Auxiliary Piping SCC

Industry/NRC Public Meeting
2/21/2024

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Agenda

- Previous Meetings with the NRC/ACRS
- 2023 EDF Operating Experience (OE)
- US Industry actions to consider the EDF OE
  - Safety Assessment
  - US Industry Inspection Operating Experience
  - Applicability Assessment
  - MRP-236, Rev. 1 Update
  - World Association of Nuclear Operators (WANO) SER 2023-02
  - Western European Nuclear Regulators Association (WENRA) recommendations

Previous Meetings with the NRC/ACRS

- Presentation at the Industry/NRC Technical Exchange Meetings - 5/25/22, 6/14/23
- Presentation at the ACRS Meeting - 11/16/22

2023 EDF Operating Experience (1/6)

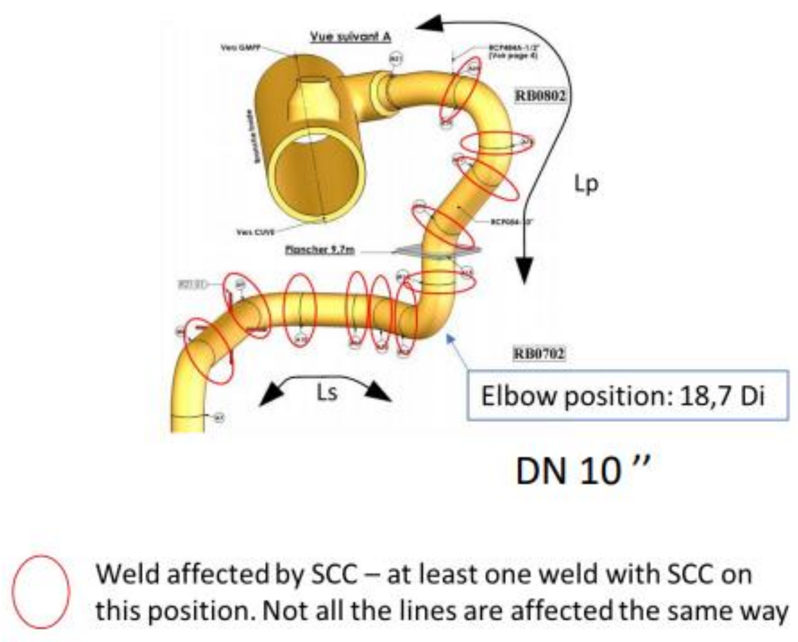
- EDF shut down all of the 1450 MWe units (4 x N4) for inspections
  - Confirmed IGSCC in the ECCS (SI) & RHR large diameter lines (from the nozzle to the 1st isolation valve) – in the base metal adjacent to the weld root run
  - EDF replaced all of the lines affected by SCC in the 1450 MWe units
- EDF submitted an investigation program to the French Regulatory Body (ASN) that addressed the entire fleet (56 Units):
  - 4 units 1450 MWe (N4)
  - 12 units 1300 MWe (P'4)
  - 8 units 1300 MWe (P4)
  - 28 units 900 MWe (CPY)
  - 4 units 900 MWe (CP0)

2023 EDF Operating Experience (2/6)

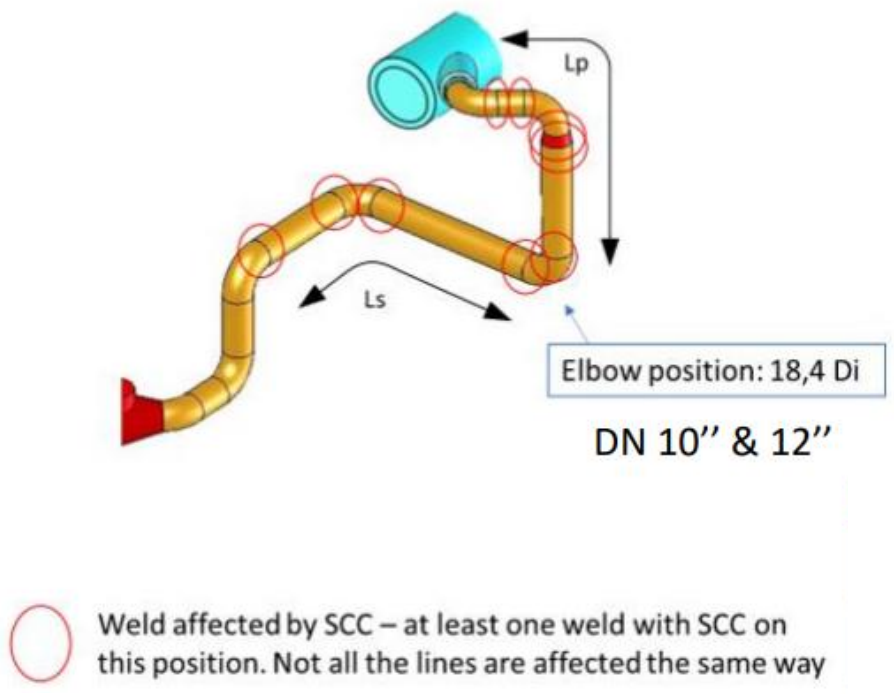
- EDF initiated a large repair program for the P’4 units (the ECCS lines on the cold leg will be replaced by mid 2024)
- EDF performed many inspections in 2022 and 2023 (962 welds were inspected, 225 repaired welds were inspected) and many metallurgical examinations (more than 230 metallography exams)
- SCC was identified in 6 welds that were repaired during construction in lines not affected by thermal stratification

2023 EDF Operating Experience (3/6)

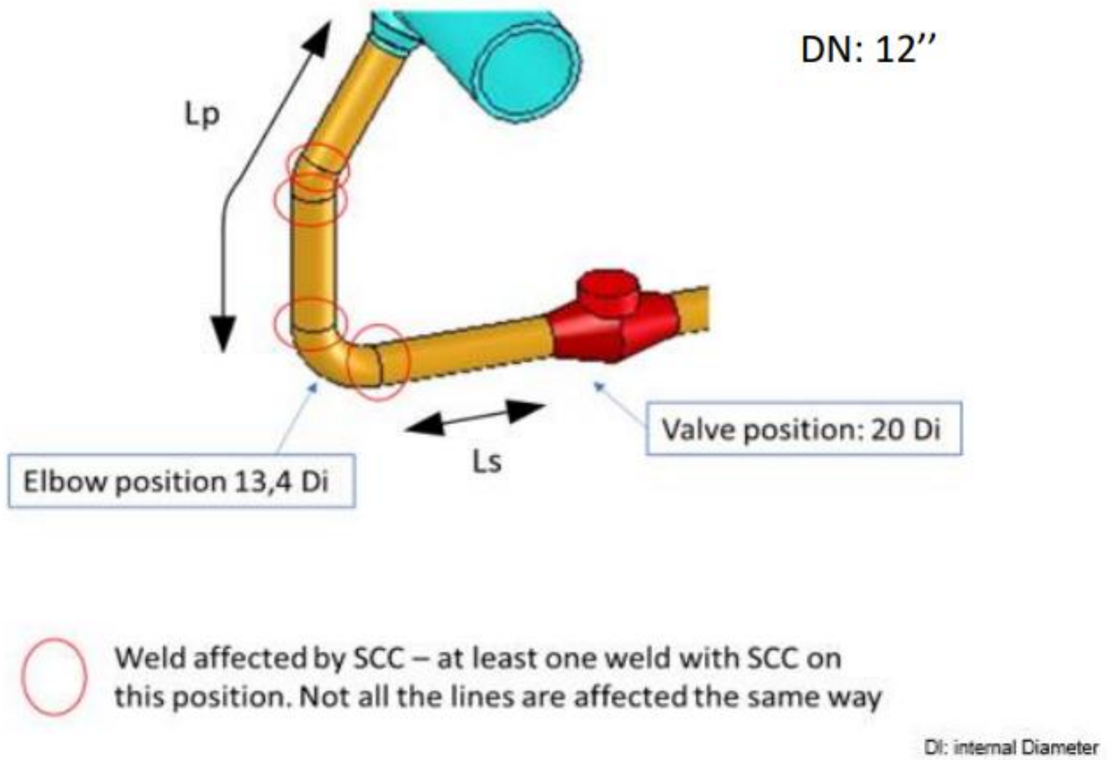
1300 MW – P'4: Safety Injection system line



N4: Safety Injection system line

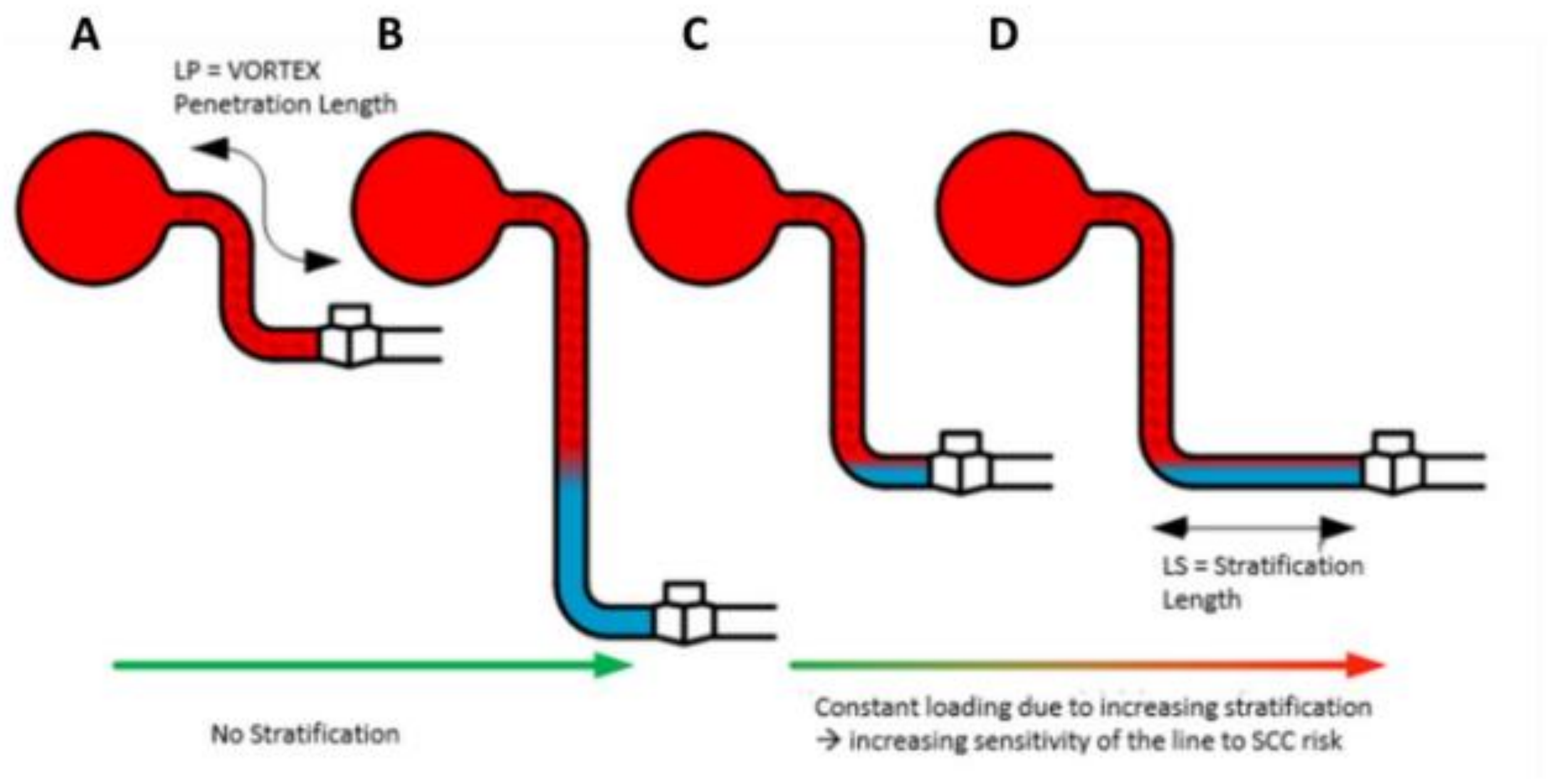


N4: Reactor Heat Removal System hot legs



- Most of the susceptible lines had several welds with SCC in the N4 and P'4 plants
- The SCC depth of the majority of the flaws were < 2mm (~80% of the flaws, however, many were up to 360º in length)
- For unrepaired welds, the largest depth was 6.48mm (1/4 TW)
- The presence of SCC was independent of the welding process (automatic GTAW, manual GTAW, orbital GTAW, or coated electrode)

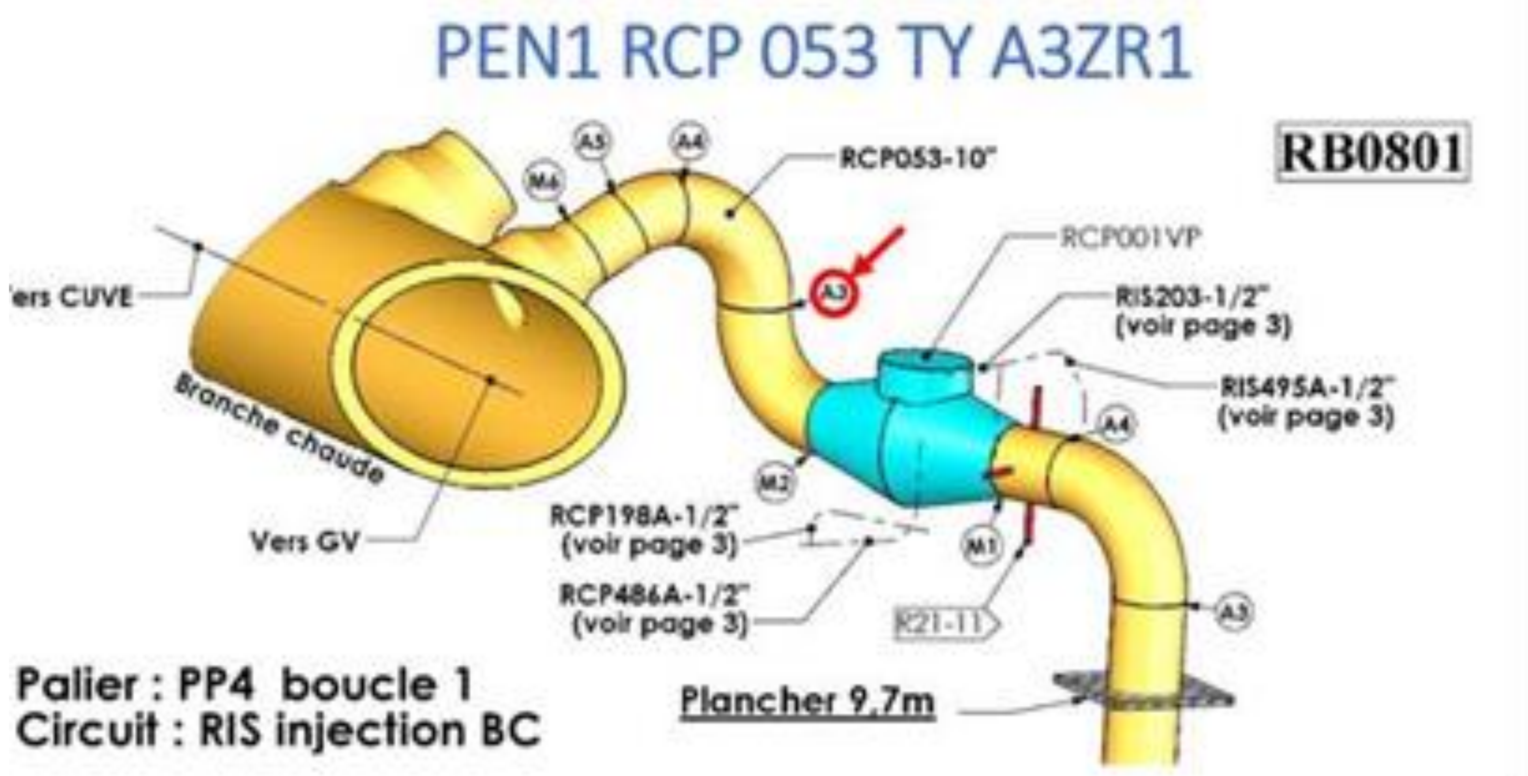
2023 EDF Operating Experience (4/6)



- Contributing Cause
  - Case A
    - Penetration of vortex up to the isolation valve; the temperature (RCS) is constant to the valve; no thermal stratification
  - Case B
    - End of vortex, kept hot, ends in the vertical section; stratification does not form
  - Cases C and D
    - End of vortex, kept hot, ends at the bend connecting the vertical to horizontal run; thermal stratification forms

2023 EDF Operating Experience (5/6)

- Penly Unit 1 - SCC
  - o The ECCS line attached to the hot leg
    - No thermal stratification
  - o An ~85% through wall SCC crack was observed near a repaired weld
    - It was repaired twice during original fabrication
    - 6” long x 0.9” deep; 1.06” wall thickness (155mm long x 23mm deep; 27mm wall thickness)
  - o Hardness along the cracks
    - 230-260 $HV_{0,1}$ upstream of the weld
    - 240-250 $HV_{0,1}$ downstream of the weld



2023 EDF Operating Experience (6/6)

- EDF Non-Destructive Testing
  - EDF has developed an advanced ultrasonic testing method for the detection and characterization of IGSCC (inspection from the outer diameter of the lines)
    - Limitation: not applicable to Main Coolant Loop nozzles and valves (ultrasonic propagation issues in cast austenitic stainless steel)
- On-Going EDF Inspection Program
  - An inspection program for 2023-2025 was defined and was implemented for the RHR and ECCS lines (8”, 10”, 12” and 14”)
  - An inspection program for 2023-2025 was implemented and is in progress for the pressurizer surge line and for small diameter lines (< 8”)
  - ECCS Line Replacement Program for the P’4 plants (1300 MWe Units)

PWROG Safety Assessment (1/4)

Approach

- The Safety Assessment is based on risk, which is a function of the likelihood and consequences
  - Likelihood of atypical SCC
    - Has this type of OE occurred at the PWROG membership plants
      - Define the locations of interest
      - Are the applicable locations being inspected?
        - Review the requirements of existing inspection programs
        - Review the planned inspection data and compare it to the locations of interest
      - Would it be identified?
        - Review the UT method to determine if it would identify these types of SCC flaws
      - Has it occurred previously?
        - Review the MRP-236 SCC OE database
        - Review the thermal fatigue OE database (MPR-85/486) for potential cases of this type of SCC
      - If it occurs in future, would it be identified?

PWROG Safety Assessment (2/4)

Approach (cont.)

- Consequences of atypical SCC
  - Could a flaw result in rupture of the piping?
    - Review available flaw evaluations to determine if a flaw could reach the critical flaw size
  - If a flaw did result in rupture, would it be bounded by the current loss of coolant accident (LOCA) analyses
    - Review the design basis LOCA analyses to identify branch line breaks that were analyzed to determine if the areas of interest were analyzed and if not, whether the locations of interest are bounded by the breaks analyzed
  - Based on the results above, assess the impact on safety based on risk

PWROG Safety Assessment (3/4)

Conclusions

- Existing inspection programs include the locations of interest
- Industry survey results indicate that the locations of interest are being inspected
- The volumetric inspection methods that are used provide reasonable assurance that significant flaws would be detected; however, an IGSCC-specific inspection method has been recommended
- A review of industry OE did not identify any cases of confirmed atypical SCC other than in the EDF OE and the one flaw at Ohi-3; there were three cases with characteristics similar to atypical SCC, but confirmatory destructive examinations have not been performed as flaw evaluations were performed

PWROG Safety Assessment (4/4)

Conclusions (cont.)

- A single break in a branch line is bounded by breaks considered in the design basis LOCA analyses

US Industry Inspection OE (1/4)

- Drivers for inspections of potentially susceptible SI, RHR, and CFL piping
  - In-service inspection (ISI)
  - Risk Informed ISI
  - MRP 146R2 – Thermal Fatigue
  - MRP 2019-008 (Interim Guidance)

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US Industry Inspection OE (2/4)

- Inspection results (Industry survey – 2010 – 2022; 55 units)
  - Passive SI Piping (large diameter):
    - 179 weld locations (including 126 elbow welds) were inspected with no reportable indications
    - 1 of 56 units have DH configurations similar to the EDF SI Piping
  - Other SI Piping (small diameter):
    - 511 weld locations (including 317 elbow welds) were inspected with no reportable indications
  - RHR Piping (large diameter):
    - 250 weld locations (including 190 elbow welds) were inspected with no reportable indications
    - 55 units have a DH configuration (one unit has a HD configuration)
  - PZR Spray Piping:
    - 87 weld locations (including 59 elbow welds) were inspected with no reportable indications (except for the atypical Ohi-3 OE)

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US Industry Inspection OE (3/4)

- NEI 03-08 “Needed” Guidance (Issued April 2023)
  - *“Intergranular stress corrosion cracking (IGSCC) specific ultrasonic testing (UT) examination techniques and personnel qualifications should be implemented when performing the planned (next and future) volumetric inspections for the locations of interest: elbow weld heat affected zone (HAZ) (both sides) for the non-isolable portions of the passive safety injection (SI) piping (i.e. Westinghouse (W) SI piping, Combustion Engineering (CE) SI piping, Babcock and Wilcox (B&W) core flood piping), residual heat removal (RHR) suction piping (i.e. W RHR piping, CE shutdown cooling piping, and B&W decay heat piping), and pressurizer spray line piping (i.e. W, CE and B&W). This recommendation does not require new inspections, but instead only recommends that the IGSCC specific examination methods be used for the volumetric inspections that are already planned (next and future). If inspections are scheduled for less than a year from the time of issuance of this recommendation, then the recommendation can instead be implemented at the subsequent inspection interval”*

US Industry Inspection OE (4/4)

- To date, two units have performed NEI 03-08 IGSCC inspections
  - The inspections used IGSCC qualified techniques and personnel
  - PDI-UT-2 “PDI Generic Procedure for the Ultrasonic Examination of Austenitic Pipe Welds”
    - Plant A
      - 2 welds on 12” Sch 140 pipe
      - Pipe to elbow welds
      - 100% exam coverage
      - ASME Section XI 2007/2008
      - Examination category R-A, item R1.20
      - No recordable indications
    - Plant B
      - 4 welds on 10” Sch 140 pipe
      - 2 welds on 4” Sch 160 pipe
      - Pipe to elbow welds and pipe to pipe welds
      - 100% exam coverage
      - ASME Section XI 2007/2008
      - Examination category R-A, item R1.20
      - No recordable indications

PWROG Applicability Assessment (1/6)

Approach

- Consider the potential root causes for atypical SCC
- Assess whether these conditions are present in the industry

PWROG Applicability Assessment (2/6)

Potential root causes for atypical SCC

- Nitrogen content of Type 316LN resulting in higher hardness in the HAZ ID due to strain-hardening behavior (relative to typical US fleet grades: 303, 304L, 316, 316L)
  - The affected EDF locations are in the newer designs (N4 and P'4), which use Type 316LN
  - However, the older EDF units (CPY design) also use Type 316LN (and 304L) and they have not been affected by this atypical SCC. Also, Type 316NG (which contains nitrogen) has been widely used in BWRs without atypical SCC.
  - If not the sole cause, this may be a contributing factor, so a literature search and OE review will be performed
- Elevated stresses in the elbow weld regions due to branch piping configurations with thermal stratification resulting in bending from differential thermal expansion
  - EDF has attributed the atypical SCC to the down-horizontal (DH) branch piping configuration (specifically when the Horizontal portion is long, Cases C and D)
- Potential Atypical Weld Residual Stress (WRS) profile
  - This profile would have an exceptionally high tensile WRS at the ID and a highly compressive subsurface
  - This could occur based on the indirect indicators: 1) the EDF OE being early onset, 2) the observed flaws are long and shallow, and 3) this profile is consistent with through thickness balance of stresses

PWROG Applicability Assessment (3/6)

Assess whether these conditions exist in the industry

- Type 316LN
  - A survey of the PWROG fleet (55 units) did not identify that any LN grades are being used
  - A literature search was performed and concluded that "*the evidence from the open literature and operating experience, the nitrogen content and associated strengthening/hardening is not considered a root cause for the atypical SCC observed at Civaux, Chooz B, and Penly nuclear power plants. Additionally, it is unlikely to be a major contributing factor to the occurrence of atypical SCC. For the bounding nitrogen content of the piping (<0.08 wt% N) found at the reactors affected, the enhancements to the relevant strengthening mechanisms, with the exception of solid solution strengthening, are not significantly pronounced relative to Type 316L based on evidence from the literature. The operating experience of Type 316LN piping in the EDF fleet indicates no historical problems of atypical SCC in this alloy outside of the newer N4 and P'4 units, and atypical SCC occurred at Ohi-3 in Type 316 piping where alloyed nitrogen was likely absent. Therefore, the alloyed nitrogen in the Type 316LN piping at Civaux-1 and -2, Chooz B-1 and -2, and Penly-1 is not considered applicable when examining the causes of the atypical SCC found at those units*"

PWROG Applicability Assessment (4/6)

Assess whether these conditions exist in the industry (cont.)

- Thermal stratification in the industry branch piping (in progress)
  - Reviewed the PWROG fleet branch line piping configurations and identify those that meet the EDF criterion (i.e., DH with a long Horizontal portion)
    - The DH configuration is not typical in the SI piping, but is common in the RHR suction piping
  - Note that, as discussed in the Safety Assessment, these locations are the primary focus of the current thermal fatigue inspection requirements (MRP-146R2, MRP 2019-008) and there are no confirmed cases of atypical SCC in the US industry

PWROG Applicability Assessment (5/6)

Assess whether these conditions exist in the industry (cont.)

- Atypical WRS profile
  - It is not practical to perform direct WRS measurements of the EDF and the US fleet to perform a direct comparison of the WRS profiles
  - Alternatively, available information will be used to perform sample case analyses for the US fleet considering:
    - Atypical WRS profile and atypical SCC based on the characteristics of the observed EDF flaws (early onset, long, and shallow)
      - For the B&W plant Core Flood Line (CFL), assuming an atypical WRS with an ID stress of 60 ksi and normal operating conditions (steady state), the crack reaches a depth of ~20% through wall and 360º around the circumference; the flaw remains stable beyond the typical operating range of a nuclear power plant and remains substantially below the allowable depth-to-thickness ratio
      - For the Westinghouse plant Safety Injection (SI) line, the initial flaw size reaches a depth of ~20% through wall and 360º around the circumference in approximately 25 years. The maximum allowable flaw sizes are greater than 50% of the wall thickness for a 360º flaw shape
    - Typical WRS profile and typical SCC based on extensive WRS measurement performed for similar BWR piping
      - For the B&W plant CFL and the Westinghouse plant SI line, assuming the typical WRS of ID stress of 30 ksi (EPRI NP-4690-SR) and normal operating conditions, the flaw grows completely through wall in > 25 years
      - The leak-detection capability will identify any degradation. LBB has been applied to the SI lines for the WEC plants

PWROG Applicability Assessment (6/6)

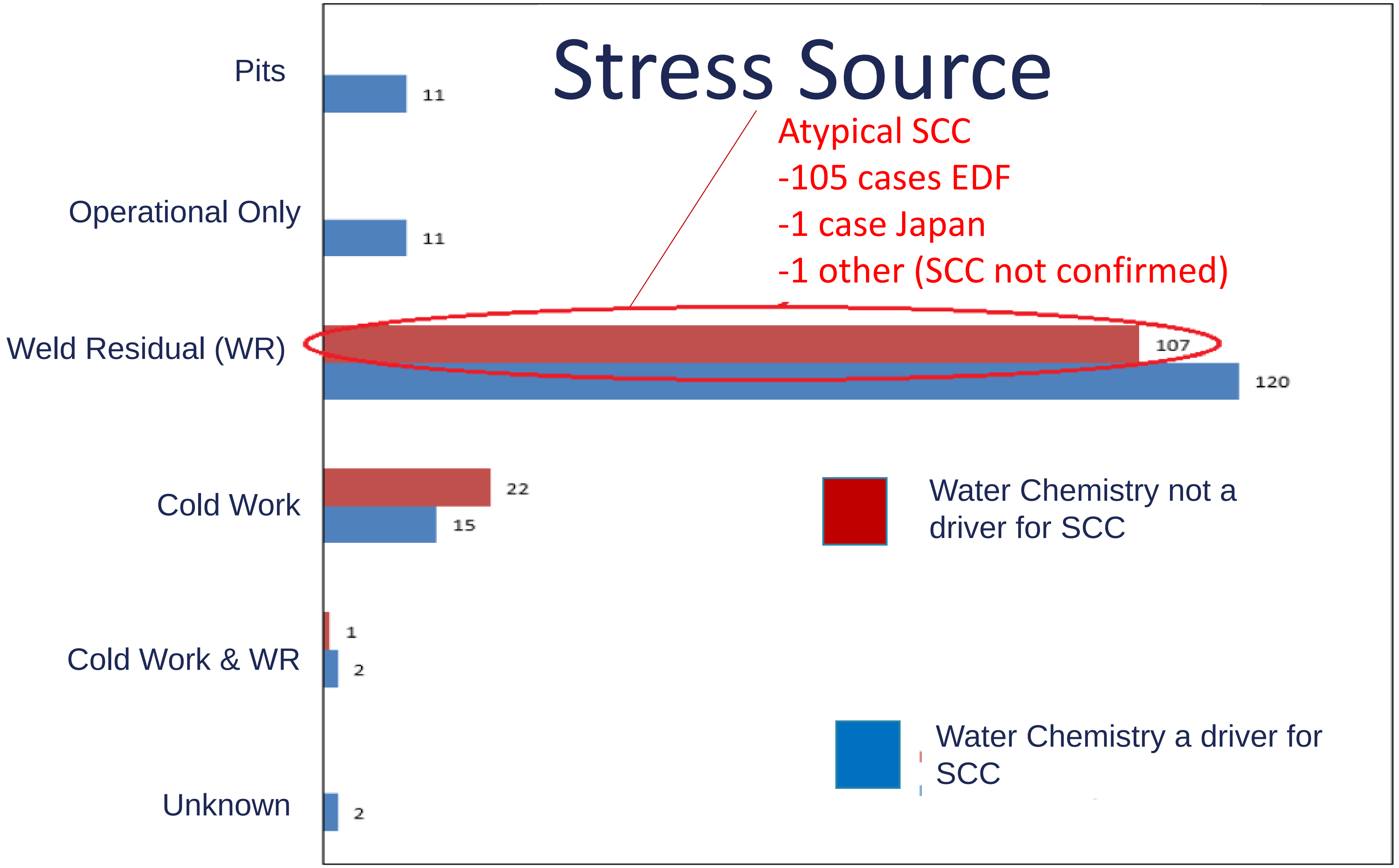
Assess whether these conditions exist in the industry (cont.)

- In addition, an expert panel will be convened to consider the welding process that could result in the postulated WRS profile
  - Based on the feedback from EDF in an expert panel meeting, the CPO/CPY and the 4 loop plants use mainly SMAW, with SCC occurring independent of the welding process used (Automatic GTAW, manual GTAW, Orbital GTAW, or coated electrode)

Revision of MRP-236, Rev. 1 (1/2)

- MRP-236 contains information regarding SCC of primary circuit pressure boundary stainless steel, including an OE database
- The last revision was completed in 2017, which did not identify any cases of SCC in the non-isolable portions of the branch line piping
- New revision (Revision 2) (in progress) is reviewing the OE since 2017
  - The only confirmed cases of SCC in non-isolable portions of the branch line piping have occurred in the EDF fleet and one case at a Japanese unit (Ohi 3)
  - Revision 2 will also include a review of the thermal fatigue OE database (MRP-85R2/MRP-468) for cases that have the potential to be similar to the EDF SCC
    - It will be focused on flaws with large aspect ratios and where a destructive exam to confirm the degradation mechanism was not performed
      - Three units have presumed thermal fatigue with these characteristics

Revision of MRP-236, Rev.1 (2/2)



- EDF/Japan OE is atypical because:
  - Given a well-controlled RCS water chemistry, WRS alone is sufficient for SCC
  - It is located in a non-isolable portion of the branch line piping
    - Previous OE identified that only thermal fatigue occurred in this piping (MRP-85R2/MRP-468), which is addressed by an inspection program (MRP-146R2)

WANO SER 2023-02 – "Stress Corrosion Cracking in Welded Areas of Safety Injection Pipes"; Issued August 2023

- WANO SER 2023-02 was issued after significant event WER PAR 22-0180 (Civaux 1) and WER PAR 22-0477 (Penly 1) were reported
  - Describes latest knowledge to date by WANO of issues and causes
  - PWROG Letter OG-23-159 Issued September 20, 2023 to assist member utilities in evaluating the SER
  - Developed jointly by PWROG/EPRI technical leads for the focus group
  - Provides the background and actions taken by the industry to proactively evaluate the atypical SCC OE
  - EPRI MRP Letter 2023-012 issued October 2, 2023 to transmit OG-23-159 to the MRP membership and provide a copy of the NRC LIC-504 safety assessment for reference

WENRA Recommendations (1/4)

- WENRA Document; “Recommendations Following the Discovery of Intergranular Stress Corrosion Cracks on some French Pressurized Water Reactors,” November 2023
- 2.1 Inspections to be performed on PWR stainless steel welds
  - Inspections have been performed to comply with In-service inspection (ISI) requirements, Risk Informed ISI, MRP-146R2 (Thermal Fatigue inspection requirements) and 2019-008 requirements (NEI 03-08 “Needed” guidance for thermal fatigue)
  - Inspections are being performed with an IGSCC qualified inspection technique and personnel (as per NEI 03-08 Interim Guidance in OG-23-82)

WENRA Recommendations (2/4)

- 2.2 Monitoring of the parameters that may influence the development of IGSCC
  - During plant operation, strict water chemistry requirements are maintained on chlorides, fluorides, conductivity, and pH to minimize the likelihood of stress corrosion cracking in stainless steel piping. Contaminant concentrations are maintained below the thresholds known to be conducive to stress corrosion cracking and the major water chemistry control standards being are included in the plant operating procedures. For example, during normal power operation, the oxygen concentration in the RCS will be in the ppb (typically <5ppb) range by controlling the charging flow chemistry and maintaining hydrogen in the reactor coolant at specified concentrations. Halogen concentrations are also stringently controlled by maintaining the concentrations of chlorides and fluorides within the specified limits. Thus, during plant operation, the likelihood of stress corrosion cracking is minimized.
  - Temperature parameters are screened for thermal fatigue

WENRA Recommendations (3/4)

- 2.3 NDT methodology recommended for the detection of IGSCC
  - Inspections are now being performed using an IGSCC qualified inspection technique and personnel (Generic Procedure PDI-UT-2); no indications have been detected to date
  - Appendix VIII qualified procedures are criteria based procedures qualified for both IGSCC and fatigue cracking
  - Qualification procedures take into account:
    - weld configurations; crowns, unground weld reinforcement,
    - pipe geometry; counterbore, weld root conditions,
  - Test sets used for qualification include field removed IGSCC
  - Include non-encoded and encoded conventional and phased array techniques

WENRA Recommendations (4/4)

- 2.4 Repairs and mitigations on IGSCC susceptible or affected welds
  - The US industry has a suite of mitigation and repair options (US NRC NUREG-0313, Code Case N-770 and associated mitigation/repair Code Cases)
    - Weld overlays (full structural, optimized weld overlay), Inlay, Onlay
    - Mechanical Stress Improvement Process (MSIP)
- 2.5 Recommendations regarding the design and manufacturing of stainless steel piping on new PWRs
  - Not applicable in the US as no new plants are being built, although may need to be considered if there is a need to replace piping in the current operating plants

Questions?