EDF Stress Corrosion Cracking Operating Experience Discussion

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U.S.NRC
United States Nuclear Regulatory Commission
Protecting People and the Environment

French Operating Fleet

- 56 reactors in operation, all Pressurized Water Reactors (PWRs)
- Built during 1970s – 1990s
- 3 main styles
  - 32 are 900 MW (CP0 and CPY types)
  - 20 are 1300 MW (P4 and P'4 types)
  - 4 are 1450^{+} MW (N4 type)
- Based on Westinghouse design, modified for French grid

Stress Corrosion Cracking Detected in French NPPs

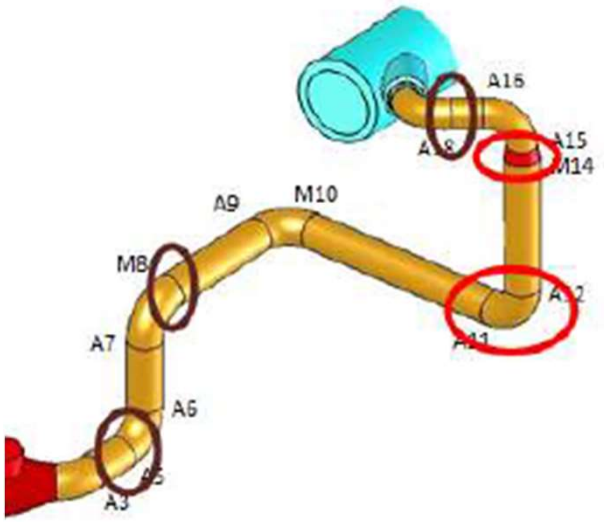
- In Oct. 2021, during the 2nd 10-year inspection, flaw indications were detected in safety injection (ECCS) lines at Civaux-1 (1561 MW).
- Indications were at pipe inner diameter, circumferential, located at elbows. Stagnant flow is expected in affected lines.
- Cracks were confirmed, attributed to stress corrosion cracking (SCC).
  - In the base metal (AISI 316L)
  - In the heat affected zone (HAZ) and mechanical affected zone (MAZ) adjacent to welds
- Additional indications were found at:
  - Civaux-2 (1561 MW) and Chooz-1 and -2 (1560 MW)
  - Penly-1 (1382 MW)

Additional Indications of SCC in Spring 2022

- EDF accelerated plans to inspect safety injection piping for similar degradation in Spring 2022
- Indications have been detected at 4 reactors:
  - Chinon-3 (954 MW)
  - Cattenom-3 (1362 MW)
  - Flamanville-2 (1382 MW)
  - Golfech-1 (1363 MW)
- SCC indications were mostly in 1300 MW and 1450 MW type reactors, not in 900 MW (older) plants
- Indications found in safety injection (SI) lines and residual heat removal (RHR) lines
- The regulator (ASN) requested additional information from EDF to assess the degradation and its extent. Is this a generic issue?

Non-Destructive Examination (NDE)

- Cracks were detected by ultrasonic test (UT)
- The UT procedure was designed to detect thermal fatigue (TF) cracks. It was not optimized to detect or size SCC cracks.
- Re-inspection of plant ECCS piping will use a revised procedure, accelerated schedule.
- Re-analysis of prior NDE data will look for missed calls, “non-relevant indications.”
- Destructive exams are needed to confirm and depth-size SCC cracks.



Destructive Examination

- Several elbows were removed and sent to EDF hot laboratory for assessment
- Intergranular cracks consistent with stress corrosion cracking (IGSCC) confirmed
- High hardness detected in the vicinity of the root weld pass
- Unusual height of the root pass at Civaux 1 weld A12
- No evidence of contamination

Further Root Cause Analysis

- IGSCC has been confirmed by destructive examination
- Degradation not expected, not in accordance with the international operating experience. No SCC on the French 900 MW plant series after 30 years.
- Weld repairs, deviations from normal weld procedures, and thermal stratification in stagnant lines may have influenced cracking.
- EDF has initiated a welding simulation program to estimate hardening and residual stresses in the areas where IGSCC is observed. The early results show that:
  - An area of limited depth on the inner side of the weld is subject to tensile stress.
  - A compression zone exists within the bulk of the weld. This compression zone could significantly slow down the propagation of the cracks.

Similar Operating Experience

- A similar crack was found in Japanese Ohi Nuclear Power Station Unit 3 pressurizer spray weld in August 2020, which was attributed to hardening from cold work on the inside diameter (ID) surface.
  - Unusual heat input at the weld
  - Restriction of weld deformation (constraint)
- Operating experience in U.S. PWRs has shown that stress corrosion cracking of 316 stainless steel is unlikely without significant abnormal conditions, e.g., cold working, grinding, contamination.

USA Experience

- The use of ASME Code Section XI is mandated by 10 CFR 50.55a with most U.S. plants using an NRC-approved risk-informed inservice inspection (RI-ISI) plan as an alternative to Section XI.
- U.S. plants examine ≈10-15% of the ASME Class 1 SI and RHR piping welds under their RI-ISI programs.
- No SCC has been found in analogous welds in U.S. PWRs.
- Welds are susceptible to thermal fatigue cracking.
- There have been ten incidents of thermal fatigue cracking since 2013, with seven found through UT examination and three by leakage.
- EPRI updated MRP-146 in 2018 to enhance the owner's voluntary programs of inspections to detect thermal fatigue cracking.

More on U.S. NDE Examinations

- Class 1 pipes are examined using multiple ultrasonic angles from four directions.
- The personnel, procedures, and equipment used on piping welds must pass rigorous performance demonstration testing under ASME Code Section XI, Appendix VIII.
- The examinations in the U.S. are optimized for thermal fatigue flaws but are capable of detecting stress corrosion cracking.
- The UT examinations have a current ability to detect cracks of 5-15% through wall and a good probability of detecting larger cracks.
- Challenges include the metal grain structure and geometric features of the pipes and welds.

Mitigation Plans - France

- Cracked piping sections have been removed and replaced.
- From September 2022, EDF intends to carry out a complete examination program, concerning all its reactors in operation, on the areas that might be affected by IGSCC.
  - Re-evaluation of prior NDE data
  - UT procedure optimized for IGSCC detection (not only thermal fatigue)
- A periodic inspection program will be defined, with a periodicity based on the sensitivity of the NDE, the growth rate of IGSCC, and mechanical elastic-plastic fracture mechanics analyses.
- EDF plans to define flaw evaluation criteria (based on length and depth of the crack) for continued operation without repair.