NRC/Industry Meeting Regarding Tube-to-Tubesheet Weld and Divider Plate Cracking Report

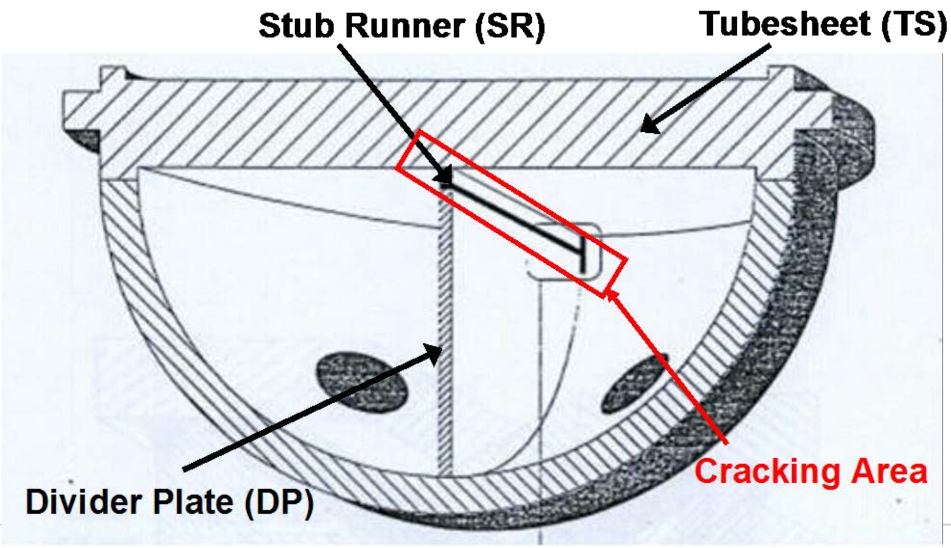
Helen Cothron, Manager
EPRI Steam Generator Management Program

Richard Smith, Sr. Associate
Structural Integrity Associates

Greg Kammerdeiner
First Energy

Background

- Primary Water Stress Corrosion Cracking has been reported in the weld between the divider plate and the stub runner in French and Swedish steam generators with Alloy 600 divider plate and Alloy 82 and 182 weld material
- SGMP completed a multi-phase project in 2010 that concluded that these cracks were not safety significant
  - EPRI Technical Report 1020988



Phase I Determined the Limiting Steam Generator

- Phase I (EPRI Report 1014982, June 2007) evaluated operating experience and determined limiting model steam generator
  - Cracks observed in divider plate and stub runner weld heat affected zones in foreign fleet.
  - Westinghouse Model 51 steam generators determined to be the limiting case for US plants.
  - Model 51 is limiting case due to thinnest divider plate and greatest vertical displacements of the centerline of the tubesheet under normal and accident conditions.
  - Compared well with foreign operating experience

Phase II Assessed Transients, Stress Reports, and Repairs

- Analysis of transients (LOCA and Non-LOCA)
- Analysis of multiple crack geometries
  - Multiple and combined origin sites
- Review of ASME Code stress reports to determine if they are affected by degraded divider plate condition
- Review of steam generator tube repairs

Background / Overview

- The design analyses for the following components did not take credit for the divider plate:
  - Tubesheet
  - Channel head
  - The lower shell
  - Tubesheet to channel head junctions
  - Tubesheet to lower shell junctions
  - Tube-to-tubesheet welds

Analyses Not Affected by a Degraded Divider Plate

- Supporting analysis and boundary conditions for lower steam generator complex
- The performance or safety function of the steam generator and the affected loop during a postulated accident condition
- The supporting analysis basis for tube plugs installed prior to 1989
- C* Alternate Repair Criteria
- H* Alternate Repair Criteria
- Alloy 800 sleeves

Analyses Sensitive to a Degraded Divider Plate but Conservative

- Divider plate factor of 76% of the vertical displacement was used in analyses for
  - Steam generator mechanical tube plugs used after 1989
  - Laser welded and TIG welded sleeves
  - F* Alternate Repair Criteria
  - W* Alternate Repair Criteria
- Conservative because 76% is **greater than the vertical displacement associated with a fully degraded divider plate (64%)**

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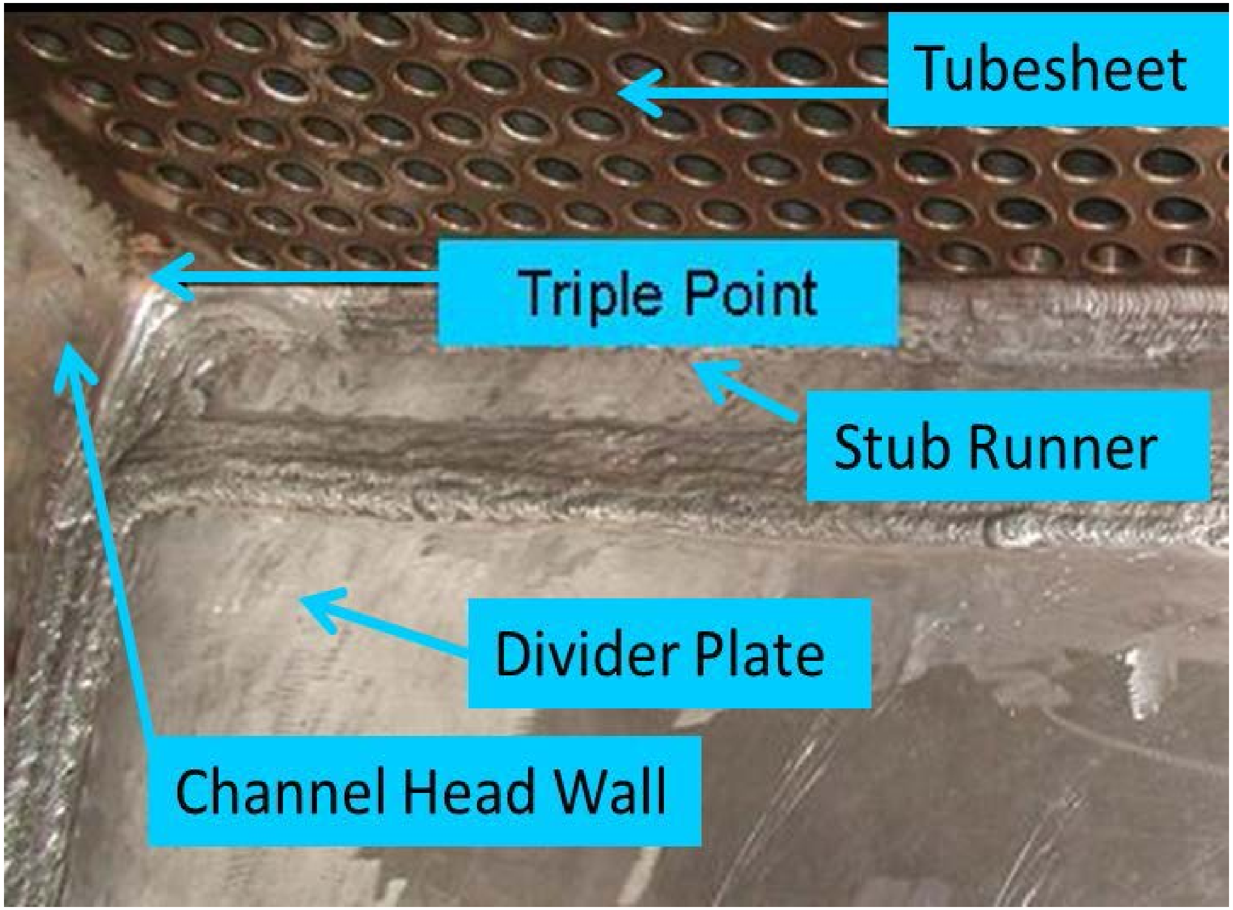
Phase II Conclusions

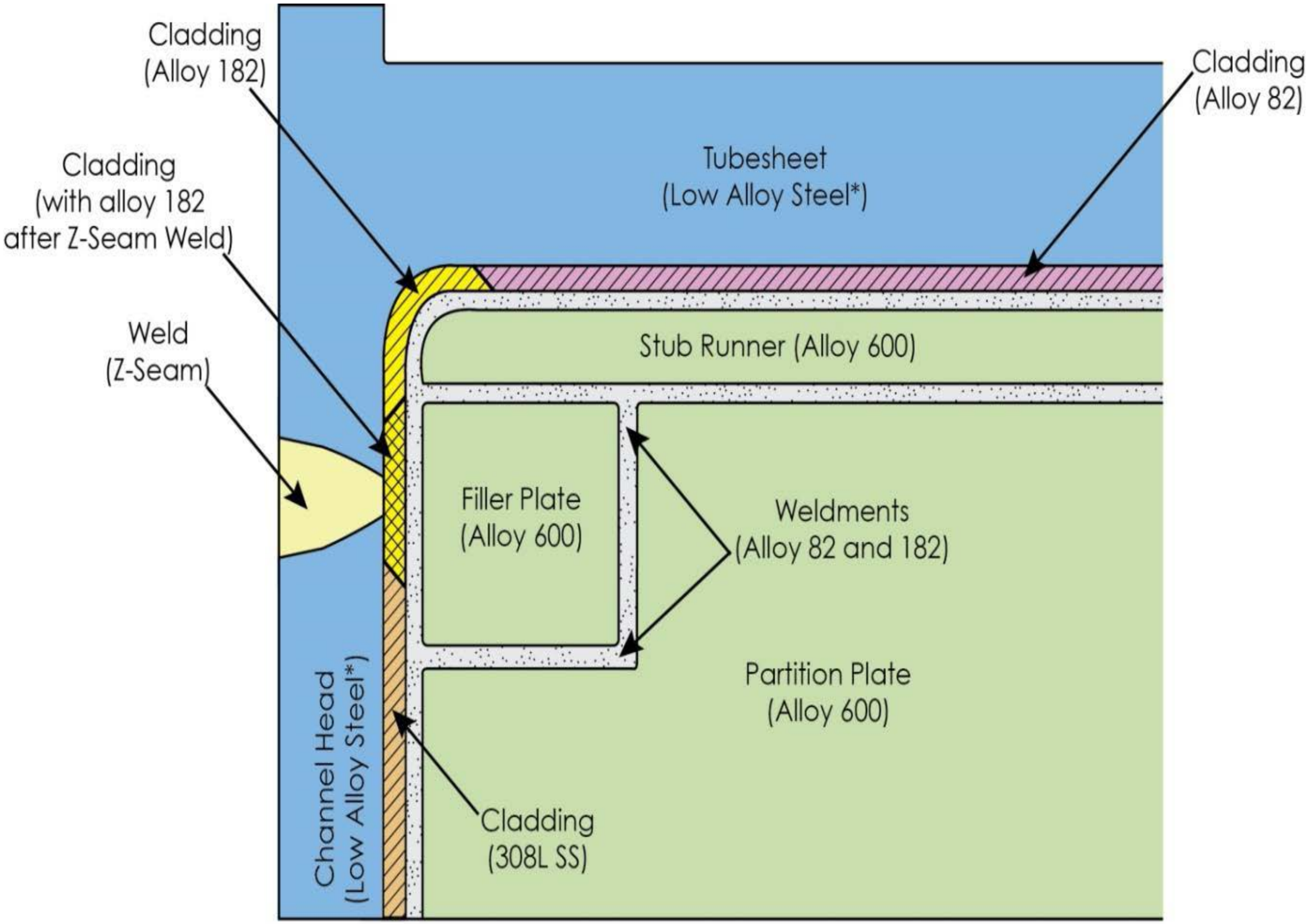
- No identified need for US plants to inspect for PWSCC based on program results
  - Degraded divider plate is not a safety concern during operations
  - Degraded divider plate is not a structural concern during operations
  - Degraded divider plate does not affect existing repair criteria or repair tools
  - Divider plate inspection not mandated by ASME Code

Divider Plate Crack Propagation

- When US plants began submitting license renewal applications to the NRC, the potential crack propagation over extended period of operation became a concern
- SGMP began a project in 2011 to address the concerns of cracks propagating over time to pressure boundary components such as the channel head or the tube-to-tubesheet weld

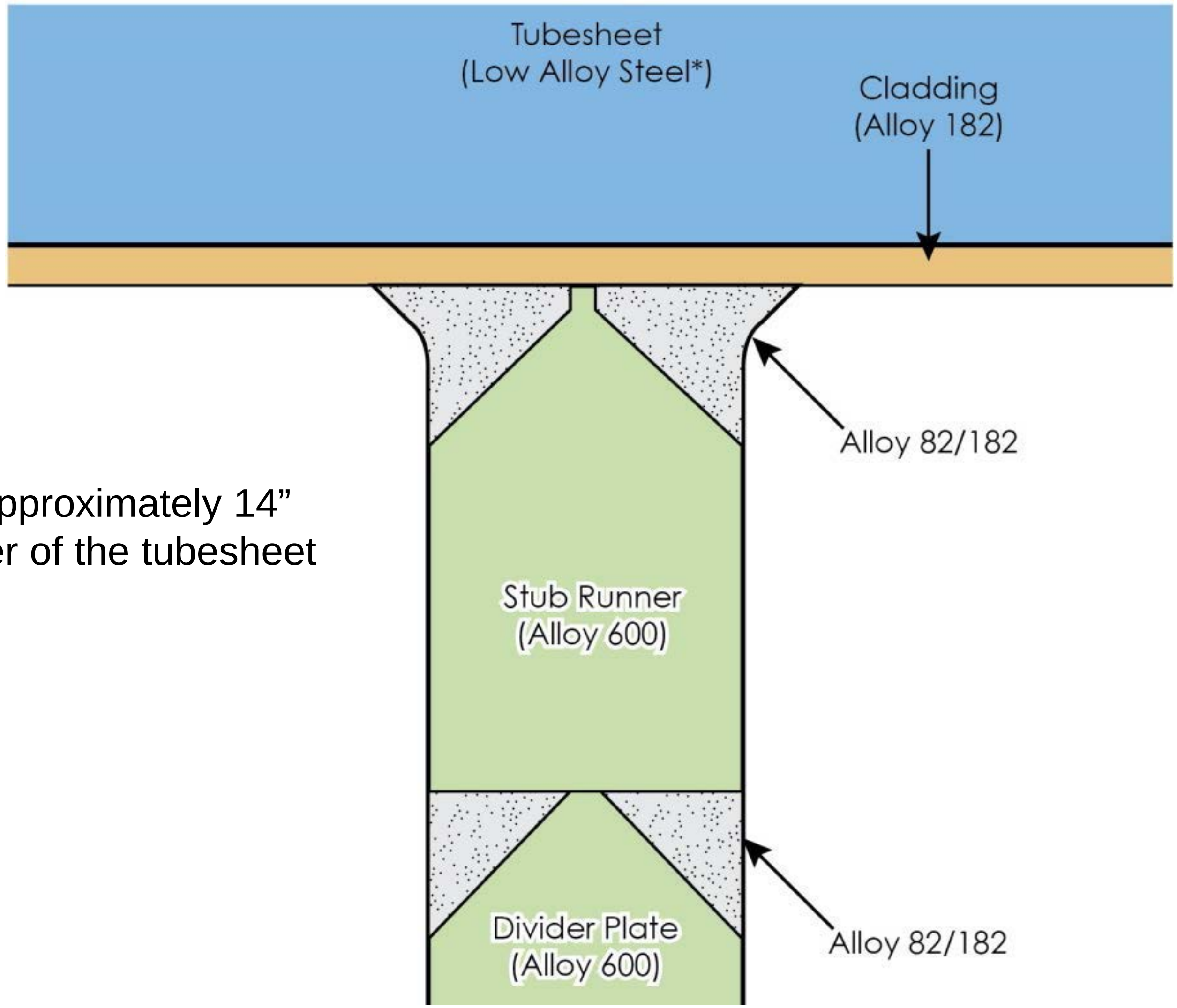


Divider Plate to Channel Head/Tubesheet Weld Configurations

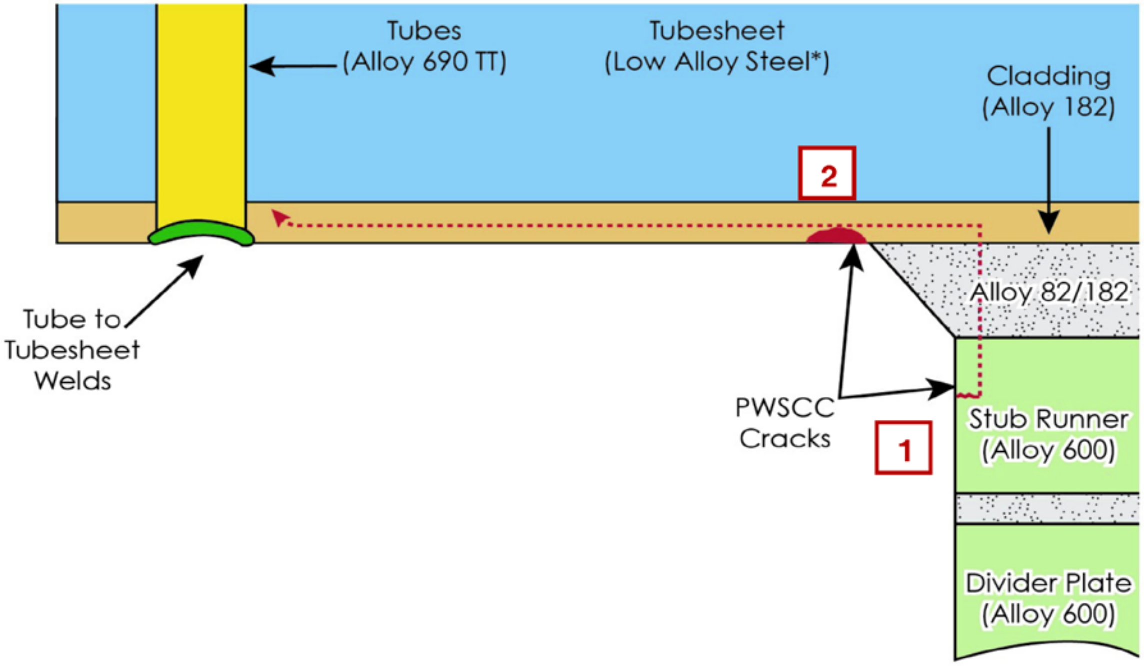


Divider Plate – Tubesheet Center Configuration

- 182 used approximately 14” in the center of the tubesheet



Divider Plate Crack Propagation Scenarios

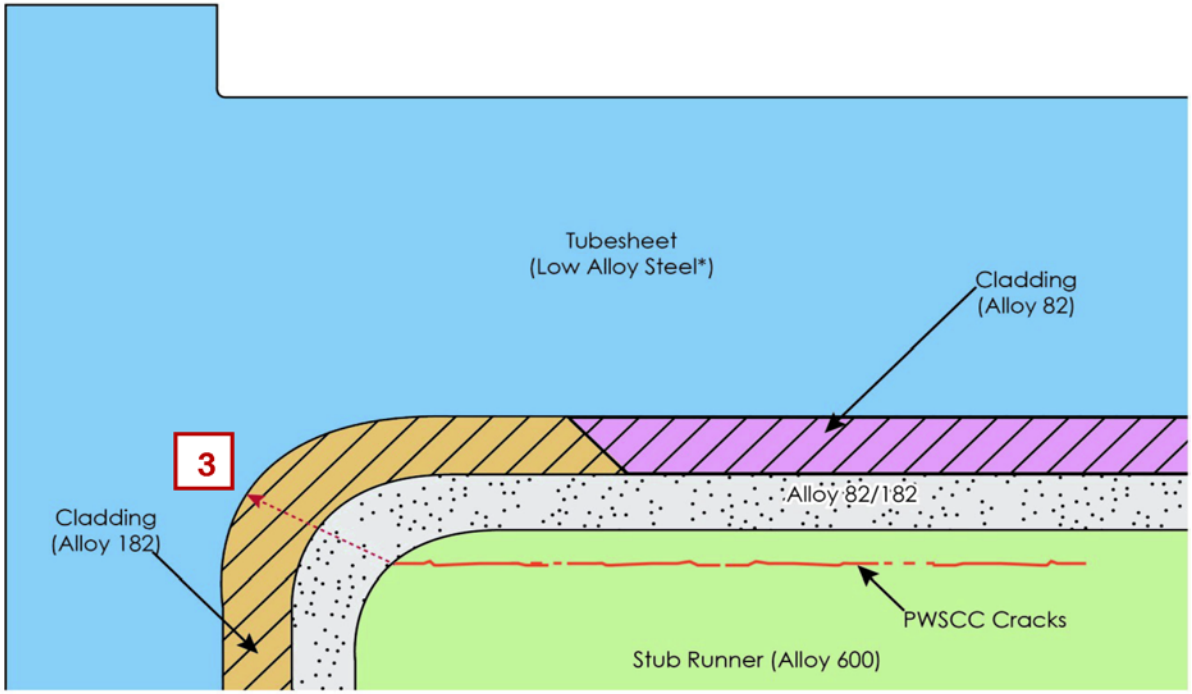


Scenario 1 assumes cracks initiate in the divider plate assembly and propagate to the tube-to-tubesheet weld

Scenario 2 assumes cracks initiate in the tube-to-tubesheet weld or the cladding

Divider Plate Crack Propagation Scenarios

Scenario 3 assumes cracks initiate in the divider plate assembly and propagate through the stub runner, the 182 weld at the triple point and through the low allow steel



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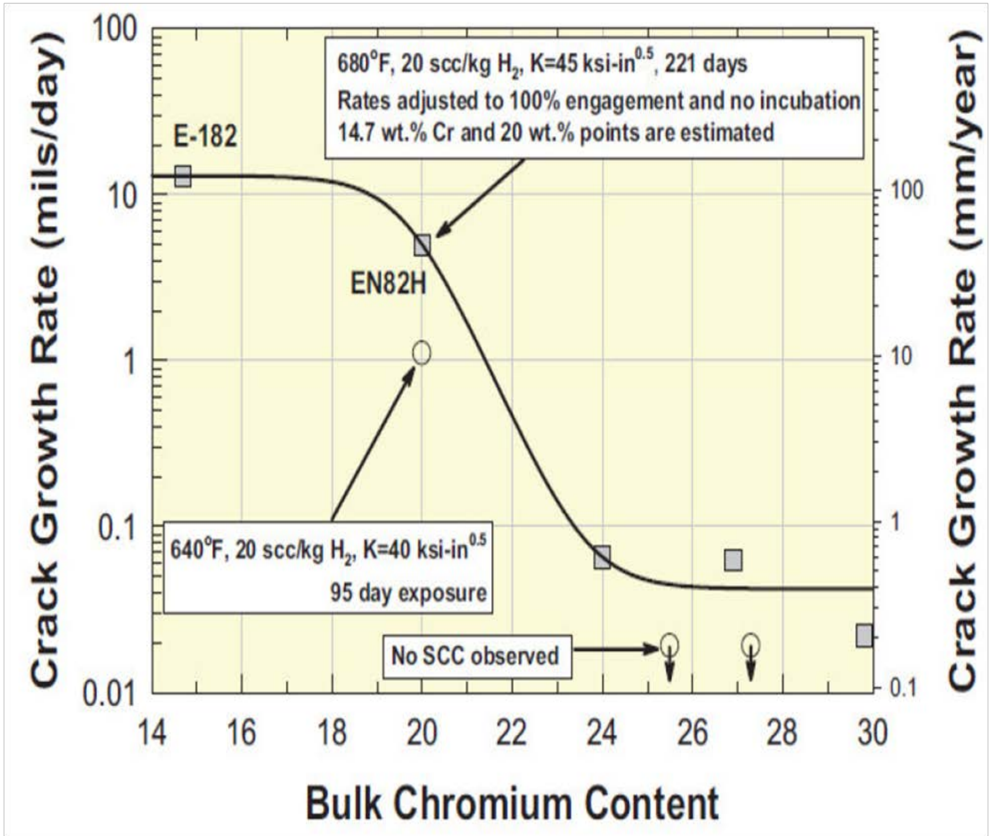
Scenarios 1 and 2

Concerning the Tube-to-Tubesheet Weld

Tube-to-Tubesheet Weld Cracking

- Industry has accepted a 24% chromium content as a conservative threshold for PWSCC initiation
  - Chromium levels down to 20% have excellent resistance to initiation based on testing and operational experience
- Objective of this project was to determine the chromium content in an autogenous weld between Alloy 690 tubing and 82 or 182 weld material
  - Construct a tube-to-tubesheet mockup to investigate



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Field Material Review

Statistic	Alloy 690 (product analysis)	FM 82	FM 182
Mean	29.3	20.7	14.4
Maximum	29.7	21.5	16.5
Minimum	29.0	19.6	13.6

- Review of chromium content in tube and tubesheet cladding material
  - SGMP Alloy 690TT steam generator tubing specification recommends a minimum chromium concentration of 28.5 weight percent
  - 191 heats of Alloy 690 tubing material were reviewed and the minimum concentration is 29 weight percent
    - All three tubing suppliers were represented
  - 17 heats of Alloy 82 were reviewed and the minimum chromium is 19.6
  - 27 heats of Alloy 182 were reviewed and the minimum chromium is 13.6

Fabrication of the Mockup

Material used for tube-to-tubesheet mockup

C	Si	Mn	P	S	Cu	Ni	Cr	Mo	Co	Ti	Nb + Ta	Al	Fe
Alloy 182 (.187-in x 14)													
.022	.47	5.1	.001	.002	.01	67.99	16.52	--	--	.54	1.83	--	7.4
.022	.34	6.67	.003	.001	.01	68.81	14.92	--	--	.49	1.39	--	7.27
Alloy 82 (30-mm Strip)													
.029	.18	2.96	.004	.002	.02	71.61	21.47	--	.03	.29	2.44	--	.85

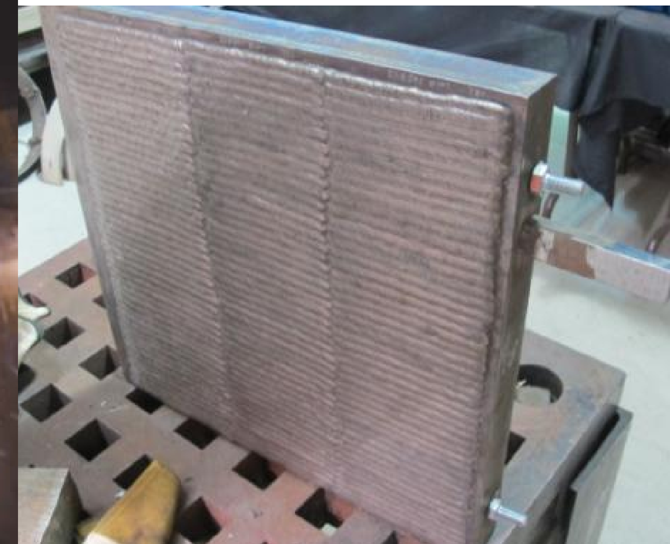
C	Si	Mn	P	S	Cu	Ni	Cr	Mo	Co	Ti	Nb + Ta	Al	Fe
.019	.19	.30	.009	.001	.04	60.4	29.3	.02	.011	.25	.004	.17	9.3

%Cr is on the upper end for cladding but we are measuring dilution not absolute composition

Fabrication of the Mockup

182 Shielded Metal Arc Welding (SMAW) process

SGMP developed prototypical tube-to-tubesheet mockups to analyze chromium levels in the tube-to-tubesheet welds



82 - Electroslag Welding (ESW) Strip cladding

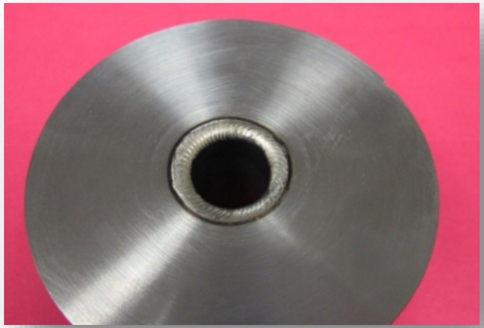
Analysis of the Chromium Content

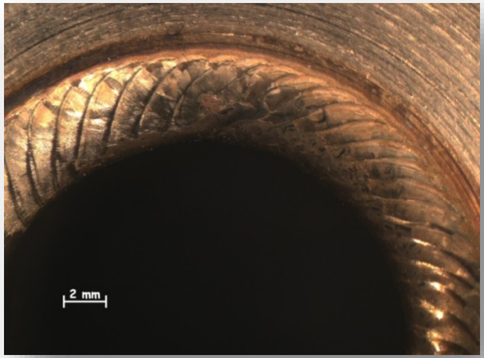
- The mockup was designed as a 3 X 4 tube-to-tubesheet matrix having 82 cladding on one side and 182 cladding on the other side
- An Alloy 690 tube was inserted into each drilled cylinder, positioned flush with each end, and welded autogenously using the Liburdi Dimetric P-Head autogenous GTAW welder (see next slide).

Analysis of the Chromium Content

- Plugs were removed from the tubesheet, cross sectioned, and weld dilution was evaluated
- It had been estimated that the weld dilution would be 50% from the tube material and 50% from the cladding material since the weld is autogenous GTAW

40 cross-sections were available for 82 welds and 34 for 182 welds to include in the tube-to-tubesheet weld dilution distributions





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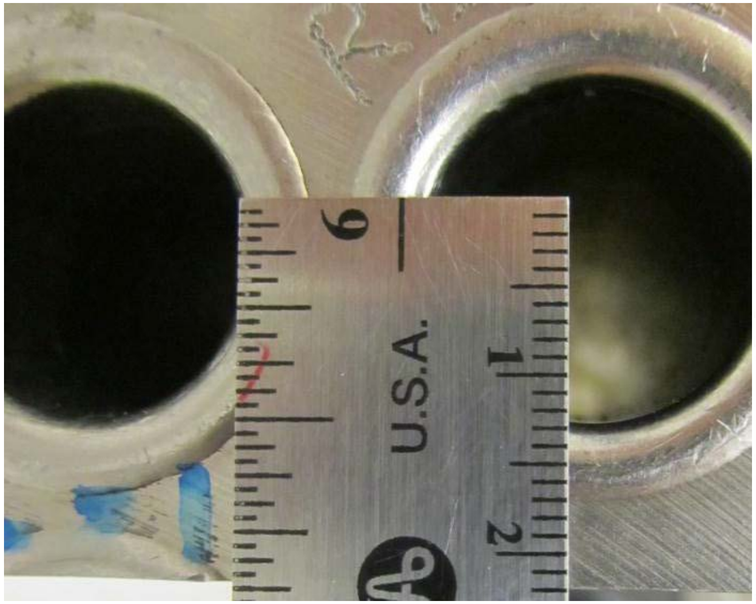
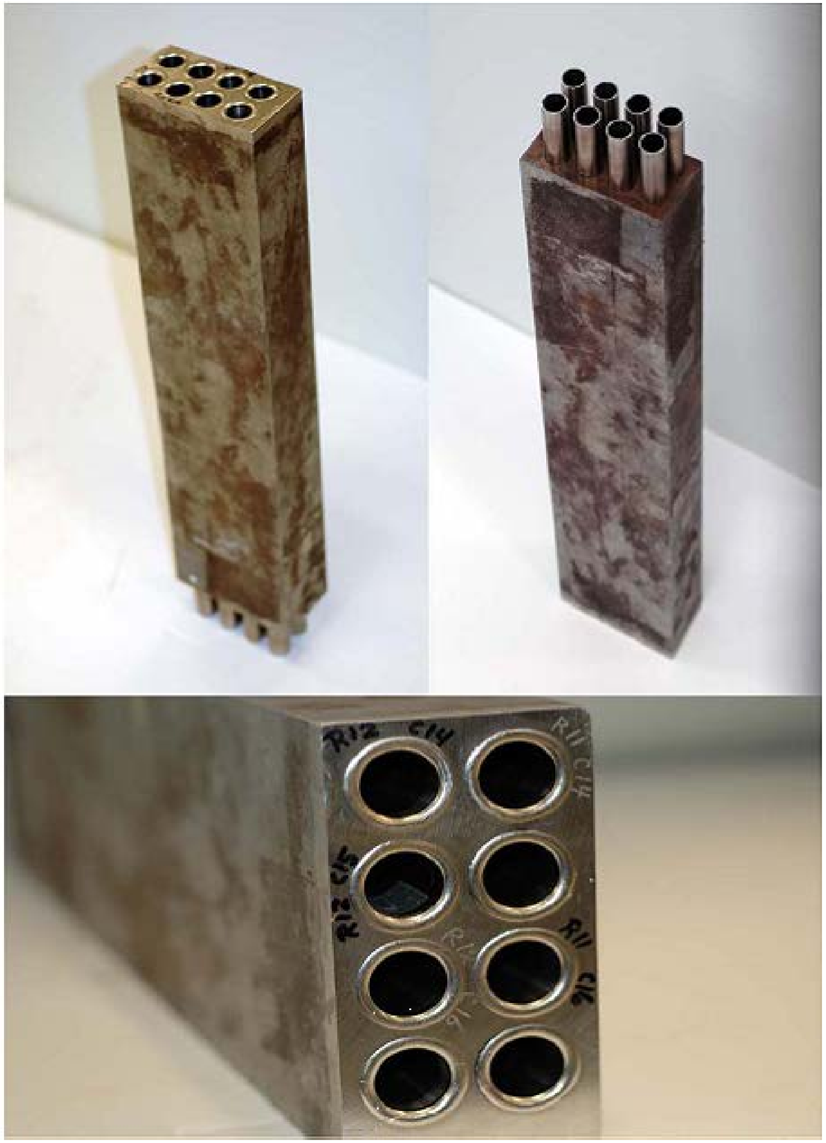
Comparison of Mockups

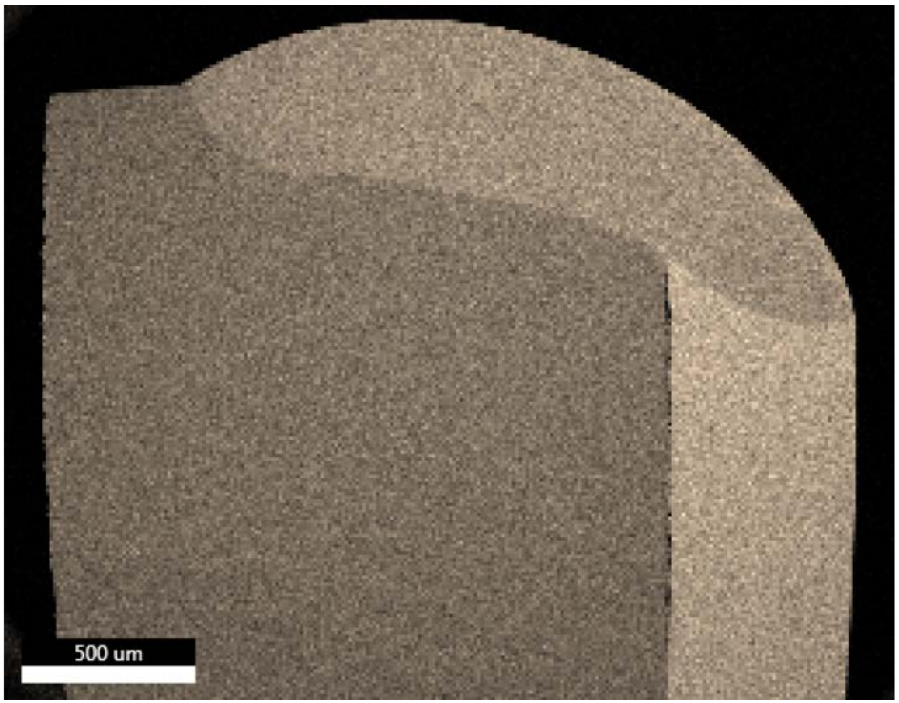
- SGMP has a mockup from a replacement steam generator fabricator with Alloy 82 clad and 690 tube material
  - Used to compare geometry of the fabricated mockup welds and to compare dilution



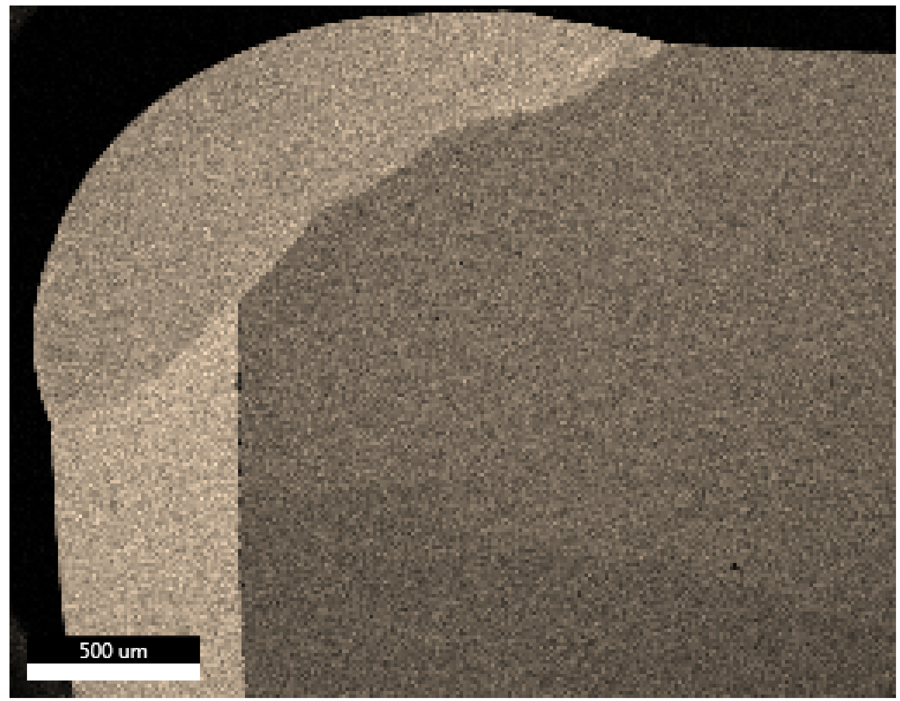


Comparison of Mockups

Mockup from RSG Fabricator



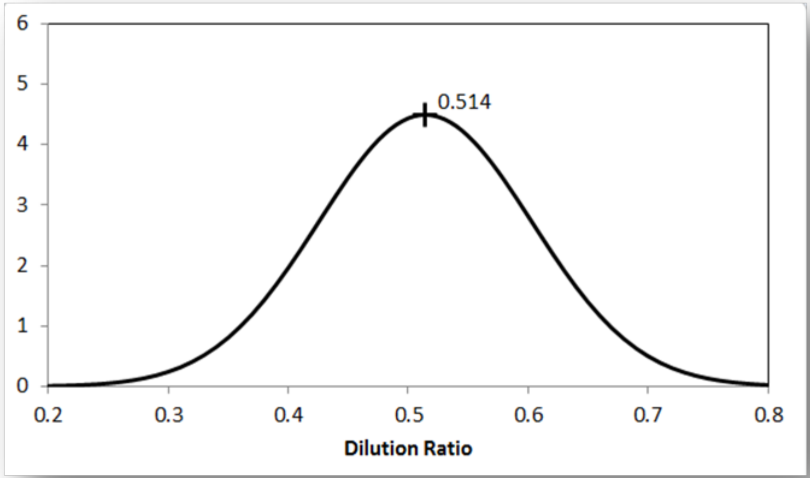
SGMP Mockup



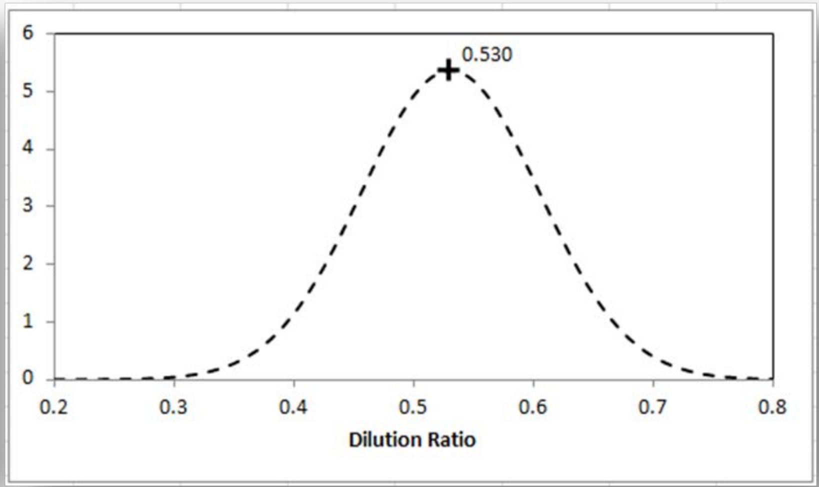
Similarity between the etched weld cross-section in the SGMP mockup to the one fabricated for this project

Analysis of Chromium Content

- The EPRI SEM system was used to mark and measure areas of features on sample cross-section macrostructures
  - Measurements were used to compute the weld dilution
  - Dilution measurements were analyzed to a “normal distribution”



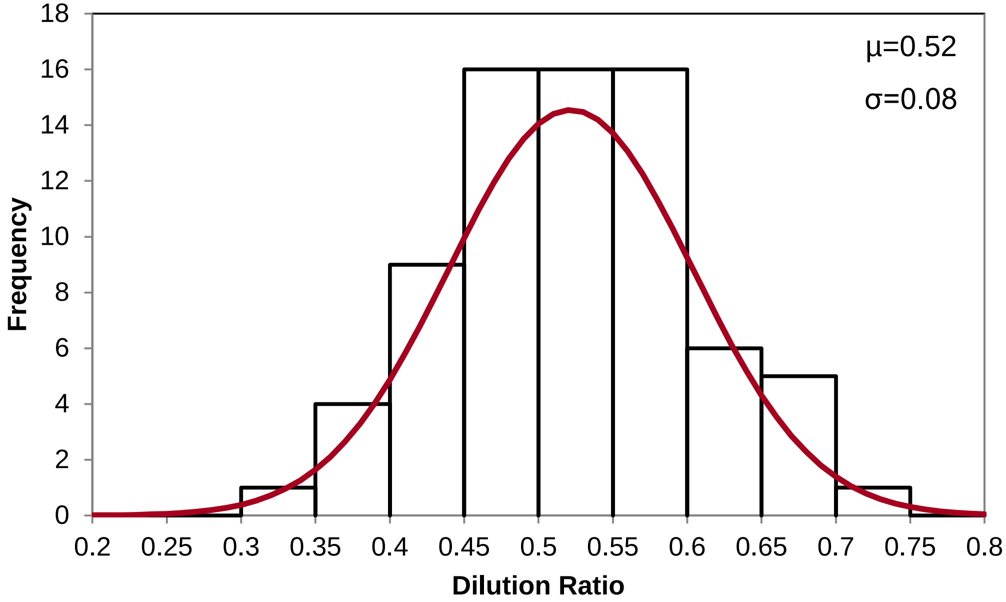
Normal distribution for the Dilution Ratio for 690 tubes welded in 82 cladding



Normal distribution for the Dilution Ratio for 690 tubes welded in 182 cladding

Analysis of Chromium Content

- The combined dataset was used to determine the mean dilution factor
  - Appropriate estimation of reality for Dilution Equation (below)



$$\%Cr_{weld} = \%Cr_{tube}\,(0.52) + \%Cr_{clad}(0.48)$$

Results of the Mockup Testing

- An autogenous weld deposit for 690 tubing material and 82 cladding has sufficient chromium content to be resistant to initiation or propagation of PWSCC (exceeds 24% Cr)
  - These welds constitute the majority of the tubesheet
- The weld deposit for 690 tubing material and 182 cladding has less chromium, but the chromium is high enough to be resistant to initiation and slow propagation of PWSCC

Predicted Cr Compositions

Statistic	% Cr in Weld (82 clad)	% Cr in Weld (182 clad)
Mean	25.2	22.1
Maximum	25.8	23.2
Minimum	24.5	21.8

Stress Analysis of the Tubesheet

- Finite element analysis of a Westinghouse Model 51 SG channel head was used to determine the stresses during normal, upset, and accident conditions
- Tensile loads are shown to be present in the divider plate region
  - The dominant mechanical bending loads are in the plane that drives a horizontal crack and would not turn the crack vertically.
  - Assuming a crack initiates, it would propagate horizontally
- The Alloy 182 cladding in the center of the tubesheet is the most susceptible to PWSCC
  - This area of concern is in compression
- Results and conclusions were independently verified by third party

Scenario 3

Concerning the Low Alloy Steel Channel Head

Stress and Fatigue Analyses

- Finite element model of the steam generator channel head
  - Design transients evaluated
  - Stress paths defined through the channel head wall
  - Through wall hoop and axial stresses mapped along these paths
  - Fracture mechanics and fatigue crack growth evaluations performed
- Maximum stress intensity factor less than the allowable values for all design basis plant conditions up to 75% of the vessel wall thickness
  - Allowable flaw is 3.9” deep and 29.6” long based on flaw tolerance considerations
- Fatigue growth evaluation performed for a postulated flaw 0.25” deep into the low allow steel
  - Evaluated axial and circumferential growth

Conclusions

- Critical crack depth is 75% of the channel head material - 3.9” deep and 29.6” long
- The bounding crack growth results in a crack depth of 8% of the channel head material
  - The circumferential crack would grow from 0.25” to 0.40” deep and from 1.9” to 3.07” long
- Forty years is chosen because this is typical for fatigue analyses

Results for 40 Year Crack Growth Period								
Stress Case	Flaw Type	Initial Flaw Depth (inch)	Final Flaw Depth (a) (inch)	Final Flaw Depth/Vessel Thickness (a/t)	Initial K max. (ksi-√in)	Final K max. (ksi-√in)	Allowable K (ksi-√in)	Pass ?
Path 1 (with residual)	Circ	0.25	0.4040	0.080	24.632	31.048	63.2	Yes
	Axial	0.25	0.2508	0.048	7.465	7.482	63.2	Yes
Path 2 (with residual)	Circ	0.25	0.2985	0.057	21.555	23.806	63.2	Yes
	Axial	0.25	0.2510	0.048	10.527	10.545	63.2	Yes
Path 3 (with residual)	Circ	0.25	0.2524	0.049	9.954	9.998	63.2	Yes
	Axial	0.25	0.2514	0.048	9.555	9.579	63.2	Yes

Conservatisms in the Fatigue Analysis

- Cracks in divider plate assemblies that have been inspected for years have shown no crack growth and thus have not approached the triple point
- It is not expected that the US fleet has divider plate cracking extending the full length of the divider plate and approaching the triple point
- The assumed initial 0.25” through wall depth primary water stress corrosion crack in low alloy steel is not realistic; but is a conservative assumption
  - Low alloy steel is not susceptible to PWSCC

Scenarios 1, 2, and 3 Conclusions

- Chromium levels in the tube-to-tubesheet welds are sufficient to resist PWSCC initiation
- Orientation of the dominant stresses associated with the tubesheet to divider plate regions strongly favor horizontal crack propagation in the stub runner or the welds on top and bottom of the stub runner
- The center of the tubesheet is in compression thus the driving force for PWSCC initiation/propagation is not present
- Stresses in the channel head region of the steam generator are insufficient to propagate a crack by fatigue into the channel head and thus would not compromise structural integrity of the channel head
- Final Report 3002002850 published October 2014

NRC Questions / Industry Responses

Industry's Position for Aging Management Programs for Steam Generator Channel Head Components

- Summarize the industry's position/plans for aging management program for these components

Discussion

- SGMP has communicated the following
  - Technical Report 3002002850 can be used to update Aging Management Plans
    - Visual inspections of present rigor are adequate to manage the Alloy 600 material in the divider plate assembly
  - EPRI SGMP Chemistry Guidelines

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Data Removed from the Tubesheet Weld Database

- Some data were removed from the database because of the tungsten weld head positioning. Why were the data removed? What is the sensitivity of the results if these data were included?

Discussion

- The welds were removed from the database to avoid introducing a bias that does not represent field welds.
- The tungsten positioning in the weld head was purposely offset to explore positioning effects; however, with the offset applied in some welds exceed the limits where an acceptable weld could be made - welds that would have been rejected by visual inspection.
  – Welding equipment is set-up on test welds to avoid these extremes

SG Channel Head Inspections

- What types of inspections are being referred to in Section 7.3? Are these inspections in accordance with the ASME Code or industry guidelines? Please discuss.

Discussion

- Currently, utilities in the US perform visual inspection of the channel head cladding, tubesheet, and all installed plugs
  - Not an ASME Code inspection
  - EPRI Technical Report, 3002000473, "Steam Generator Channel Head Degradation Failure Modes and Effects Analysis"
  - Westinghouse Nuclear Safety Advisory Letter 12-1 recommended visual inspections
  - SGMP sent Nuclear Safety Advisory Letter to all members via email
  - NRC Information Letter IN 2013-20
  - Inspection recommendations are included in Revision 4 of the Integrity Assessment Guidelines draft to be published 2016

Inspections from Outside the SGs

- Summarize the inspection results for the Z-weld (tubesheet to shell weld). Given the closeness of these inspections to the triple point, if something unexpected were to occur, would these inspections possibly give an opportunity to detect cracking were it to occur (e.g., detect leakage or boric acid residue during the performance of the inspection if a throughwall flaw had occurred as a result of divider plate cracking)?

Discussion

- One Z-weld is required to be inspected every 10 years per ASME Section XI
  - This inspection would identify leakage in the SG being examined
- The area is part of routine boric acid walk downs
  - These inspections would most likely identify leakage
    - Research conducted on full scale mockups on reactor vessel bottom mounted nozzles indicates that significant boric acid deposits can result from relatively small leaks
    - Research results provide a qualitative reference to support the conclusion that a leak from the channel head, even at levels below safety significance, would most likely produce boric acid residue that would be detectable through the insulation.

Example of Boric Acid Leakage from Reactor Vessel Bottom Mounted Nozzle Full Scale Mockups

0.01gpm

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NEI 03-08 Requirement for RCS Leakage Monitoring

- Leakage from the steam generator channel head would most likely be detected from “online” leakage monitoring.
  - The NEI 03-08 “needed” requirements detailed in PWR Owners Group letter OG-08-0400 establishes a required online leak detection limit that should provide ample margin for a plant to detect leakage from the steam generator channel head
  - Utility procedures must include action levels and responses to increasing levels of RCS leakage

Applicability of Conclusions Regarding Design Credit for the Divider Plate

- Previously, the stresses within the tubesheet were assessed for cracks in the divider plate. For some steam generators, we believe no credit was given for the presence of the divider plate during the original design. For other steam generators (primarily replacements), some credit may have been given for the divider plates in reducing stresses within the tubesheet. Please re-summarize the analyses performed and their results.

Discussion Follows

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Applicability of Conclusions Regarding Design Credit for the Divider Plate

- Westinghouse Model 51 was determined to be the bounding design for Westinghouse steam generators
  - An investigation in 2008, EPRI Technical Report 1016552, concluded that Westinghouse-designed SGs were the only design susceptible to divider plate cracking
- The divider plate function is to divide the channel head into hot and cold legs. It is not part of the primary pressure boundary
- Documents reviewed with respect to impact of a degraded divider plate
  - ASME Stress Reports
  - LOCA and non-LOCA transients
  - SG tube plugging and sleeving qualifications
  - Accident analysis
  - Alternate repair criteria
- Conclusion: A crack running the full length and depth of the weld is not a safety concern

Applicability of Conclusions Regarding Design Credit for the Divider Plate

- The conclusions of the report bounds the Westinghouse steam generator fleet
- AREVA and B&W have indicated that their replacement steam generators are not susceptible to divider plate cracking due to materials and design
  - Report not applicable

Operating Experience with Alloy 82

- Please clarify the operating experience with Alloy 82 with respect to its susceptibility to cracking. The NRC staff is under the impression that welds which have exhibited cracking may have been fabricated using both Alloy 82 and Alloy 182, and hence it cannot be conclusively stated that cracks have not occurred in welds fabricated from Alloy 82.

Discussion Follows

Weld Design Information

- Butt weld design drawings normally show “82/182” to designate the filler metal
  - Permits the use of either GTAW (82) or SMAW (182) processes
  - Since the welds were applied manually (more recently machine welds have been used), the weld root and hot pass normally will be applied using the GTAW process, then the process is switched to SMAW to fill the cavity.
  - The design permits GTAW to complete the weld but the welding efficiency is much lower and production clearly suggests using SMAW for the fill. The Cr content of 82 is approximately 20% Cr while 182 is approximately 14%Cr. This difference in Cr content is why 82 is more resistant to PWSCC.

Weld Design Information

- Alloy 600 steam generator channel heads use this type of butt weld for the stub runner to divider plate and the stub runner to tubesheet weld buildup.
- The same SMAW procedure is used to join the divider plate to the channel head. Thus the Inconel surfaces exposed to the coolant will be 182 weld deposits and the Alloy 600 divider plate itself.
- SMAW electrodes (182) are used to restore cladding around the triple point because of the need to weld over Inconel and also and to tie into the austenitic stainless steel cladding applied to the channel head surfaces
- The hot and cold leg nozzles are installed in a similar progression. Small nozzles can be an exception where GTAW may be used to install the entire nozzle (e.g. drain nozzle)

Operating Experience with Alloy 82

- There is one report of a crack in an inlet nozzle location where a running crack initiating in Alloy 182 intersected a small portion of the Alloy 82 material
  - Example of crack propagation, not initiation
- Alloy 82 weld deposits have a long history of resistance to SCC initiation
  - Butt welds used with Inconel 600 safe ends used Alloy 82 for the root and hot pass using GTAW (for both the Alloy 182 buttered end of the nozzle and the stainless steel pipe on the opposite end of the safe end. The butt joint was completed using Alloy 182 and the SMAW process.
  - BWR environments are generally accepted to be more aggressive than PWR environments.
  - IGSCC of these butt welds would begin either in the nozzle buttered region or the sensitized HAZ of the stainless steel.
  - As IGSCC progressed it cracked around the Alloy 82 instead of initiating in it or propagating through it.
  - It is acknowledged that laboratory studies can be set up to crack Alloy 82 deposits, but it is very difficult to initiate such cracking either in BWR or PWR environments. This is largely due to the Cr content. Theoretically, Alloy 82 will crack under the right conditions, but realistically, operating experience of many years suggests excellent resistance to PWSCC and IGSCC on these environments.

Normal Cladding vs Structural Butter

- Please clarify the difference between normal cladding and a structural butter (refer to page 2-3).

Discussion Follows

- Cladding and structural butter differ in two ways
  - Code qualification is different for the two applications
  - The purpose of the two applications is different
- Structural butter is required to be capable of transferring loads and as such the weld qualification is tested to demonstrate that capability.
- Cladding is used as a corrosion barrier and the requirement is to be corrosion resistant and to be bonded to the surface. Thus the testing is for deposit chemistry and to demonstrate bond strength so it will not delaminate

Utility Mockup

- On page 2-19, there is reference to a mockup from another utility. Please discuss whether inclusion of this data would affect the conclusions of this report.

Discussion

- Several tube-to-tube sheet welds were removed from a vendor mockup that was used for NDE testing.
- The removed section was quartered then polished and etched to document that the test welds performed by EPRI produced representative weld profiles as obtained as produced by a vendor.
- The vendor mockup welds were not included in the database because of a lack of specific records for the materials used. This avoided the inclusion of data that might bias the dilution distributions.

EdF Experience

- Intergranular stress corrosion cracking was reported on both the hot- and cold-leg sides of the channel head at Dampierre. Please clarify where this cracking occurred on the cold-leg (in the tubes, in the divider plate, etc.). Refer to page 3-22.

Discussion

- Both hot and cold legs of the Dampierre original steam generator #27 retired from loop 3 were found to display intergranular SCC. A large section was removed of the cracked locations and studied extensively in the laboratory.
- Shallow surface intergranular cracking was observed along the top and bottom surfaces of the stub plate adjacent to the base metal on both sides of the divider plate. Some interdendritic crack paths were observed along the welds joining them to the divider plate and the tube sheet.
  - Cracking was shallow in all cases and appeared to be restricted to a thin surface layer believed to be associated with cold working (grinding) during manufacturing. It was noted that cracking was intermittent but extended over a significant length.
  - The studies assumed that crack initiation in welds might be linked to some manufacturing aspects (grinding or arc striking...).
- Tubes were not affected

EdF Inspections Since 2002

- EdF committed to inspect and has not challenged the commitment
  - They do not view this as a safety concern
  - Performed inspections since 2002 on divider plate for 900MW plants – Alloy 600 51Bs thin divider plate (1.3”)
    - Identified SCC indications
  - Performed inspections since 2002 on divider plate for 1300MW plants – Alloy 600 thicker divider plate
    - 1 steam generator with small defects associated with markings welded on the stub
      - Not related to 51B experience or any of the scenarios of the final report
  - Performed inspections since 2002 on divider plate for 1400MW plants – Alloy 690 material
    - No SCC

Model 51 Bounding Steam Generator

- This report potentially applies to all steam generators. On page 4-3, it was indicated that the model 51 steam generator was considered the most limiting steam generator. Given the current fleet of steam generators in operation in the U.S., is this still the case?

Discussion

- The conclusions of the report bounds the susceptible Westinghouse steam generator fleet
- AREVA and B&W have indicated that their replacement steam generators are not susceptible to divider plate cracking due to materials and design
  - Report not applicable

Applicability to a Once Through Steam Generator Design

- Discuss the applicability of the information in this report to once-through steam generators (recognizing there is no divider plate in once through steam generators)?

Discussion

- The information related to the divider plates would not be applicable to OTSGs since they don't have divider plates.
- The potential for cracking in the cladding or tube to tubesheet welds would be similar for OTSGs or recirculating SGs. All AREVA B&W ROTSGs have 52/152 tubesheet cladding and therefore they are not susceptible to this issue.

Loose Parts Impacting Cladding

- Page 5-17 (and page 5-1) implies that possible loose parts may result in steam generator channel head degradation (refer to Figure 5-26). Where was this degradation located (channel head cladding, divider plate, etc.). Please discuss the applicability of this report to plants in which loose parts have impacted the tubesheet cladding or divider plate complex.

Discussion

- The loose part impact at the Chinon B4 steam generator shown in Figure 5-26 was described as PWSCC in the hot water box but did not identify specific location. It did indicate the impact was from a loose part of several kilograms. Reference 5-2 was cited in the report.
- The main focus of the cited study was on the stub plate and its welds, and on the low yield strength mismatch between the stub plate and the divider plate material causing strain in the stub plate.

Loose Parts Impacting Cladding

- When plants identify loose parts in the channel head of the steam generator, they evaluate the damage for continued operation
- The cracking in Chinon B4 was local to the impact area from the loose part and never reported to have propagated to the triple point

Cold Working

- The first and second paragraph on page 5-24 are not clear on what is necessary for the stress corrosion cracking to occur. For example, can cracking occur in a divider plate with no cold-working? Is cold-working considered a "fabrication defect?"

Discussion

- The stress corrosion cracking requires three concurrent conditions – some threshold tensile stress state, susceptible material, and supporting environment.
- The stress can be cumulative from many sources including those applied by cold working.
- Heavy cold working (such as severe surface grinding) also influences the susceptibility of the material itself.
- Surface grinding also smears and tears the surface of stainless steel thus introducing sites more vulnerable to crack initiation.
- Finally, cold-working is not considered a fabrication defect because many of the metal working processes are necessary for fabrication.
- Surface cold working can be mitigated if the design so designates.

Design Guidance for New Steam Generators

- As a result of this effort, does the industry plan to make any recommendations regarding material or design considerations for the design of new (including replacement) steam generators?

Discussion

- SGMP currently has guidance for manufacturing steam generator tubing
- No current plans for developing guidance for designing steam generators
  - New designs incorporate advanced materials and improved manufacturing processes

Fatigue Growth Analysis Based on 40 Years

- Some of the analyses performed in support of your assessments for divider plate cracking appear to assume 40 years of steam generator operation.   Some units may operate their steam generators for a longer period of time, for example up to a maximum of 80 years of plant operation for subsequent license renewal. Please discuss which analysis were based on 40 years of operation and whether the conclusions would still be valid for steam generator operation for a longer period of time (e.g., up to 80 years or the maximum steam generator operating term for a plant license period of 80 years).

Discussion Follows

Fatigue Growth Analysis Based on 40 Years

- 40-year is the typical growth period in an ASME fatigue assessment
- This was assumed adequate in that the cracking identified at EdF plants after more than 20 years of operation did not extend to the triple point
- Based on operating experience, it is not likely that any operating plant has divider plate cracks that extend the full length of the divider plate and have propagated into the low alloy steel
  - This was the beginning condition of the fatigue growth analysis
  - To require 60-year assessment, the assumption has to be made that PWSCC grew into the low alloy steel year one of SG life

Loads Evaluated

- Because each plant has a unique set of design/licensing bases for their steam generators, did the analyses in this report address the limiting load levels from the entire range of design/licensing basis loadings for the population of plants that this report covers? For any design/licensing basis conditions that may have loads greater than those addressed in this report, please discuss how these greater loading levels would change the conclusions in this report, both for a fully degraded divider plate (through-wall flaw) and for one with less serious degradation.

Discussion Follows

Loads Evaluated

- Peak pressures and temperatures were assumed to exist for the duration of the transients; therefore evaluation of dynamic loads were not required.
  – Time varying or transient temperatures and pressures would reduce the pressure and thermal loads.
- A fully degraded divider plate will not result in an increased pressure differential across the tubesheet in any postulated SG operating condition. Mixing of fluid temperatures through the crack opening area due to bypass flow would result in a less critical result for the applied stress on the tubesheet junctions because the hot leg temperature would decrease.
  – Crack scenarios that would result in less communication between hot and cold leg are also bounded

Conclusions

- SGMP has communicated the following to utility members
  - EPRI Technical Report 3002002850 can be used to update Aging Management Plans
    - Visual inspections of present rigor are adequate to manage the Alloy 600 material in the divider plate assembly
  - EPRI Technical Report, 3002000473, “Steam Generator Channel Head Degradation Failure Modes and Effects Analysis” recommends inspecting channel head each time primary side inspections are performed
- EPRI SGMP Chemistry Guidelines
- Defense in Depth
  - Boric acid walkdowns would most likely identify through wall leakage
  - RCS leakage monitoring would most likely identify leakage during operation
    - Capability to detect small delta leak rate changes
    - Radiation monitors

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