A Probabilistic Approach to Baffle Bolt IASCC Predictions

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Objectives

• Use probabilistic methods and a statistical approach to evaluate cracking in Type 304/347 SA and Type 316 CW baffle-former bolts
• Determine failure probabilities due to IASCC as a function of stress ratio and fluence
• Apply the model to several PWRs to correlate with plant data
• Use the model to predict trends and estimate numbers of baffle-former bolt failures for future inspection planning
Overview of Methodology

- Reviewed IASCC Test Data from the literature
- Developed Generic IASCC Trend Curve (Stress Ratio versus Dose)
- Calculated Ratio of Each Data Point to Trend Curve
- Fit Data Point Ratios to Weibull Distribution
- Applied and Compared to Baffle Bolt Inspection Results at Ginna/Point Beach 2 (Circa 1999)
IASCC Test Data

- Data from O-Ring and Constant Load Tests irradiated in operating plants (Fyfitch, et al., 14th Int. Conf. on Environmental Degradation of Materials in Nuclear Power Systems, 2009)

- Materials include 304 (SA) & 316(CW) Stainless Steel
  - Note: Data for Type 347 SS was not included specifically, however, SSRT data indicate that the IASCC susceptibility is Type 347 is similar to that of Type 304

- Stresses normalized to irradiated Yield Strength

- Stress levels from all tests are assumed to be nominal (P/A) with no stress concentration factors
IASCC Trend Curve

- Trend curve is similar to threshold curve on prior slide, but was modified to bound most (but not all) failure points
- Intent is not a Go-NoGo threshold, but rather to estimate probability of IASCC
- IASCC “Susceptibility Ratio” computed for each data point as (%YS) / (curve %YS) at applicable Dose
- Ratio is single parameter that reflects both stress and dose
- Ratio of 1.0 indicates small (but non-zero) probability of failure
Resulting Weibull Distribution

Failure points sorted by IASCC Ratio and plotted on Weibull paper.

Non-Failure points treated as “test suspensions”
Trial Application to Ginna/Point Beach 2
(Circa 1999 Inspections)

- Geometry & Inspection Results obtained from EPRI TR-114779 (Feb. 2000)
- Bolt Stresses and Dose approximated (with help of ANATECH) based on generic 4-Loop plant analysis Assumes bolt stress/temperature/dose distributions are comparable
  - 4-loop bolt pattern (1088 bolts/48 baffle plates/8 former levels) adapted to 2-loop geometry (728 bolts/36 baffle plates/7 former levels)
  - Stress/Dose estimated based on approximate location relative to core
  - Greatest source of uncertainty in analysis
Trial Application – Results Summary

- EFPY Predictions
  - no SCF
  - Predictions w/SCF=1.3
  - Predictions w/SCF=2

PB-2 Insp Results
- Ginna Insp Results
Sensitivity Study for Bolt Material Type
## Trial Application – Predicted Bolt Location Comparison

| Baffle Plate-Bolt # | 1-1 | 1-2 | 2-1 | 2-2 | 2-3 | 2-4 | 2-5 | 2-6 | 3-1 | 3-2 | 4-1 | 4-2 | 4-3 | 4-4 | 5-1 | 5-2 | 6-1 | 6-2 | 7-1 | 7-2 | 8-1 | 8-2 | 9-1 | 9-2 | 9-3 | 9-4 |
|--------------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Level 7            | X   |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Level 6            | XX  | XX  |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Level 5            | X   |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Level 4            | x   |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Level 3            | X   |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Level 2            | XX  |   x |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Level 1            | X   |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |

**Legend:**
- Red: High Probability of IASCC Predicted
- Yellow: Moderate Probability of IASCC Predicted
- Green: Low Probability of IASCC Predicted
- XX: Failed Bolt Location at PB-2
- X: Bolt w/UT Indication at PB-2

**Diagram:**
- Former Plates (7)
- Baffle Plates (36)
- Baffle Plate to Former Plate Bolts (728)
Summary / Conclusion

• Methodology developed for predicting probability of baffle bolt IASCC
  – Based on test data reported in the literature
  – Single IASCC susceptibility parameter derived that incorporates effects of stress and dose
  – Data well-fit by a Weibull distribution

• Methodology applied and compared to baffle bolt inspection results at Ginna/Point Beach 2 (Circa 1999)
  – Bolt stress/dose vs EFPYs approximated (crudely) based on bolt location relative to generic 4-loop plant analysis Significant uncertainty in this approximation, but results compare reasonably well with experience
  – Results predict steep increasing cracking trend at 15~20 EFPY
  – Results also show expected benefits of higher strength CW bolts