Technical Justification for the Ghent Version 2 Probe Qualification and Probability of Detection

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Background

- NRC Safety Evaluation Report (SER) for approval to extend the Nickel Band Tubesheet Sleeve to 8 Cycles stated that the following would need to be addressed for permanent approval. (ML18348B206)
  - Qualified Inspection Technique for the parent tube behind the nickel band
  - Resolution of questions regarding the POD for the inspection technique
- The Ghent Version 2 probe was developed and designed to provide enhanced flaw detection capabilities in the parent tube behind the nickel band region in the lower tubesheet joint.

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Ghent Version 2 Probe Design

- Ghent Version 2 probe is a magnetically biased rotating transmit-receive probe.

- Strong rare earth magnets suppress the effects of the nickel
  - Improves ability to saturate the nickel material
  - Improves inspection capability of parent tube behind the nickel
  - [ ]a,c,e mega gauss oersted (MGO) strength of the Version 1 probe

Ghent Version 2 Probe

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Ghent Version 2 Probe Qualification

- The Ghent Version 2 probe was fully qualified for flaw detection in accordance with the EPRI Steam Generator Examination Guidelines Appendix H, Revision 8

- Testing program completed to study the probability of detection capabilities

Additional details of each program are provided in the next two Sections

Ghent Version 2 Probe
Site-Specific Appendix H Qualification

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Sleeves at Beaver Valley 2

- Alloy 800 sleeves contain nickel and microlok bands located within the roll expansion region
  - Original qualifications for the Alloy 800 sleeves were performed using a **+POINT™[1]** eddy current coil that addressed various areas of the sleeve assembly, however, excluded the parent tube adjacent to the nickel band region.
  - A different inspection technique was required that improves detection through the masking effects attributed to the nickel band.
  - The Ghent G3/G4 probe produced the most promising detection improvement during a feasibility study.

[1]POINT is a trademark or registered trademark of Zetec, Inc. Other names may be trademarks of their respective owners.

Site-Specific Qualification Requirements

- Site-specific qualifications (non-EPRIQ techniques) as a minimum, requires an IQDA verify and document compliance with Appendix H of the EPRI SG Examination Guidelines.

- The technique being qualified is for DETECTION only.
  - Appendix H requires flaw depths ranging from 60% to 100%. (It is acceptable to use flaw depths below 60%.)

- Table H-2 of the EPRI guidelines provides the minimum number of flawed grading units >60% through-wall (TW) that must be detected to meet the technique acceptance criterion of POD > 0.80 at a 90% confidence level
  - With a total of flawed grading units = 25, then minimum number that must be detected = 23.

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Flawed Samples Created for Qualification

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Flawed Samples & Initial Testing

- Each of the parent tube samples are Alloy 600 material, 0.875 inch in diameter with a wall thickness of 0.050 inch.
- The sleeves were installed into the parent tube and positioned with the notches adjacent to the nickel band.
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- Worked with probe manufacturer [ ]a,c,e.
  - Version 1 Ghent probe had [ ]a,c,e.

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Modification to Ghent Probe

- Additional probe modifications were performed by Zetec to create the Ghent Version 2 probe

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  - [ ]a,c,e were achieved with the Ghent Version 2 probe.
    - [ ]a,c,e
    - Detection requirements for qualification were met

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Peer Review

- Beaver Valley Unit 2 Site-Specific ETSS # DMW-G3/G4-Ni, Revision 0 was created to provided process detail for acquisition and calibration and reporting requirements for analysis

- Three IQDA analysts were used for the peer review.
  - Independently they were able to verify the requirements that Appendix H of the EPRI guidelines were met.
  - A review of the ETSS was performed, with all 3 approving.
  - Next, a review of the eddy current data for each indication with the intent of determining if the indication was detectable.

- Results for the QDA
  - IQDA #1 – [ ]a,c,e detectable
  - IQDA #2 – [ ]a,c,e detectable
  - IQDA #3 – [ ]a,c,e detectable

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- Each IQDA analyst signed that the technique met Appendix H requirements

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Probability of Flaw Detection in the Alloy 800 Mechanical Sleeve Lower Tubesheet Joint Using the Ghent Version 2 Eddy Current Probe

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May 26, 2020

General Approach to POD Development

- Obtained parent tube crack samples
- Installed parent tube crack samples into tubesheet simulant collars
- Installed Alloy 800 nickel band tubesheet sleeves into parent tube/collar assembly
- Tested assembly with Ghent Version 2 probe
- Destructively tested crack samples to determine crack depth
- Evaluated inspection and test results to develop probability of detection (POD) curves

Parent Tube Crack Samples

- Parent Tube Crack Samples were obtained from EPRI to develop crack based POD Curves
  - 4 Tube Samples containing 12 Axial ODSCC Cracks
  - 0.875 inch x 0.050 inch Alloy 600 tubing
- Each Sample tested without sleeve with +POINT probe to obtain baseline data
- The flaw depths ranged from [ ]^{b} to [ ]^{b} as determined from subsequent destructive examination
  - One sample at [ ]^{b} depth
  - Remaining depths ranged from [ ]^{b} to [ ]^{b} TW

Parent Tube/Sleeve/Collar Assembly

- Tubesheet split collar simulants were manufactured with a tube bore closely matching the tube outer diameter
  - Minimize flaw deformation when expanded into collar
- Parent tube samples were manually hard rolled into tubesheet simulant collar to firm contact
  - Minimize flaw deformation when expanded into collar
- Each sample tested with Ghent Version 2 probe
- Following testing, sleeves were removed and parent tube tested with +POINT probe and standard Ghent probe

Ghent Version 2 Test Results

- 4 of 12 axial ODSCC flaws were detected in the parent tube behind the sleeve nickel band within the tubesheet simulant collar
  - The depth size of the detected flaws ranged from [ ]^{b} to [ ]^{b}
  - The depth of flaws not detected ranged from [ ]^{b} to [ ]^{b}
    - All but one flaw not detected were less than [ ]^{b}

- Post-test eddy current if parent tube with no sleeve and collar showed no change to the flaw sizes
  - Successful measures to mitigate flaw deformation

Parent Tube/Sleeve/Collar Test Results

			As-Received Parent Tube	Sleeve/Tube/Collar Assembly	Post-Test Parent Tube (No Sleeve)		
Parent Tube Sample Identification	Flaw Number	Location (degrees)	Baseline +POINT Vpp	Behind Nickel Ghent Version 2 Vpp	Final +POINT Vpp	Final Standard Ghent Vpp	DE Exam Depth %TW
J-2-3	1	31	0.71	NDD	0.74	1.20	
	2	71	1.49	0.35	1.49	2.62	
	3	102	0.73	NDD	0.70	1.07	
	4	285	0.21	NDD	0.21	0.27	
J-3	1	91	NI	NDD	0.44	0.28	
	2	91	NI	NDD	0.44	0.63	
	3	168	18.07	3.76	20.49	21.60	
	4	278	0.26	NDD	0.21	0.21	
	5	354	0.27	NDD	0.26	0.59	
J-8	1	46	0.86	0.09	0.86	1.38	
	2	228	0.40	NDD	0.36	0.63	
J-12A	1	312	1.02	0.39	1.41	2.55	

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NI- Not initially recorded
NDD-No degradation detected

Probability of Detection (POD) Development

- Industry accepted POD modeling methods were used to develop POD curves from testing program
- Generalized Linear Modeling (GLM) binary hit-miss models used in accordance with the EPRI SG Integrity Assessment Guidelines
  - Flaw detection (hits) assigned "1"
  - Flaw non-detection (miss) assigned "0"
  - Log-logistic POD curves developed
- Two types of POD curves developed
  - Simple Hit-Miss POD from raw detects/non-detects from testing
  - Noise-based POD from simulations of noise and voltage to depth correlations from testing

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Simple Hit-Miss Curve

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Noise-Based POD Curve

- Used Industry Model Assisted POD (MAPOD) methodology
  - Voltage amplitude noise distribution
  - Flaw depth to flaw voltage correlation (Ahat)
  - Signal-to-noise thresholds for flaw detection
- Inputs combined through probabilistic simulations to determine hits/misses to produce log-logistic POD curve
- Noise distribution developed from Ghent V2 probe Appendix H program and samples
- Ahat distribution from POD test program and destructive examination of crack samples
- S/N thresholds developed from results of POD test program

Noise and Ahat Distributions

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Noise-Based POD Curve, Linear Ahat

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Alternate Noise-Based POD

- Observations during the test program suggest that the effects of the nickel may introduce unique conditions not accounted for in the noise-based POD method.
- Effects of the nickel reduces the flaw voltage amplitude without apparent influence from noise, thus making the noise-based POD result overly conservative
  - MAPOD method assumes noise is the only parameter contributing to masking flaws
- An alternate noise-based POD curve developed with an adjusted Ahat function to address the voltage reduction caused by the nickel

Alternate Noise-Based POD Curve

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Ghent V2 Probe POD Comparisons

- The results of the three POD methods are
  - Simple POD(0.95) = 74.5% TW
  - Unadjusted MAPOD POD(0.95) = 93.7% TW
  - Alternate MAPOD POD(0.95) = 86.0% TW
- Simple Hit/Miss POD considered "More True" since it is empirically determined by Detections and Depths. Effect of noise and Nickel is inherent.
- Unadjusted MAPOD POD considered overly conservative since it includes compounding effects of voltage reduction from nickel and noise effects
- Alternate MAPOD POD is more comparable and more conservative to the empirical Simple Hit/Miss POD

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Applicability of OD Flaw Detection to ID Flaws

- PWSCC flaw samples were not available for this test program. ODSCC flaw samples were readily available.
- The POD curves developed from this test program provides a conservative estimate of ID flaw detection based on eddy current theory.
  - Eddy current test frequency of 70kHz concentrates the magnetic field at the inner surface of the parent tube
  - Magnetic field strength is lower at the outer surface of the parent tube – providing lower detection capability for OD originating flaws.
- Detection of parent tube ID originating flaws are expected to be significantly better than the POD curves developed.

Operational Assessment Using POD Curves

- To demonstrate the acceptability of the developed POD curves, an Operational Assessment was performed to show that SG performance criteria will be satisfied after one cycle of operation with potentially undetected flaws
  - Fully probabilistic analysis
  - EPRI default growth rates used
  - Assumed three undetected flaws
  - Assumed flaws located in freespan to allow use of burst and leakage equations
    - Extremely conservative
    - Burst is actually eliminated due to tubesheet
    - Leakage is actually reduced due to tubesheet full depth hard roll and sleeve joint

Operational Assessment Results

- All SG Performance Criteria satisfied using the three developed POD curves

Case	Applied POD Curve	Probability of Burst (%)	Probability of Leak (%)	Upper 95th Percentile SLB Leakage (gpm)	Lower 5th Percentile Burst Pressure (psi)
Case A	Simple Hit/Miss	1.15	0.034	0	5355
Case B	Alternate Ahat	2.25	0.106	0	5025
Case C	Unadjusted Ahat	3.53	0.148	0	4746
SG Performance Criteria	--	≤5	≤5	≤0.10	≥ 4525

Conclusions

- POD curves for detection of parent tube flaws behind nickel band region in the lower tubesheet sleeve joint have been successfully developed based on actual Ghent Version 2 inspection and destructive examination of actual outer diameter stress corrosion crack samples.

- The developed POD curves have been demonstrated to support an operational assessment for at least one cycle of operation.

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Approval Information
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