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Technical Meeting Between Steam Generator Task Force and NRC Technical Staff

November 14, 2019

Public Comment to February 13, 2019 SGTF Presentation - "*Operational Assessment Process Could Safely Replace Existing Prescriptive Technical Specification Inspection Intervals*"

Comment #1

- Second generation steam generators with thermally treated Alloy 600 tubing:
  - There are several examples from the industry presentation that illustrate potential weaknesses in the assumptions used in the operational assessment process:
    - The third bullet on slide 27 states: “Expect that only a limited number of crack indications with minor severity will be occasionally observed in the future.” The term “minor severity” is an appropriate generalization for the majority of the cracks but there are some notable exceptions.
      - An Alloy 600TT steam generator identified:
        - Axial ODSCC at the top of the hot leg tube sheet which was removed for metallographic analysis and the maximum crack depth on three cracks was 100% through wall (2008)
        - Circumferential ODSCC at the top of the hot leg tube sheet which was removed for metallographic analysis and the maximum crack depth was 80% through wall (2008)
        - Axial PWSCC in the U-bend Area which leaked during an in situ pressure test (2009)
        - Axial ODSCC at the tube support plate showed increase voltage after in situ pressure test (2012)

Discussion Regarding the Axial ODSCC Cracking at the Top of Tubesheet

- For the plant referenced had a history of cracking and would not have been allowed to go longer than one cycle between inspections
- The axial length of the indications in question was small (0.14 inch maximum) and thus does not represent a burst potential
- All industry axial ODSCC indications at TTS are located in the expansion transition and thus initiation is likely assisted by expansion residual stresses
- Cold working due to the expansion process will increase burst pressure
- Tube was damaged during tube pull; estimated burst pressure ~9700 psi
  - Essentially equal to the non-degraded tube section burst pressure

Discussion Regarding the Circumferential Cracking

- While maximum depth was 80%TW (from destructive examination), percent degraded area, which controls burst capability, was only 21% (structural limit ~75%)
- Measured burst pressure of 10,725 psi is essentially equal to the non-degraded tube section burst pressure

Discussion Regarding U-Bend PWSCC

- The leak rate from in situ pressure testing was 0.002 gpm (Information Notice 2010-21) at steam line break pressure, significantly less than the performance criteria
- A geometric anomaly was observed by bobbin coil at the eventual flaw location in early inspections
- Periodic testing showed a gradual phase angle progression suggesting slow growth
- This is the only U-Bend crack identified in Alloy 600TT tubing
  - Supplemental thermal treatment following bend forming should have reduced residual stresses to near straight leg levels (~2 ksi)
  - The development of SCC suggests the geometric anomaly was created after thermal treatment (otherwise stresses too low to cause initiation)

Discussion Regarding ODSCC Axial Indication at Tube Support Plate

- This indication was in an high residual stress tube
  - Plants with high residual stress tubes assess them separately in their operational assessment

Conclusions Regarding the Indications Noted (With the Exception of the High Residual Stress Tube)

- While the Axial and Circumferential ODSCC at TTS exhibited deep depths, burst pressures are ~2.5 times $3\Delta P_{NO}$ performance criteria
- None of these indications would have been a challenge to tube integrity even if left in service another cycle
- Following these early instances, analysis methods were improved and industry awareness increased, thus improving inspection adequacy
- Plants with existing cracking inspect every outage

Comment #2

- The first bullet on slide 28 states, " Industry trends and plant OE show that cracking indications reflect flaws in small tube sub-populations."
  - This was an accurate characterization in 2002. This was initially limited to high stress tubes from the manufacturing process.
  - Subsequent experience showed this mechanism is not limited to high stress tubes. Low row tubes with stress relieved U-bends displaying the signature of high stress tubes in the low frequency eddy current data have been identified and preventively plugged at most plants.
  - Higher row tubes do not display unique eddy current characteristics and those that potentially have high stress were identified by applying a statistical threshold (minus two sigma) to the eddy current voltages measured at the u-bend tangent regions. Industry wide the minus two sigma tubes are mostly still in service.
  - Circumferential PWSCC within the tube sheet was initially believed to be associated only with bulges and over expansions from the manufacturing process. Eddy current reporting of such geometry variations are based on amplitude ($\geq$18 volts) or estimated diametral expansion values ($\geq$0.0015"). Recent results show this mechanism at locations with geometry variations below these reporting thresholds

Discussion Regarding Cracking in Small Sub Population

- The incidence rate of SCC indications on non-high residual stress tubes in A600TT steam generators has been sporadic (including the most limited steam generators), and does not emulate the incidence rates observed in A600MA tubing
- The majority of the cracking in Alloy 600TT are in two sub populations
  - High residual stress tubes
  - Corner tubes in 3 steam generators at one plant

Comment #3

- Slides 31-33 includes a vendor developed X-Probe POD curve for axial PWSCC at TTS. The plant-specific POD was better than the curve on the ETSS
- Discussion
  - The developed curve uses data from an ETSS (peer reviewed by members of industry), plant specific noise measurements, and the EPRI MAPOD POD simulation methodology.
  - As plant specific noise is used, the developed curve will vary from the POD provided in the ETSS.
  - The MAPOD methodology can be considered a lower bound POD estimation since it includes variance about the flaw amplitude-depth regression and a conservative signal- to-noise parameter for estimation of detection capability.

Comment #4

- Another factor to consider in whether skipped inspections are appropriate for alloy 600TT plants that have experienced axial ODSCC is how benign signals are addressed during the inspections
  - Benign signals refer to bobbin coil indications that resemble flaws which originate from conditions such as a manufacturing burnish marks or small dings
  - Typically there are many hundreds of thousands of these signals in alloy 600TT plants. Tubes with free span axial ODSCC detected in 2012 were associated with benign signals. These signals are evaluated by comparing the outage data with the first ISI data. If they vary by more than a certain amount, the indications is tested with a rotating coil or array probe.
  - The change criteria is a best estimate not based on test data. None of these indications are included in Appendix I ETSS for axial ODSCC.

Discussion Regarding Benign Signals

- Bobbin is qualified to detect cracking in less than 5 volt dings
- Only three crack-like indications (in one tube) have been reported in Alloy 600TT tubing associated with benign signals
  - None of these indications challenged tube integrity

Comment #5

- This is a discussion regarding the ability to depth size ODSCC. The comment is that ODSCC sizing can result in underestimation of non-detected indication populations returned to service.
- Discussion
  - The accuracy of depth measurements of detected indications does not affect the accuracy of the estimation of depth distribution of non-detected indications
  - Beginning of cycle flaw population is determined by the POD curve
  - Assessments are performed under quality assurance programs by qualified personnel
  - The utilities perform a comparison of condition monitoring results to past operational assessment predictions
    - No operating experience of issues with operational assessment predictions

Comment #6

- Third generation steam generators with thermally treated alloy 690 tubing
  - I am skeptical about the ability to accurately predict tube wear initiation and growth rates over extended intervals beyond the current prescriptive requirements. Accurate predictions rely on the premise that thermal-hydraulic conditions on the secondary side of the steam generator do not vary significantly. Specifically, I am concerned about the cumulative buildup of deposits on the outside surface of the tubing and how these can influence wear patterns and growth rates.
    - An example - Alloy 600MA Combustion Engineering steam generators' predominant wear was tube wear at support straps in the upper bundle in 1984. By mid 1990's fouling and erosion/corrosion of the lower support eggcrates had caused significant wear in some tubes at these elevations. In situ pressure testing was subsequently required to establish that tube integrity had been maintained over the previous operating interval.

Discussion

- The example OE is not applicable to current steam generators with stainless steel supports
- The more applicable concern today is the accumulation of deposits within supports that can change local flow magnitudes and directions and can change growth rates
- Current secondary side operating regimes have greatly reduced iron transport thus resulting in lesser total deposit inventory compared to operation 20 to 25 years ago
- Industry focus and attention to maintenance of the secondary side has increased compared to early plant operating experience
- Many examples of replacement SGs with significant operating time show either attenuating or stagnant wear growth

Comment #7

- This comments questions the ability to adequately describe growth rates for atypical wear performance plants given the Integrity Assessment Guidelines statement that it is more reliable to utilize growth rate data from repeat indications.
- Discussion
  - Growth rates are most accurate when comparing past inspection data to current data however we do account for large new indications
  - Benchmarking of the prior OA results is performed using current outage data, and results of the benchmarking would prompt modification of OA methods if the OA predictions are not bounding.

Comment #8

- Steam generators are designed with more tubes than necessary to provide core cooling under accident conditions, removing tubes from service with wear depths well below the repair limit reduces the plugging margin. Skipping more than two inspections would likely result in even further reductions in the administrative repair limit.
- Discussion: Plugging limits are established and documented for each plant. This margin is maintained by the engineering programs.

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