

Safety Concerns Regarding Potential Pressurizer Weld Cracking



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PWSCC Experience in Alloy 82/182 Butt Welds, Prior to MRP-139 Examinations

- Plants with leaks
 - Palisades (261) – in 1993, 3" circ, pressurizer nozzle-to-safe end for relief valve
 - V.C. Summer (201) – in 2000, axial; reactor vessel nozzle-to-hot leg pipe weld
 - Tsuruga 2 (199) – in 2003, axial; pressurizer nozzle-to-safe end weld for relief valve
- Plants with cracks/indications
 - 2000
 - Ringhals 3&4 (228/202) – axial; reactor vessel nozzle-to-hot leg pipe welds
 - V.C. Summer (201) – 1" circ and axial; reactor vessel nozzle-to-hot leg pipe weld
 - 2003
 - TMI-1 (349) – axial; surge line-to-hot leg nozzle weld
 - Tihange 2 (240) – axial; pressurizer nozzle to surge line weld
 - 2005
 - Calvert Cliffs 2 (335) – axial (length & depth unknown); hot leg drain nozzle-to-safe end weld
 - D.C. Cook 1 (357) – 1.23" axial; pressurizer nozzle-to-safe end weld for safety valve

Prior to November 2002, nondestructive examination techniques were not required to meet Appendix VIII criteria and as such are not considered to have been reliable in detecting PWSCC in dissimilar metal butt welds in U.S. reactors

Age of plant from date of commercial operation to identification of indication shown in ()



Industry Actions on PWSCC Issue Prior to Wolf Creek

- MRP-139, Primary System Piping Butt Weld Inspection and Evaluation Guideline issued in 2005
- “Mandatory” program under NEI 03-08, “Guideline for the Management of Materials Issues”
- Provides guidance for volumetric and visual inspection of Alloy 82/182 butt welds in PWR RCS
- Augments inspection of ASME Section XI
 - Baseline inspections followed by periodic inspection
 - Periodic inspection requirements similar to code for mitigated welds
- First priority is pressurizer weld locations, followed by hot leg and then cold leg welds



Regulatory Approach on Dissimilar Metal Butt Weld Generic Concern Prior to Wolf Creek (WC)

- Deferred taking prompt regulatory action in 2005 based on utility implementation of MRP-139
- Requested ASME develop inspection requirements that will be incorporated into 10 CFR 50.55a
 - ASME agreed to support NRC request
 - Code Case under development



Pre-Mitigation Pressurizer Inspections¹

- Plants that completed examinations prior to mitigation
 - Calvert Cliffs 1 (4)²
 - Calvert Cliffs 2 (4)
 - Davis Besse (6)
 - Farley 2 (2)
 - Palisades (2)
 - Prairie Island 2 (1)
 - San Onofre 2 (5)
 - San Onofre 3 (5)
 - Sequoyah 2 (1)
 - Watts Bar (6)
 - Wolf Creek (6)
- Examination Results
 - Calvert Cliffs 1
 - Relief nozzle, axial, 0.1 " deep, 8% TW, 0.6" long
 - 2 other indications at hot leg temperature locations
 - Calvert Cliffs 2
 - No indications at pressurizer locations
 - Axial indications at hot leg drain
 - Davis Besse
 - No indications – weld exam limitations
 - Limited coverage on surge and spray safe end weld
 - Farley 2
 - No indications
 - Palisades
 - No indications
 - Prairie Island 2
 - No Indications
 - San Onofre 2 (App III also used)
 - 2 axial indications
 - Not PWSCC; Not surface connected
 - San Onofre 3 (App III also used)
 - No indications
 - Sequoyah 2
 - No indications
 - Watts Bar
 - No indications
 - Wolf Creek
 - 3 Circ indications in surge nozzle
 - Circ indication in safety "C" nozzle
 - Circ indication in relief nozzle
 - No indications in spray/"A", "B" safety nozzles

¹ Inspections qualified to Section XI, Appendix VIII requirements

² Number of welds inspected shown in ()



Pressurizer Weld Inspection Summary

- 11 plants have conducted some type of pre-mitigation weld inspections
- 42 welds have been examined
 - Some of these examinations have been limited due to:
 - Cast Stainless Steel
 - Coverage less than 90%
- 4 examinations out of 42 have detected PWSCC flaws or about 10%
 - 3 of 4 welds with indications had circumferential flaws



Time of Discovery of Wolf Creek Flaws

- Flaws discovered prior to application of pre-emptive weld overlay on pressurizer connections with dissimilar metal butt welds
- Inspections were performed to establish weld condition prior to weld overlay
- Inspections were required under MRP-139, “Primary System Butt Weld Inspection and Evaluation Guideline”
 - Guidelines allow to apply overlay, then inspect
- Event Notification made on October 11, 2006



Wolf Creek Examinations Surge Nozzle

- Surge Nozzle – 3 Circ. Flaws; 38” ID weld length
 - 4” ~31% Through Wall
 - 2.2” ~25% Through Wall
 - 0.8” @ inner surface
 - Last Volumetric Examination: 1993 (not PDI qualified)

Note: procedure qualified for flaw detection and length measurement (not depth measurement); examiner qualified for flaw detection but not for length measurement; all readings confirmed by EPRI



Wolf Creek Examinations Safety & Relief Nozzles

- Relief Nozzle – 1 Circ. Flaw; 16.3” ID weld length
 - 7.7” ~26% Through Wall
 - Last Volumetric Exam: 2000 (not PDI qualified)
- Safety Nozzle – 1 Circ. Flaw; 16.3” ID weld length
 - 2.5” ~23% Through Wall
 - Last Volumetric Exam: 2000 (not PDI qualified)

Note: procedure qualified for flaw detection and length measurement (not depth measurement); examiner qualified for flaw detection but not for length measurement; all readings confirmed by EPRI



Concerns with Inspection Findings

- Wolf Creek: first large/multiple circumferential flaws identified
- Expectations were to see small axial indications, not large/multiple circumferential indications
 - Circ flaws can lead to rupture
- Large circ flaws increase need to complete baseline inspections on a timely basis



NRC Analysis of Wolf Creek Flaws

- Based on Wolf Creek inspection data, completed analyses to estimate:
 - when crack initiated
 - time for flaw to result in leakage
 - time to reach critical flaw size
- Analyzed surge, relief, and safety nozzle welds
- Calculated time ranges based on different assumed residual stress profiles, different fracture mechanics models, and with and without safe shutdown earthquake loading
- Best estimate calculations not feasible due to uncertainties in residual stresses



NRC Analyses of Wolf Creek Flaws (cont'd)

- Surge nozzle weld flaws - largest flaw
 - 11% long on the inner diameter (ID),
 - ~31% Through Wall (TW)

Time Frame	Normal Loads (Yrs)	Safe Shutdown Earthquake Loads (Yrs)
Initiation to measured size:	0.3 to 2.7	0.3 to 2.7
Measured size to leak:	1 to 2.2	1 to 2.2
Leak to rupture:	0.8 to 3.7	0.6 to 3.4
Total: Initiation to rupture	2.1 to 8.6	1.9 to 8.3

Note: Did not analyze possible linkage of multiple flaws since no information available on whether located in same plane. Possible non-conservative assumption



NRC Analyses of Wolf Creek Flaws (cont'd)

- Relief nozzle weld flaws –
47% long on the ID, ~26% TW

Time Frame	Normal Loads (Yrs)	Safe Shutdown Earthquake Loads (Yrs)
Initiation to measured size:	0.6 to 2.7	0.6 to 2.7
Measured size to leak:	1.9 to 2.6	1.9 to 2.6
Leak to rupture:	see note*	see note**
Total: Initiation to rupture	2.5 to 5.3	2.5 to 5.3

***8 cases - no time from leak to rupture; range for 3 cases - 0.2 to 0.5 yrs; 1 case - 1.3 yrs**

****8 cases – no time from leak to rupture; range for 3 cases – 0.1 to 0.4 yrs; 1 case 1.2 yrs**



NRC Analyses of Wolf Creek Flaws(cont'd)

- Safety nozzle weld flaws -
15% long on the ID, ~23% TW

Time Frame	Normal Loads (Yrs)	Safe Shutdown Earthquake Loads (Yrs)
Initiation to measured size:	0.5 to 2.9	0.5 to 2.9
Measured size to leak:	2.6 to 8*	2.6 to 8*
Leak to rupture:	see note**	see note***
Total: Initiation to rupture	3.4 to 11.5	3.3-11.4

* 1 case showed unusually long time from measured size to leak

**4 cases - no time from leak to rupture; range for 8 cases – 0.3 to 5.3 yrs

***4 cases - no time from leak to rupture; range for 8 cases – 0.2 to 5.2 yrs



Assessment of Results

- General Observations
 - Long circ flaws decrease time to leak and time between leak and rupture
 - Circ flaws in thick walled welds less likely to leak prior to rupture
- Specific Observations
 - Relief line has the least margin between leak and rupture: 8 of 12 cases analyzed showed first leakage at rupture
 - Safety line analysis resulted in 4 of 12 cases with first leakage at rupture
 - Surge line analyses resulted in some time between leakage and rupture in all cases
 - Most analyses indicate that time to failure can be less than two operating cycles



Assessment of Results (cont'd)

- Potential conservatisms in analyses
 - Residual stress relaxation depending upon assumed distribution
 - Axisymmetric residual stress distribution depending upon assumed distribution
- Potential non-conservatisms in analyses
 - Did not analyze interaction of flaws in surge line weld
 - Wolf Creek piping loads not bounding for other PWRs
 - Wolf Creek indication sizes may not be bounding
- Uncertainties
 - Residual stress distribution virtually impossible to quantify and analyzed cases may not be bounding or may be conservative
 - Condition of 37 units that have not been inspected or mitigated
 - Differences between Wolf Creek weld configuration/materials/construction and other PWRs
 - Flaw depths



Assessment of Results (cont'd)

- Uncertainties may dominate potential sources of conservatism
- Staff in process of making a regulatory decision on whether inspections or overlays of pressurizer welds need to be completed in a more expedited time frame
- In making a regulatory decision, staff interested in balancing factors such as
 - Analysis results appear to indicate the need to address pressurizer welds on a timely basis
 - Analysis results may not be bounding
 - Lack of operating experience involving leakage of circ cracks
 - Absence of destructive examination results of detected indications
 - Risk considerations of pipe failure and consequences
 - Any additional insights from industry



Inspection/Mitigation Summaries

Outage Season	# Plants in Outage	# of Welds to be Addressed	# of Welds Planned for Mitigation
Spring 07	12	67	63
Fall 07	14	73	62
Spring 08	10	57	57
Fall 08	1	1	1