PWR Owners Group

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Mark Honeycutt, Duke (FG Chair) – Auxiliary Piping Stress Corrosion Cracking Operating Experience Focus Group and Industry Coordination – Presentation #12

June 2025 NRC/Industry Materials Technical Exchange Meeting

Agenda

- EDF SS SCC and Thermal Fatigue OE Update
- Auxiliary Piping SCC OE Focus Group Update

EDF SS SCC and Thermal Fatigue OE Update

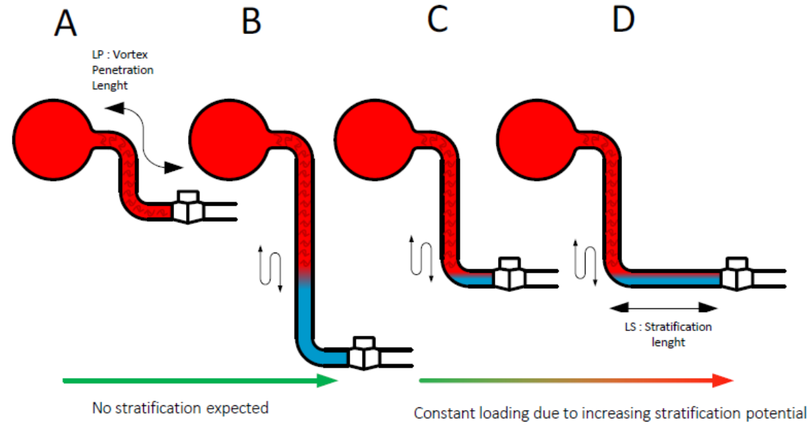
Aux Piping SCC OE FC Update - June 2025 NRC/Industry Materials Technical Exchange Meeting

EDF Feedback on Operating Experience 11/5/2024 (1/5)

- EDF provided overview of operating experience
  - Overall summary
    - Cracks located in the thermally affected areas (heat affected zones) of the welds on stainless steel pipes, in the non-isolable part of the main primary circuit (to the first isolation valve)
      - ❑ Affected systems: safety injection system and reactor heat removal system
      - ❑ Affected piping: 8 to 14 inches piping, piping wall 0.91 inch (23 mm) (SCH160) to 1.31 inch (33.3 mm) (SCH160) with majority being 1 inch (25.4 mm) thick (10” SCH140), types 304L, 316L and 316LN
    - >1000 weld NDE conducted since 2021 (mainly using advanced UT methods), and destructive examination performed on 330 welds (up to November 2024)
      - ❑ >200 Intergranular Stress Corrosion Cracking (IGSCC) flaws with depth from 0.5mm to 23mm, however only two cracks were greater than 6.5mm in depth (25% of typical pipe thickness)
        - ❖ These two cracks were in welds repaired at construction (total of 7 repaired welds with flaws)
        - ❖ NDE capable of detecting IGSCC flaws >2mm
      - ❑ 13 thermal fatigue cracks detected

EDF Feedback on Operating Experience 11/5/2024 (2/5)

- Overall summary
  - Sensitivity to IGSCC a function of presence and extent of thermal stratification
  - When thermal fatigue flaws were detected on a line also showing IGSCC flaws, fatigue flaws were located to the end of the affected portion (Where thermal loads are the most susceptible to fluctuations)
- No pollutants observed during operation or in the cracks analyzed by destructive examination (DE)
- O_2 ingress
  - Water injection (aerated) occurs on one primary loop, but all four loops similarly affected by IGSCC, which implies O_2 not a relevant variable
- Temperature
  - No IGSCC or thermal fatigue identified in ‘cold’ portions (T<200°C) of longest dead legs



EDF Feedback on Operating Experience 11/5/2024 (3/5)

- EDF preliminary conclusions
  - Sensitivity of a given weld to IGSCC seems to be driven by accumulation of aggravating factors
    - Line design enhancing thermal stratification risk
    - Severe weld repairs
    - Cyclical loads
  - 2nd order effects that can assist initiation such as component misalignment, small manufacturing defects
  - Internal surface grinding – very efficient in preventing IGSCC and Thermal Fatigue

EDF Feedback on Operating Experience 11/5/2024 (4/5)

- EDF lessons learned
  - Auxiliary lines design is believed to have an influence on IGSCC sensitivity that could explain the numerous cracks found on some EDF 4 loops reactor's lines (higher thermal stratification risks)
  - Both IGSCC and thermal fatigue flaws were found on the same type of line and on similar design lines on different reactors
    - This confirms the EDF hypothesis of cyclical loads contribution to IGSCC development
    - IGSCC initiation needs higher monotonous stress which is not likely to happen under normal operating conditions
  - Variability of IGSCC development between lines and reactors with a strictly similar design is believed to be mostly induced by different local thermo-hydraulic behaviors, linked to vortex penetration
    - Different thermal loadings can be induced on each loop, given the vortex position is different from one line to another
    - Variation of the vortex's position in a given line during operation can lead to cyclical loads that would cause cracking

EDF Feedback on Operating Experience 11/5/2024 (5/5)

- EDF Strategy and On-Going Investigations
  - By 2026 EDF will have inspected or replaced 55 % (about 1550) of all welds located in hot portions of 8 to 14” SIS and RHR dead legs
  - Plan is to pursue NDE on non-inspected welds over the next decade to reach a final coverage of 75% on this scope, with an NDE technique capable of detecting cracks above 2 mm depth (IGSCC and fatigue)
  - In parallel, investigations have been launched on other austenitic stainless steel welds operated in primary water
  - 27,5” to 31” main coolant lines: PT was performed on 23 primary elbow welds - no IGSCC suspected
  - 14” and 16” pressurizer surge lines
    - UT was performed on 16 welds (mostly repaired) - no IGSCC suspected; all repaired welds shall be inspected throughout each reactor ten year ISI outage
    - DE was performed on 8 surge line welds (14”) on Fessenheim 1 (900 MWe) dismantled reactor - no cracks
  - Auxiliary lines OD < 8”: a dedicated NDE DE program aiming at 126 welds, mostly repaired, (being performed 2024-2026)

Auxiliary Piping SCC OE Focus Group Update

Purpose of the Auxiliary Piping SCC OE Focus Group

- Coordinates efforts between the PWR Owners Group and EPRI-MRP in evaluating this OE
- Focus
  - Understanding causal factors associated with recent auxiliary piping SCC operating experience and the potential relevance to the rest of the industry
  - Development of industry positions and/or guidance as needed
  - Regulatory interactions

Auxiliary Piping SCC OE Focus Group Roadmap

	2021	2022	2023	2024	2025
Utilities	Provide Research Guidance				
			ASME Code Guidance for CGR		
EPRI		SCC White Paper			
	PWR SS SCC CGR (MRP-458)		Complete		
		WRTC Type 316LN Strain-Hardening Research			
		MRP-236-R2 Pressure Boundary SS SCC OE In progress			
PWROG		Industry Inspection Survey		Complete	
		Safety Assessment PWROG-23007-NP		Complete	
			Applicability Assessment- In progress (PWROG-24002)		
ASME			CGR Curves, RI-ISI Review - In progress		
NRC				Endorse CGR Curves	
		Safety Assessment (ML23236A079)			

Interim guidance for inspections transmitted via PWROG Letter OG-23-82. Rev 1 of letter issued July 2024

Status of PWROG Program Tasks (1/3)

- Task 1: Focus Group
  - Meetings
    - In-person Focus Group Meetings held 4/25/22, 8/16/22, 12/13/22, 4/18/23, 5/8/24 Call with INPO; 6/20/2023
    - Multiple virtual Focus Group meetings, most recent; 6/19/24 (FAQs), 9/19/24 (RI), 11/21/2024 (EdF Presentation review), 1/16/2025 (Weld repair search discussion)
    - Presentation at Industry/NRC Tech Exchange 5/25/22, 6/14/23, 6/25/24
    - Presentation at ACRS Meeting 11/16/22
    - Virtual presentation for Japan Virtual Workshop 2/13/23
    - Presentation at NRC Public Meeting 2/21/2024
    - European PWROG Materials Workshop 11/5/2024
  - Recent Discussions
    - Expert Panel meeting regarding weld/WRS held 7/12/23

Status of PWROG Program Tasks (2/3)

- Task 2 Part : Safety Assessment (PWROG-23007-NP)
  - Complete April 2023
  - Transmitted to NRC For Information May 2023 (‘read only’ access)
  - PWROG letter OG-23-82 issued; defines the NEI 03-08 Needed Guidance regarding IGSCC specific examination methods
  - PWROG letter OG-23-82 Rev 1 issued to include FAQs
- Task 2 Part 2: Applicability Assessment
  - Expert Panel meeting regarding weld/WRS held 7/12/23
  - Tasks 4 (PWROG-23036-P; Task 4 Core Flood Line Sample Flaw Evaluation) and 5 (PWROG-23040-P; Westinghouse Flaw Stability Assessment of Stress Corrosion Cracking Operating Experience in Non-Isolable Stainless Steel Branch Piping) (completed – inputs to Applicability Assessment)
  - Draft report (PWROG 24002 Rev 0; An Assessment of the Potential Applicability of the EDF Safety Injection Line Cracking Experience to the PWR Fleet). Being finalized

Status of PWROG Program Tasks (3/3)

- Task 3: Data Collection
  - Data incorporated into Safety Assessment (Task 2 Part 1), Complete
- Task 4: B&W Core Flood Line Sample Case
  - Final report published and transmitted (PWROG-23036-P)
- Task 5: WEC SI Line Sample Case
  - Final report published and transmitted (PWROG-23040-P)

Tasks 4 and 5 support the Applicability Assessment (Task 2 Part 2)

- PWROG-24011-P, “Applicability of Stress Corrosion Cracking of Stainless Steel Observed in EDF Plants to other Designs,” issued
  - Reviewed vintage US plant material hardness and sulfur content to compare to EDF OE
    - Estimated 30x to >200x slower SCCGR for vintage US SS pipe (due to effects of lower hardness and higher sulfur content)
    - Assumes same stress level (material difference only)

Summary of Activities Since the Last Meeting (1/10)

- **IGSCC Survey Results up until April 29, 2025**
  - **No indications reported to date**

Line type	Spring 2023		Fall 2023		Spring 2024		Fall 2024		Spring 2025		Fall 2025			
	# Welds	Plant	# Welds	Plant	# Welds	Plant	# Welds	Plant	# Welds	Plant	# Welds	Plant		
Safety Injection Accumulator (10 & 12")			4	W4	1	W3	2 4	W4 W4	3	W4				
Core Flood (14")					2 1	B&W B&W								
Safety Injection (6")					2 2	W3 W4			*3*	*W4*				
RHR/ Decay Heat Removal (10", 12", 14")			2 2	B&W W4	1 2 2 1 2 1	W4 B&W B&W W3 W3 W3	1 2 7 4 1 1	W4 W4 W3 W4 W3 W2	*2*	*W4*				
Pressurizer (PZR) Spray			2	W4	4 2 1 2 1	W4 W3 B&W W3 W3	*6* 5 1	*W4* W3 W3						
PZR PORV Supply Lines (6", 4", 3")					8	W4								
RHR-Mixing Tee					*3*	*W4*								
Various Welds	25	International W3 (ASIS, SI, RHR, EBS systems)			38 22	International W2 International W3	33 *5* *TBD*	International W3 *W4* *CE*	*3* *8* *8*	*W4* W4 *W3*	*6* *3*	*W3* *W4*		
TOTAL EXAMS COMPLETED	25	No U.S.	10	All U.S.	95	29 U.S.	61	18 U.S.	11	All U.S. so far			202	68 U.S.

Spring 2026	
# Welds	Plant
1	*W4*

Fall 2026	
# Welds	Plant
11	*W3*
3	*W4*
3	*W4*

Spring 2027	
# Welds	Plant
2	*W3*

Summary of Activities Since the Last Meeting (2/10)

- OG-23-82 Revision 1 issued to include Frequently Asked Questions to support utilities in scoping IGSCC inspections per the NEI 03-08 Needed Guidance
- NEI 03-08 recommendations did not change

1. Which systems/piping are required to be inspected?
   a. Systems as per the FSAR
   i. Passive Safety Injection/Core Flood Lines
   “Passive” refers to Safety Injection/Core Flood Lines designed to be gravity-fed from an upstream reservoir, such as an Accumulator or Core Flood Tank, rather than actuated by use of an upstream pump, such as a Safety Injection Pump or Charging Pump. The UFSAR for a given plant may specifically define which systems are considered passive.
   ii. Residual Heat Removal/Shutdown Cooling/Decay Heat Lines; suction side
   iii. Pressurizer Spray Lines; suction off of the RCS

Summary of Activities Since the Last Meeting (3/10)

2. Which dimensions of piping require inspection?
   a. Diameter
      i. Passive Safety Injection/Core Flood Lines
         - 8, 10, 12, 14 NPS
      ii. Residual Heat Removal/Shutdown Cooling/Decay Heat Lines
         - 8, 10, 12, 14 NPS
      iii. Pressurizer Spray Piping
         - 3, 4, 6 NPS
3. Which piping welds are within the scope of this guidance?
   a. All elbow welds (including HAZ) for non-isolable branch line piping within the systems identified in item #1 above.
      i. “Non-isolable” refers to the section of branch line piping between the RCS main loop piping connection and the first isolation valve on the branch line.
      ii. While not part of the NEI 03-08 “Needed” requirement, the inclusion of additional piping welds (other than elbow welds) within the non-isolable sections of these piping systems is encouraged.

Summary of Activities Since the Last Meeting (4/10)

4. Which examination programs are applicable?
   a. All examination programs including, but not limited to, ASME B&PV Code Section XI (ISI), Risk-Informed ISI (RI-ISI), MRP-146, MRP 2019-008, and License Renewal commitments.

5. What is the examination volume?
   a. At a minimum, the inner 1/3t of the weld and adjacent heat affected zone (HAZ) on each side of the weld shall be examined with the IGSCC techniques and personnel.
   b. The amount of adjacent HAZ is determined by the requirements governing the examination, i.e., ISI, RI-ISI, or MRP-146. When MRP-146 requires additional base material to be examined beyond the HAZ, the thermal fatigue examination guidance of MRP-146 shall be followed for this additional base material examination.

Summary of Activities Since the Last Meeting (5/10)

6. Are new inspection plans required?
   a. No new inspection plans are required. Welds within the scope of this guidance that have already been scheduled for inspection in a refueling outage shall be inspected using the applicable IGSCC techniques with qualified personnel.
7. Is Expansion of inspection scope required if indications are detected?
   a. Scope expansion requirements shall be dictated by the applicable inspection program for which the examination was being performed (i.e., ISI, RI-ISI, MRP-146, LR, etc.) and the site's Corrective Action Program (CAP) process.
8. How are detected flaws evaluated?
   a. Follow the Acceptance Standards per the guidance of the applicable inspection program for which the examination was being performed (i.e., ISI, RI-ISI, MRP-146, LR, etc.).
   b. Flaw evaluation should consider the applicable failure mode and crack growth rate for the material and environment of interest.

Summary of Activities Since the Last Meeting (6/10)

- Discussion on Weld Repair search (1/16/2025)
  - How should the industry treat weld repair searches
  - The purpose of the meeting was to discuss the need for performing documentation searches for weld repairs in the PWROG fleet and then to implement inspections of these specific welds to augment the currently applied OG-23-82 R1 guidance

IGSCC sensitity ranking	Scope	Amount of welds with NDE and/or DE	IGSCC DE confirmed cracks ≤ 2mm depth (%)	IGSCC DE confirmed cracks ≤ 2mm depth (#)	IGSCC DE confirmed cracks >2mm depth and UT Indications >2mm (%)	IGSCC DE confirmed cracks >2mm depth and UT Indications >2mm (#)		
Sensitive	Non repaired welds	328	36%	118	21%	69		
Less-sensitive	Non repaired welds	128	3%	4	4%	5		
Non-sensitive	Non repaired welds	84	2%	2	0%	0		
RIS BC P'4 et N4	Non repaired welds	37	3%	1	6%	2		
	Non repaired welds TOTALs	577	Total # Flaws ≤ 2mm depth	125	Total # Flaws >2mm depth	76	Total # Flaws	201

IGSCC sensitity ranking	Scope	Amount of welds with NDE and/or DE	IGSCC DE confirmed cracks ≤ 2mm depth (%)	IGSCC DE confirmed cracks ≤ 2mm depth (#)	IGSCC DE confirmed cracks >2mm depth and UT Indications >2mm (%)	IGSCC DE confirmed cracks >2mm depth and UT Indications >2mm (#)		
Sensitive	Repaired welds	48	21%	10	11%	5		
Less-sensitive	Repaired welds	53	0%	0	4%	2		
Non-sensitive	Repaired welds	197	0%	0	2%	3		
RIS BC P'4 et N4	Repaired welds	18	0%	0	11%	2		
	Repaired welds TOTALS	316	Total # Flaws ≤ 2mm depth	10	Total # Flaws >2mm depth	12	Total # Flaws	22

Summary of Activities Since the Last Meeting (7/10)

- Discussion on Approach to Weld Repairs (1/16/2025)
  - Of the 316 repaired welds examined by NDE/DE by EDF
    - 22 welds with cracks (7%)
      - 10 less than ~0.08 inches (2 mm) deep (3%)
      - 12 greater than ~0.08 inches (2 mm) deep (4%)
        - 10 cracks were less than ~0.25 inches (6.5 mm) deep
        - 2 cracks were greater than ~0.25 inches deep. (The two deepest cracks had depths of ~0.91 inches (23 mm; 91% TW) and ~0.44 inches (11.3 mm; 34% TW))

Summary of Activities Since the Last Meeting (8/10)

- Discussion on Approach to Weld Repairs (1/16/2025)
  - The proportion of EDF welds inspected by NDE and DE and confirmed to contain flaws is approximately 35% (13% by NDE and 22% by DE)
  - The proportion of EDF weld repairs with flaws is small (7%) and of that proportion an even smaller number of flaws that would be detectable by NDE (4%)
  - Weld repair search would be very time consuming without high level of confidence of finding meaningful data
  - There is the potential that given the process of weld fabrication, flaw detection, implementation of weld repairs, many of these weld repairs will not have been documented
  - Generally, UT cannot be used as a means of detection for weld repairs unless they are in base metal and the weld repairs are specifically being searched for

Summary of Activities Since the Last Meeting (9/10)

- Discussion on Approach to Weld Repairs (1/16/2025)
  - The Safety Assessment (PWROG-23007), concluded that welds with repairs tend to develop typical SCC flaws with small aspect ratios that should cause leakage well before risk of rupture, therefore there should be no safety concern for not inspecting welds with fabrication repairs.
    - EDF has also stated “Stability in every condition was justified by mechanical calculations for all the confirmed defects: no safety concerns to be reported so far”
  - Leak before break is applicable to piping above 6 inches NPS which encompasses the piping of concern in the SI and RHR systems (8, 10, 12 and 14 inches).

Summary of Activities Since the Last Meeting (10/10)

- Discussion on Approach to Weld Repairs (1/16/2025)
  - Given the leak before break expectation, the large effort to perform a records search that may or may not have a positive outcome, the EDF experience of a small number of cracked weld repairs, the generally small dimensions of these flaws (except for 2), the decision was made by the Focus Group that no communication will be sent to the utilities to perform a records search for weld repairs or to expand the scope of inspections beyond the existing guidance

Next Actions

- Issue Applicability Assessment (Rev 0)
- Issue draft MRP-236 Revision 2 for member review 3rd quarter 2025
- Wrap up PA-MSC-1950 Rev 3