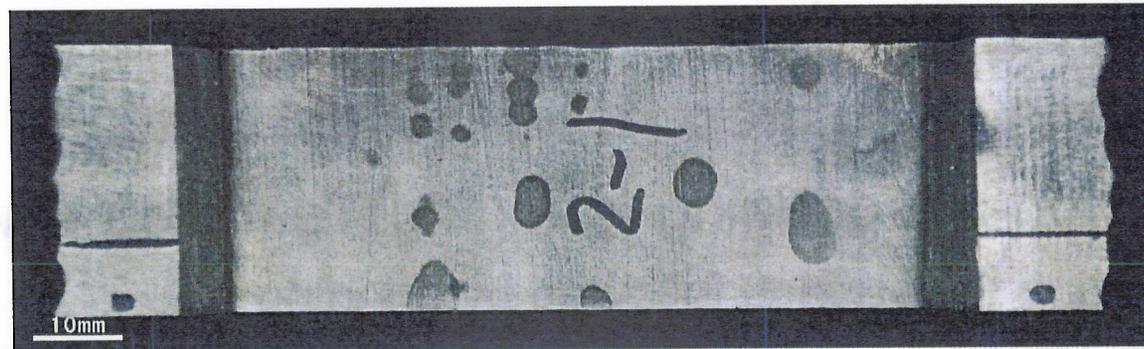
- Entire channel head surface clad with stainless steel for corrosion protection
- Clad removed to prepare for Inconel buttering
- Air carbon-arc gouging (gouging) removed clad
 - Gouging the surface followed by grinding
 - Gouging process results in martensite formation and case hardening of surface from the increased carbon content and rapid quenching caused by the large heat sink of the channel head
 - Hardened surface was not completely removed by grinding

Higher hardness regions and variations in surface conditions led to weak weld bonding with less than design strength



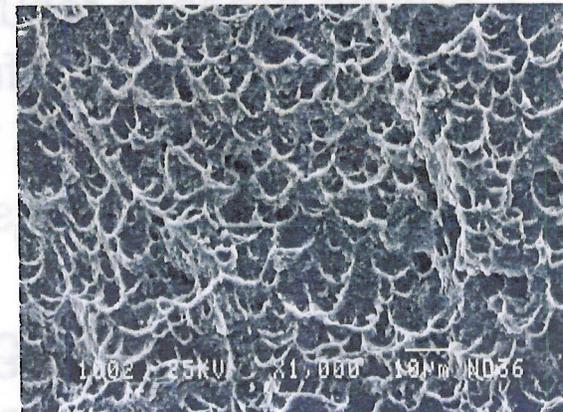
Unit 3 RSG Root Cause Investigation Metallographic Evidence for Weak Bond

Mockup - gouging showing case hardening locations



Poor bonding – flat, featureless surface
at fusion boundary

Boat
Sample



Good bonding – ductile failure
in weld

Unit 3 RSG Root Cause Investigation Mockup Program

- Weld process mockups were fabricated:
 - Reproduced divider plate to channel head weld process
 - Scale sample testing of fabrication process
 - Reproduce the butter/clad separation using other processes
 - Determine carbon contamination effects



Unit 3 RSG Root Cause Investigation Mockup Program Results

- Mockups supported conclusion from fabrication review
 - Produced local areas of high hardness following gouging
 - Results of carbon contamination confirmed

Addition of carbon to welding process creates a material condition more susceptible to brittle fracture

Unit 3 RSG Weld Separation Root Cause

Separation was caused by use of gouging to remove stainless steel clad and prepare low-alloy steel channel head for Inconel butter
Led to weak weld bond
Reduced weld strength below design

Unit 3 RSG Root Cause Investigation Potential for Hydrogen Induced Cracking

- Unable to completely exclude Hydrogen Induced Cracking (HIC)
 - Mockup tests with hydrogen added reproduced brittle failure
 - Gouging produces higher hardness
 - Higher stress provided by steeper weld joint edge (gouging)
- May leave the butter to base metal weld more vulnerable to hydrogen-induced cracking
- Speculation that welding rod controls may have contributed moisture

Steps have been incorporated in repair plan to control all potential sources of hydrogen to mitigate this mechanism

Unit 3 RSG Repair Plan

Repair Scope Confirmation

- Stress analysis performed under hydrostatic test conditions with separation present
- Pressure boundary components (channel head, tubesheet, lower shell, and nozzles) had acceptable stress levels – not challenged
- Divider plate stresses slightly above allowable near edge of separation
- Visual, PT and UT examinations confirmed acceptability of reuse of divider plate and butter/clad region not affected by separation



Unit 3 RSG Repair Plan

- Excavation method is manual grinding, gouging not used
- Replacing affected regions of weld, butter and clad
- Additional in-process NDE to monitor repair
- Reduced hydrogen potential through higher baking temperatures, longer preheat time and moisture control of weld consumables
- Groove and joint created by clad removal process will have shallow edge profile – lower stress
- Repair process is currently undergoing review and revision

Assessment of Unit 2 RSGs

- RSGs for Unit 2 had been fabricated, tested, shipped and received at San Onofre when the issue was first identified in RSGs for Unit 3
 - Received same factory inspections as Unit 3 RSGs
- Additional inspections performed at San Onofre RSG temporary storage facility to same standards as used at MHI for the root cause inspections for Unit 3
- Visual, PT, and UT

No separation and no cracking found

Assessment Unit 2 RSG's (Continued)

- Comparison of Unit 2 to Unit 3 RSGs
 - Gouging was not used in Unit 2 RSGs
 - Machining used to remove clad
 - No carbon contamination
 - No resulting regions of excessive hardness
 - Lower levels of stress in the U2 machined groove
 - Butter groove corner radius and lower slope result in much lower stresses in Unit 2 RSGs
 - Longer pre-heat duration and higher post-baking temperatures have a favorable influence on hydrogen concentration in Unit 2 RSG welds

Summary

- Based on inspection results and differences in fabrication, Unit 2 RSGs have structurally sound divider plate welds
- Unit 2 RSGs are acceptable for installation
- Unit 3 RSGs will be repaired and shipped

In addition however, SCE intends to conduct additional confirmatory inspections



Additional Confirmatory Inspections for Units 2 and 3

- Remote visual inspection of divider plate to channel head and divider plate to tubesheet welds
- Repeat baseline inspections - straight beam UT from accessible locations outside the channel head
- Inspections will be conducted during
 - First steam generator inspection outage
 - Outage near the end of the first 10-year interval

Conclusion

- Unit 2 RSGs are acceptable for installation and operation
- Unit 3 RSGs, as repaired, will be acceptable for installation and operation

