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February 28, 2001

U S Nuclear Regulatory Commission
Attn: Document Control Desk
Washington, DC 20555

PRAIRIE ISLAND NUCLEAR GENERATING PLANT
Docket Nos. 50-282 License Nos. DPR-42
50-306 DPR-60

Response to NRC Questions Dated February 12, 2001

By letter dated, February 12, 2001, the NRC transmitted questions related to the current Unit 1 Steam Generator Inspection. These questions followed a February 9, 2001, meeting between NMC and the NRC.

At the meeting on February 9, 2001, Prairie Island presented information on eddy current "noise", characterized the eddy current "noise" in all of the rows 1 and 2 U-bends in the Prairie Island Unit 1 steam generators, and provided information to define the "flaws of potential tube integrity significance" in the low row U-bends.

As a result of the February 9, 2001, meeting with Prairie Island representatives and NRC staff, the NRC issued follow-up questions in the following areas:

1. Structural Integrity Analysis
2. Eddy Current Inspections
3. Dents, Flow Slot Hour-glassing and Secondary Side Inspections
4. Root-cause Analysis
5. Conclusion

The Prairie Island Unit 1 steam generators are operable. The eddy current examination met all Technical Specification and NEI 97-06 requirements. All tubes with indications exceeding repair criteria were repaired or plugged. The condition monitoring process, including in situ pressure testing, found no tubes which exceeded the structural or leakage performance criteria.

All rows 1 and 2 U-bends were examined with medium frequency +Point™ rotating coil probes. Prior to the outage, noise criteria for the examination of low row U-bends were

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established by XCEL and Prairie Island procedures using the latest industry information and guidance. U-bends exceeding medium frequency noise criteria were examined with high frequency +Point™ rotating coil probes. No tubes examined with high frequency probes exceeded the high frequency noise criteria.

The circumferential U-bend indications found in R1C52 were pressure tested in situ and met the performance criteria.

In accordance with the voltage based repair criteria (GL 95-05) and NEI 97-06 (Steam Generator Program), a preliminary operational assessment has been prepared for the Prairie Island Unit 1 steam generators. The preliminary operational assessment identified no short term or long term operability issues for the next cycle.

At this time, Prairie Island has met its regulatory requirements and industry commitments with respect to the steam generators. All defective tubes found during the inspection were plugged or repaired. There were no new corrosion degradation mechanisms found in the Prairie Island Unit 1 steam generators this outage. The active degradation mechanisms are well understood, have been present in the Prairie Island steam generators for the last ten years, and have been identified prior to exceeding performance criteria. Conservative technical and programmatic changes have been made in the Steam Generator Program in response to recent industry events.

Attachment 1 contains answers in response to the NRC's follow-up questions from the February 9, 2001 meeting regarding Prairie Island RFO-21 Unit 1 steam generator eddy current results.

In this letter we have made no new Nuclear Regulatory Commission commitments. Please contact Richard P. Pearson (651-388-1121) if you have any questions related to this letter.

Michael D. Werner
Plant Manager
Prairie Island Nuclear Generating Plant

c: Regional Administrator - Region III, NRC
Senior Resident Inspector, NRC
NRR Project Manager, NRC
J E Silberg

Attachment:
1. Prairie Island Response to NRC Questions dated February 12, 2001

ATTACHMENT 1

Prairie Island Response to NRC Follow-up Questions dated February 12, 2001 from the February 9, 2001 Meeting Regarding Unit 1 Steam Generator Eddy Current Test Results

Introduction

A variety of steam generator tube degradation mechanisms typical for Alloy 600 tubing are active in the Prairie Island steam generators and will be discussed in the Technical Specification required reports to follow.

This report specifically addresses questions related to eddy current indications indicative of possible primary water stress corrosion cracking in the rows 1 and 2 U-bend region.

All rows 1 and 2 U-bends were examined with medium frequency +Point™ rotating coil probes. Prior to the outage, noise criteria for the examination of the low row U-bends were established by XCEL and Prairie Island procedures using industry information and data. U-bends exceeding medium frequency noise criteria were examined with high frequency +Point™ rotating coil probes. No tubes examined with the high frequency probes exceeded the high frequency noise criteria.

One tube, R1C52 contained two inside diameter single circumferential indications located on the intradose of the U-bend. The largest of these circumferential indications was located on the inside of the U-bend, one inch distance axially from the apex. This tube was pressure test in situ to 5550 psig with no leakage, burst, or post in-situ eddy current changes.

The normal main steam operating pressure assumed for the next cycle is 690 psig.

Unit 2 rows 1 and 2 U-bends were stress relieved in May 2000.
Unit 1 rows 1 and 2 U-bends were stress relieved in January 2001.

Structural Integrity Analysis - NRC Questions

> *In the February 10* (sic), *2001 meeting, you presented two approaches to support a conclusion regarding minimum structurally significant flaws in terms of voltage. Provide an explanation of these approaches, the source and applicability of the data, the burst model(s) used, analyses performed, supporting assumptions, conclusions, and how you arrived at your conclusions.*
>
> *Describe the performance demonstration program used to estimate the flaw sizing accuracy used in the U-bend structural analysis. This should include the number and type of tube and flaw specimens and the applicability of the data set to plant-specific conditions (e.g., geometry, flaw signal characteristics, and signal-to-noise ratios), and*

whether the sizing accuracy represents the performance of the eddy current system (technique plus personnel) against ground truth.

Provide the data base that supports the crack growth rates used in the structural analysis. Discuss why this data base is applicable to Prairie Island Nuclear Generating Plant (PINGP).

Provide the data base that supports the burst correlation to voltage and flaw length. Discuss why it is applicable to PINGP.

Structural Integrity Analysis - Prairie Island Response

Two circumferential inside diameter indications were found in tube R1C52 in 12 SG near the apex of the U-bend on the intradose of the bend. The circumferential length of the limiting indication was 0.7 inches which is less than one-half of the condition monitoring limit of 1.68 inches[1]. This condition monitoring limit was derived using the conservative assumption of 100% TW cracking for the entire length. . The maximum depth of the indication, assuming an upper 95th percentile sizing error per EPRI ETSS 96701, was less than 80% TW, thus demonstrating leakage integrity. In situ testing demonstrated that a minimum strength of 3ΔP was met and no leakage occurred at the 3ΔP test pressure.

Circumferential cracks of this size and larger could have remained in service for the next cycle of operation and still have met deterministic structural and leakage integrity requirements at EOC 21. In terms of meeting a 3ΔP strength requirement, the limiting allowable 100% TW circumferential crack length at EOC is 1.88 inches[2]. Moreover, the circumferential indications in R1C52 were easily detected, particularly in light of increased emphasis on indications in low row U-bends.

The limiting form of degradation in low row U-bends is axial primary water stress corrosion cracking (PWSCC). No U-bend indications of this type were found in the current inspection at Prairie Island Unit 1. Historically, a total of 5 axial indications in low row U-bends have been found in all previous inspections at Prairie Island Units 1 and 2. Table 1 provides information on all of the U-bend eddy current indications found in the Prairie Island Steam Generators.

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[1] The "Condition Monitoring Limit" is the combination of measured flaw parameters (in this case length and depth(assumed to be 100% TW) at which the calculated burst pressure equals three times the normal operating differential pressure. For Condition Monitoring limits, the calculation includes uncertainties in the NDE sizing technique, the material properties of the tubing and the burst pressure relationship.
[2] This length is the "EOC Allowable Structural Limit" and includes uncertainties only in the material properties of the tubing and the burst pressure relationship.

SG	TUBE	Axial Location	Bend Location	Indication, Extent	Max % @ MV	Max Volt	Phase Angle	Plug	EFPY
11	1-13	07H + 7.47 TO + 8.02	APEX Intradose	SAI, 0.55"	73 % ID	3.44	37	1991	14.1
12	1-15	07H + 3.86 TO + 4.22	HL Tangent Extradose	SAI, 0.36"	70% ID	1.84		1994	16.6
12	1-46	07H + 4.03 TO + 4.24	HL Tangent Intradose	SAI, 0.21"	70% ID	1.12	23	1997	19.6
12	2-6	07H + 13.88	CL Near the Tangent	MBM 1990 Bobbin	N/A	3.79		1981	5.73
21	1-24	07H + 10.81 TO + 11.39	CL Tangent No down indicator	MAI, 0.58" 2 indications 0.57" & 0.51"	63% ID	2.17	25	1997	18.8
21	1-93	07H + 3.58 TO + 3.84	HL Tangent Intradose	SCI, ~66 degrees	~96%	1.68	30	2000	21.6
12	1-52	07H + 7.5 TO 7.69 07H + 7.78 TO 8.15	Both are on CL side of APEX Intradose	SCI, ~74 degrees SCI, ~98 degrees	49% ID 56% ID	0.58 1.06	20 22	2001	23.2

Table 1
Rows 1 and 2 U-bend Indications at Prairie Island

Given the previous occurrence of axial U-bend PWSCC at Prairie Island and other similar plants, four different approaches were used to evaluate the structural and leakage integrity of postulated axial degradation in low row U-bends at Prairie Island Unit 1. Axial degradation was selected since it conservatively bounds circumferential indications in the U-bend region.

1st Approach: Standard Approach (evaluate all combinations of length and average depth)

Figure 1 shows a plot of the structural depth versus structural length for ID axial cracks leading to a 3ΔP burst pressure of 4635 psi at 0.95 probability for the best estimate structural limit, the EOC allowable limit and the physical repair limit. The EOC allowable limit includes material property and burst equation uncertainty. The physical repair limit defines the limit of the actual physical dimensions of cracks which must be found to ensure that minimum 3ΔP strength requirements will be met at the end of the next cycle. The physical repair limit accounts for crack growth over the next cycle of operation. Figure 1 shows that axial ID cracks in U-bends with average depths of about 50% TW must be found by inspection to ensure structural integrity requirements over the next cycle of operation. Historically, Prairie Island has detected indications meeting the physical repair limits of Figure 1.

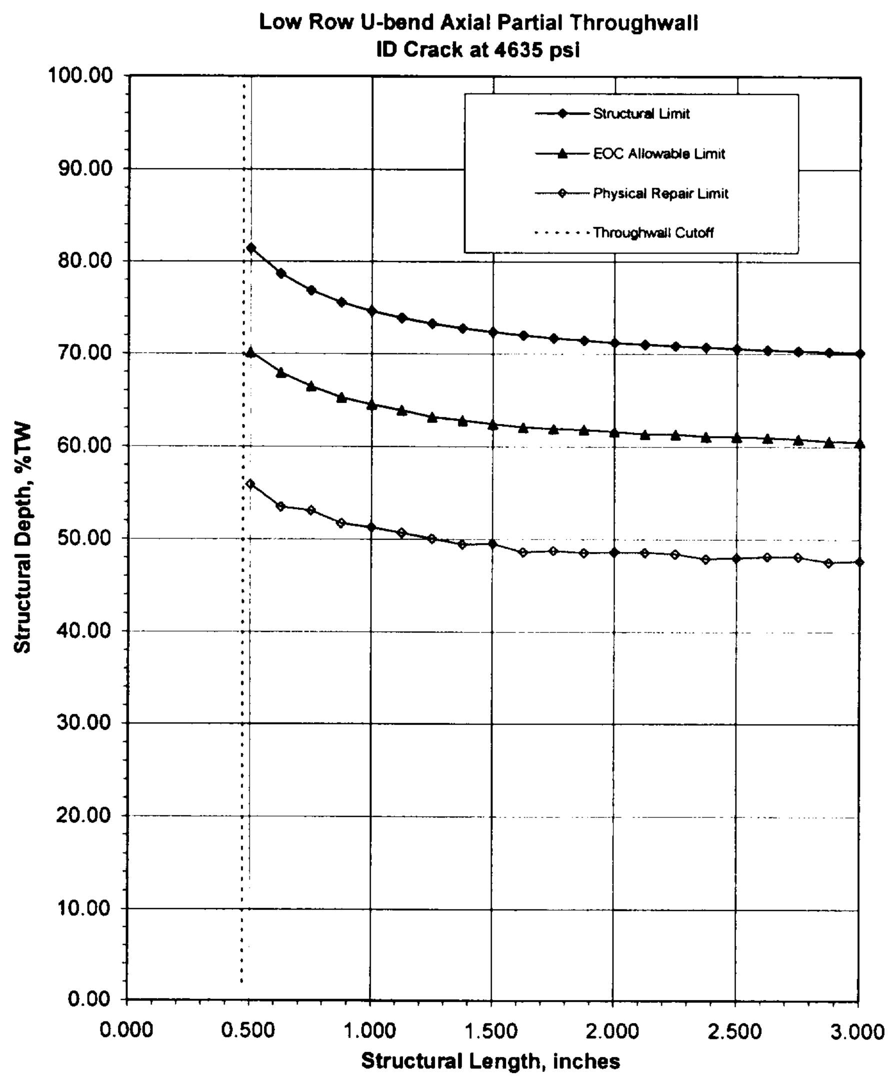

Figure 1
Structural Limit[3], EOC Allowable Limit and Physical Repair Limit Curves for Axial PWSCC in Low Row U-bends

The burst equation used in Figure 1 is taken from the EPRI Flaw Handbook (in final publication), Section 5.1.4, Part-through-wall Axial Cracking. It is based entirely on

[3] Structural Limit is determined using best fit burst equation and average material properties

pulled tube burst test data. The parameters in the Framatome (B. Cochet) equation were empirically determined from a pulled tube burst test database.[4]

The growth rate distributions used to construct Figure 1 are the same as those used in the Westinghouse/E-Mech CMOA analysis for Indian Point Unit 2 (Figure 5.5).[5] The log normal distribution of average depth crack growth rates has an upper 95th percentile growth rate of 12.9%TW/EFPY and a median value of 3.45 %TW/EFPY. The length growth rate distribution meets or exceeds that used in the Indian Point 2 CMOA.

The flow strength (average of yield + ultimate at temperature) used for all degraded U-bend analyses is 79.05 ksi. Again, this is the same as used in the Indian Point 2 CMOA and reflects a conservative bound to test results and the tensile properties of cold worked row 1 and row 2 U-bends.

2nd Approach: Assume Worst Case Undetected Axial Crack Profile is Equivalent to larger indication in R1C52 U-bend

The second approach assumed a worst case undetected crack profile and demonstrated that growth of this worst case profile over the next cycle of operation resulted in an EOC condition that met a minimum degraded tube burst strength of 3ΔP with at least 0.95 probability and a 95/95 SLB leak of zero. The worst case undetected axial crack in a low row U-bend was conservatively assumed to be equivalent to the detected circumferential indication in R1C52 at the apex. With the +Point™ probe, comparable axial and circumferential crack sizes will generate comparable signal amplitudes. Thus the signal from the circumferential crack in tube R1C52 could be considered as an axial crack with about a 1.06 volt response. Figure 2 shows the crack depth versus length profile using the technique and sizing correlations in EPRI ETSS 96701. This assumed worst case undetected axial crack profile was grown in length and depth over the next cycle of operation in the Profile_Pro Monte Carlo simulation program. The methodology of accounting for sizing errors and profile growth adjustments is essentially the same as applied in the ARC methodology for axial PWSCC at dented TSP intersections. Additional elements of conservatism include the elimination of ligament strengthening effects, use of the ANL burst equation for partial depth axial cracks and assuming that, once wall penetration occurs, the burst strength reduces to zero instead of the full length through-wall crack value. Note this is even more conservative than a current proposal to assume a full length 100 %TW crack when wall penetration occurs at any point. Also note that inclusion of NDE sizing errors

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[4] E-Mech internal calculation based on variety of OD and ID axial cracks in different tubing sizes and manufacturers

[5] "Indian Point-2 U-bend PWSCC Condition Monitoring and Operational Assessment", Westinghouse Report SG-00-05-008, Prepared by Westinghouse Electric Co. and E-Mech Technology Inc., June, 2000, docketed by Consolidated Edison.

is equivalent to assuming a worst case undetected axial crack with an actual physical depth about 15 %TW deeper than that illustrated in Figure 2.

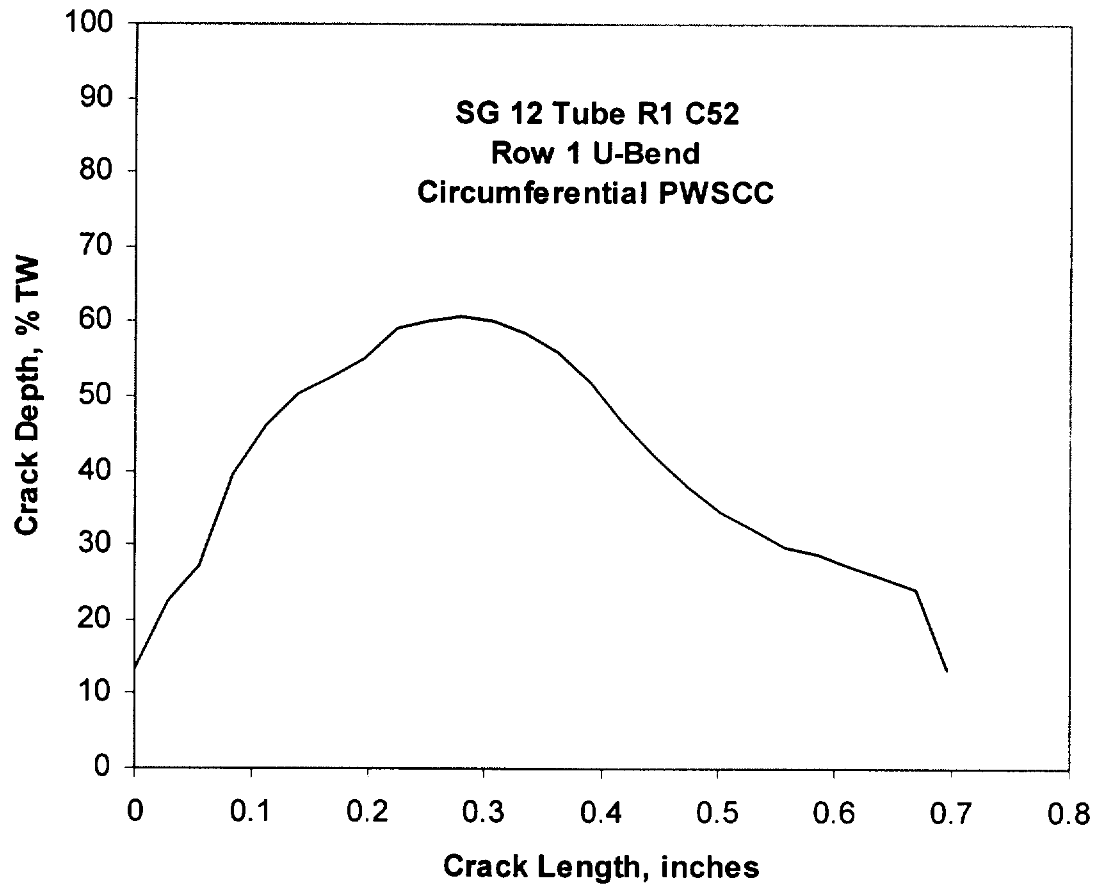


Figure 2
Crack Profile of the Detected 1.06 Volt Row 1 Circumferential Crack
Assumed to be the Worst Case Undetected Axial Crack

Figure 3 shows the distribution of projected EOC 21 burst pressures for the assumed worst case U-bend axial crack. The 3ΔP minimum degraded tube burst strength is met at the 95th percentile worst case level (lower 5% on Figure 3). The projected 95/95 SLB leak rate is 0.00 gpm. A very conservative worst case of undetected axial PWSCC in a low row U-bend, evaluated in a manner that is more conservative than an approved ARC methodology, meets deterministic structural and leakage integrity requirements at EOC 21. At Prairie Island, the detection capability for the occurrence of PWSCC in low row U-bends exceeds the levels needed to detect a flaw of potential tube integrity significance.

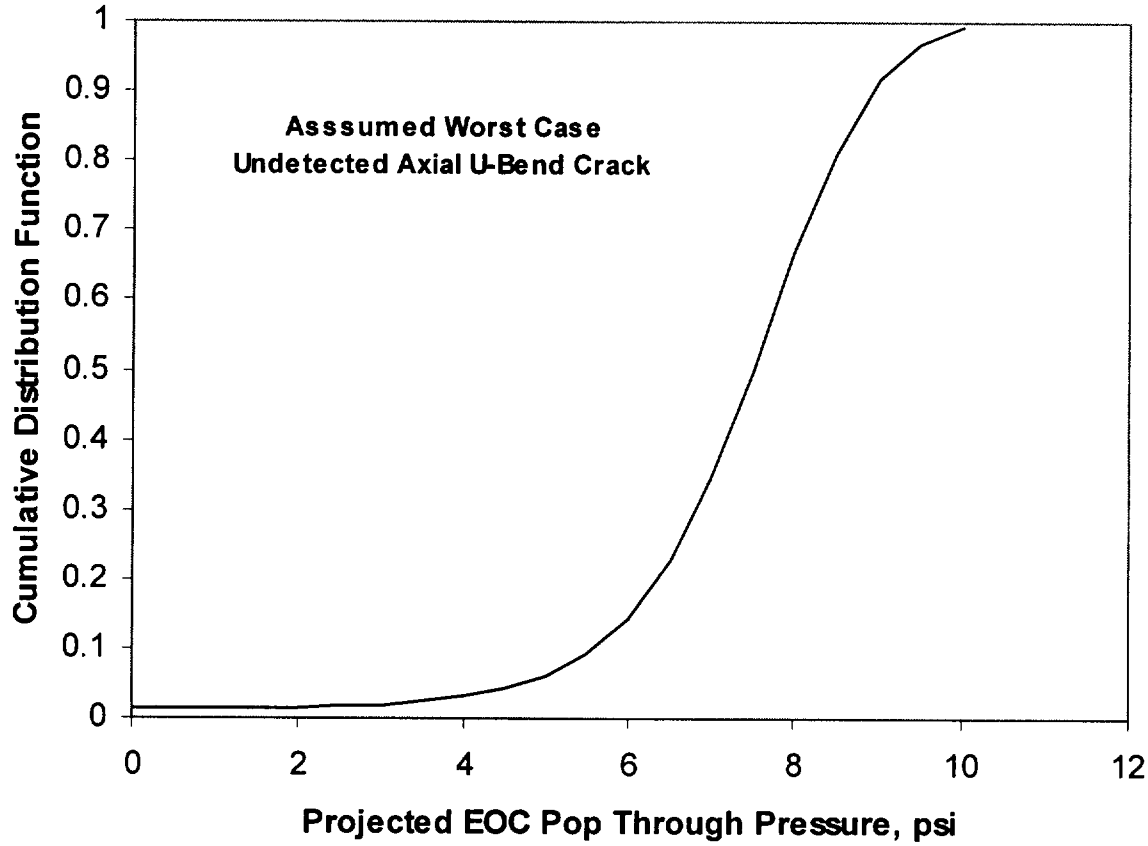


Figure 3
Distribution of Projected EOC 21 Degraded Tube Burst Pressures
Assumed Worst Case Undetected Low Row U-bend Axial Crack

3rd Approach: Use Framatome equation to calculate burst pressures from NDE Axial Crack Profiles at Indian Point 2. Using calculated burst pressures, develop correlation with measured +Point™ voltages.

The third approach used to evaluate postulated axial cracks in U-bends deals directly with the question of +Point™ signal amplitude of cracks which must be detected and the ability to detect such signals in the Prairie Island Unit 1 U-bend eddy current signal noise. In this approach a correlation is needed between eddy current signal parameters and minimum expected burst pressure. Burst pressure depends on indication length

and +Point™ signal amplitude, in this case, volts. This can be demonstrated from RPC data in the bobbin voltage ARC database and by the correlations presented below.

The Westinghouse/E-Mech CMOA analysis for Indian Point 2 lists NDE determined axial crack profiles along with average depth and effective length from 400 kHz +Point™ data. See Section 3 and Table 3-5 of the Indian Point 2 report. With these depths and lengths, use of the original Framatome equation provides estimated lower bound burst pressures (*ELBP*). The original Framatome equation is within 1% of the lower 95th tolerance interval of pulled tube burst pressures where actual profiles are known from destructive examinations. Correlation of estimated lower bound burst pressure in psi with measured +Point™ voltages, *V*, (peak to peak at 400 kHz) and +Point™ lengths, *L*, from the Indian Point 2 data yields the equation:

$$ELBP = 11340 - 1593 \bullet V - 1837 \bullet L$$

Figure 4 shows a plot of *ELBP* versus the fitted values from the above equation. The 13 point fit is excellent. The standard error of estimate about the regression line is 759 psi.

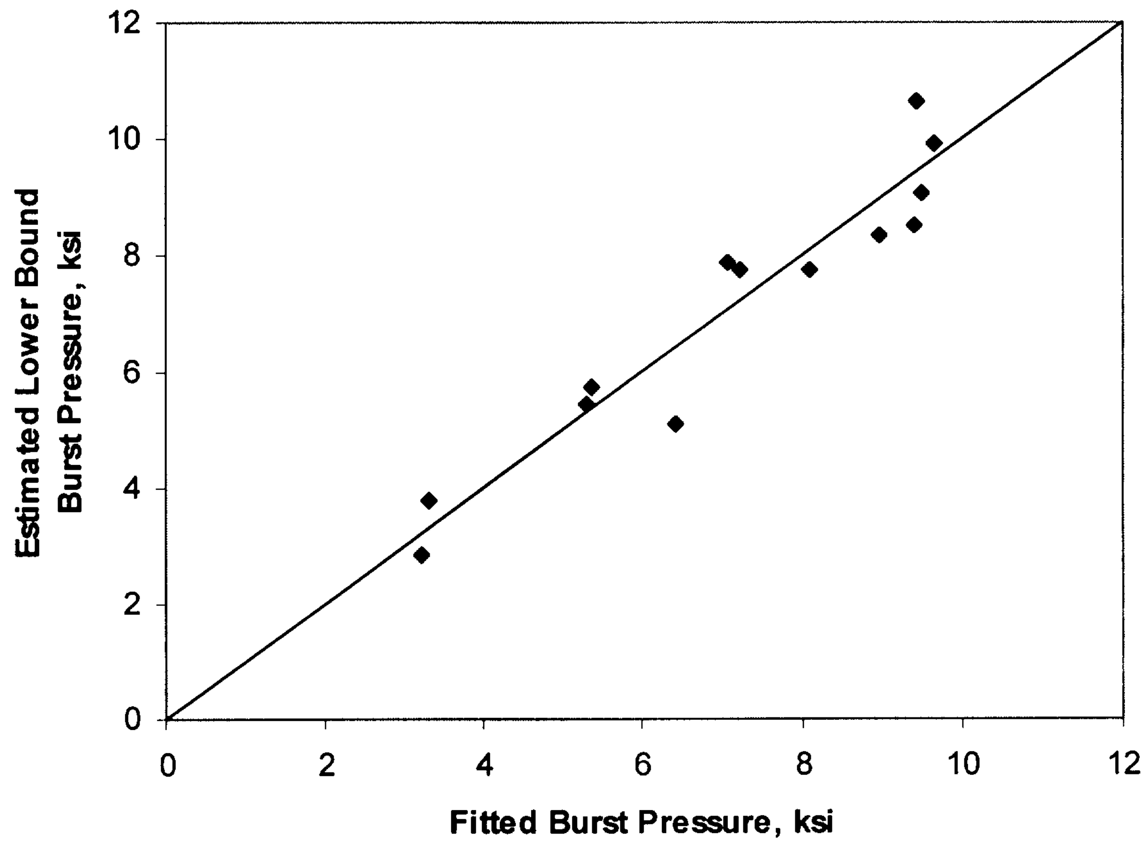


Figure 4
Estimated Lower Bound Burst Pressures
From IP2 400 kHz NDE Crack Profile Versus Fitted Volts/Length Correlation

In order to meet a $3\Delta P$ burst pressure of 4635 psi after the next cycle of operation (1.512 EFPY) an allowance for scatter about the regression fitted burst pressure and growth of degradation over the next cycle must be considered. The limiting change in burst pressure for very long flaws is 115 psi for each increase in average crack depth of 1% TW. Shorter length flaws will decrease in burst pressure by a lesser amount. Thus the growth rate distribution can be converted into a distribution of strength decreases over the next cycle of operation. Using Monte Carlo techniques, the scatter about the regression line plus the distribution of strength decreases caused by crack growth over the next cycle of operation were combined to calculate the burst strength incremental allowance for scatter and crack growth, needed at the beginning of a cycle to ensure a minimum degraded tube burst strength at EOC of $3\Delta P$ at 0.95 probability with 95% confidence. This value is 2713 psi. Thus a regression equation burst pressure of

(4635 + 2713), or 7348 psi defines the +Point™ indication voltage, as a function of length, that needs to be detected during an inspection against the Prairie Island Unit 1 U-bend noise background.

The conservative "should detect" line is shown in Figure 5. +Point™ volts and length are shown in Figure 5 for all previous U-bends indications, either axial or circumferential, found in Prairie Island Units 1 and 2.

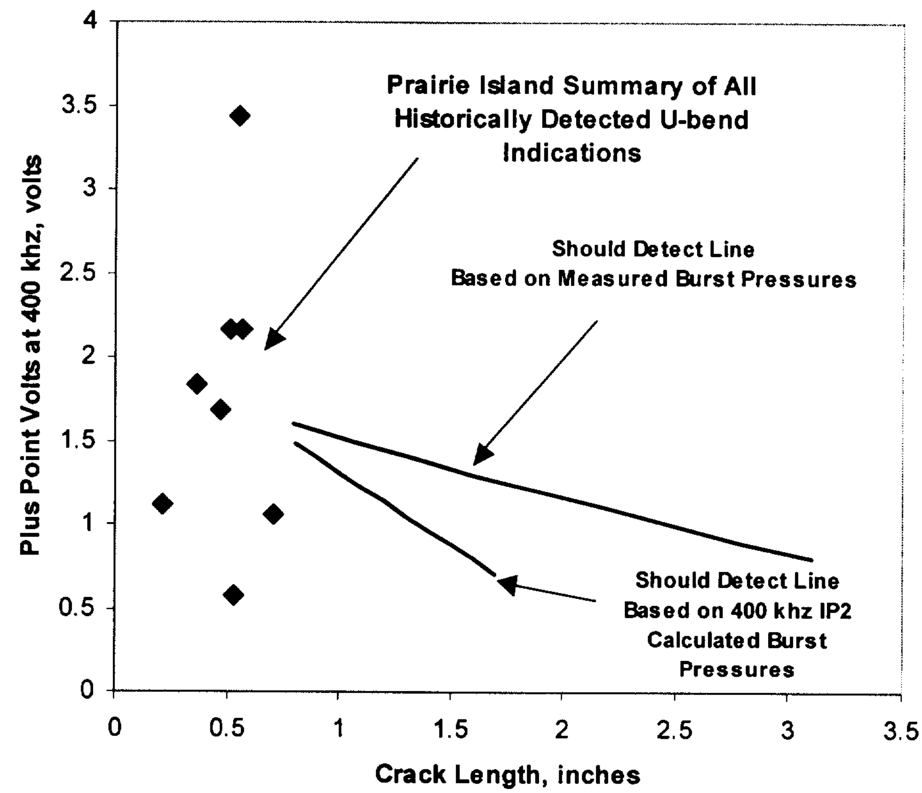


Figure 5
"Should Detect" Lines of +Point™ Volts Versus +Point™ Length for Low Row U-bends

Figure 6 illustrates the distribution of axial and circumferential U-bend cracks previously found at Prairie Island Units 1 and 2. This cumulative distribution plot uses the Benard equation to include the effects of a small data base. For axial cracks the upper 95th percentile crack length is about 0.6 inches. At this length a 1.66 volt indication should be detected to ensure structural integrity over the next cycle. This voltage decreases to 1.48 volts at a length of 0.8 inches. Note from Figure 1 that after about 1 inch the length of the crack has only a small effect on the burst pressure. Since the Prairie

Island Unit 1 worst case noise in a U-bend at 300 kHz is 1.09 volts (peak to peak), detection of axial U-bend PWSCC indications is more than adequate. Beginning in 1997, the U-bend indications in Table 1 were in situ pressure tested. None leaked at main steam line break pressure and none burst at 3ΔP. In the entire history of Prairie Island, no primary to secondary leakage has occurred in the Prairie Island rows 1 and 2 U-bends.

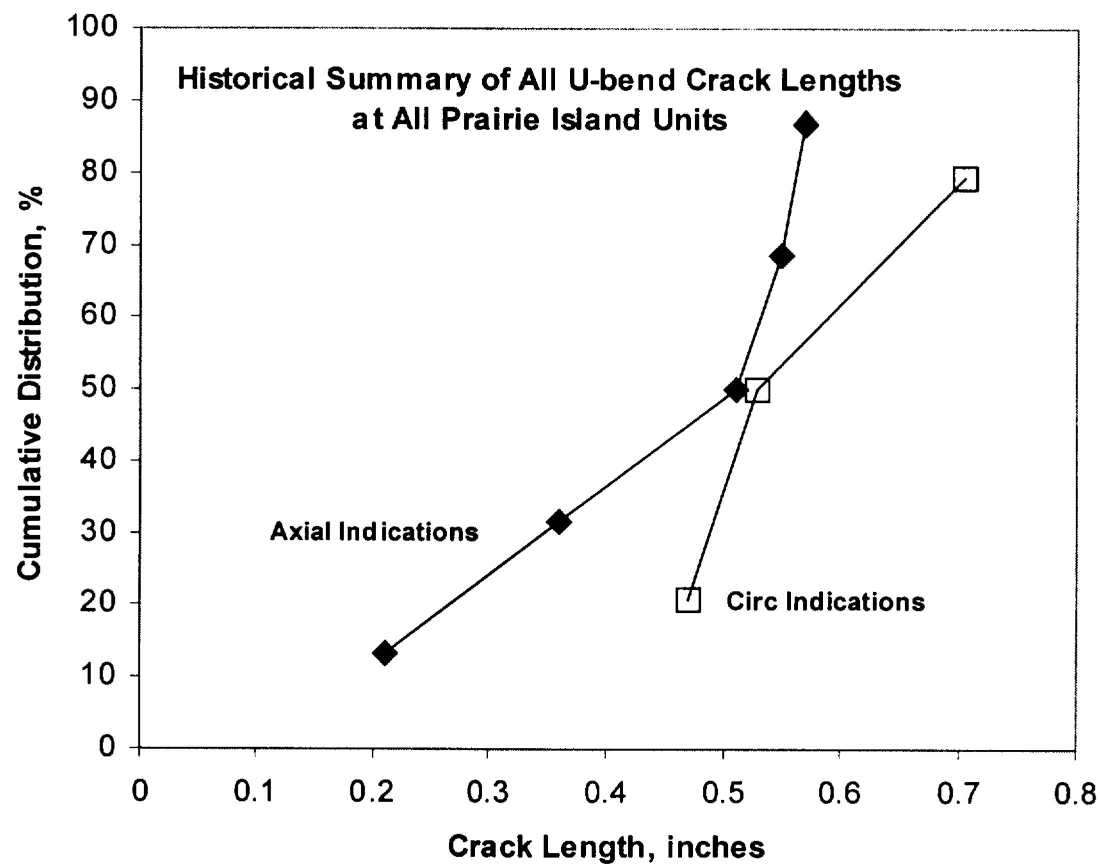


Figure 6
Historical Distribution Low Row U-bend Axial Crack Lengths at Prairie Island Units 1 and 2, Circumferential Cracks Also Shown

The above analysis is conservative for several reasons. Lower bound burst and strength relationships were used. Random sizing errors in NDE crack profiles offset each other in the regression fit and systematic errors in the NDE crack profiles are more than offset by allowances for scattering about the regression fit. Additionally, for a given crack size, the 300 kHz +Point™ indication voltages at Prairie Island will be larger

that of the 400 kHz +Point™ indication data from Indian Point 2 because the eddy current probe at Indian Point 2 was excited above the optimum frequency in contrast to the optimum response at 300 kHz at Prairie Island.

4th Approach: Develop a between measured burst pressure and measured +Point™ voltages from ID axial cracks generated in doped steam

A demonstration of the conservatism of the above analysis is provided by the fourth approach to evaluating the effect of axial degradation on the integrity of low row U-bends. Burst test data (43 tests) is available for simulated axial PWSCC at dented eggcrate lattice tube supports.[6] Laboratory testing in doped steam created ID axial cracks near prototypic loading conditions. The eddy current signal response of these cracked specimens were a very good match to signals observed in service degraded tubes with the same degradation dimensions and were used for probability of detection studies. Thus measured burst pressures were available as a function of +Point™ voltage and +Point™ length. Burst pressure measurements were converted from tubing 0.750 inch diameter by 0.048 inch wall thickness to the 0.875 inch diameter by 0.050 inch wall thickness tubing of interest here by scaling according to the ratios of mean radius to wall thickness. To a good approximation the +Point™ voltages will translate directly between the two tubing sizes.

After normalization of the measured burst pressures to a flow strength of 79,050 psi, burst pressure, in psi, was correlated with +Point™ voltage, *V*, and +Point™ length, *L*. The regression equation for burst pressure (*BP*) is:

$$BP = 12754 - 3171 \bullet V + 330 \bullet V^2 - 5.06 \bullet V^3 - 833 \bullet L$$

The agreement between measured normalized burst pressure and the fitted equation is very good as shown in Figure 7. The standard error of estimate of normalized measured burst pressure about the regression line is 1207 psi. As before, the scatter about the regression line plus the distribution of strength decreases caused by crack growth over the next cycle of operation were combined to calculate the burst strength incremental allowance for scatter and crack growth. This is the allowance needed at the beginning of a cycle to ensure a minimum degraded tube burst EOC strength of 3ΔP at 0.95 probability with 95% confidence. The total scatter and growth burst pressure allowance is now 3207 psi. Thus a measured burst pressure of (4635 + 3207), or 7842 psi entered into the above regression equation defines the +Point™ indication voltage, as a function of length, that needs to be detected during an inspection against the Prairie Island Unit 1 U-bend noise background. Given a

[6] Based on Proprietary Utility Test Results, permission received to use correlation results.

polynomial in *V*, the "should detect" line of volts versus length is found by entering *V* and solving for *L*. This line, based on measured burst pressures lies above the conservative "should detect" from the Indian Point 2 profile calculated burst pressures. Given the nature of this exercise, the two "should detect" lines are in excellent agreement. The conclusion is as before, in the noisiest low row U-bend at Prairie Island Unit 1, the signal to noise ratio of the "should detect" axial indication will be above 1.5 to 1 and there is no issue of the detectability of a limiting U-bend indication.

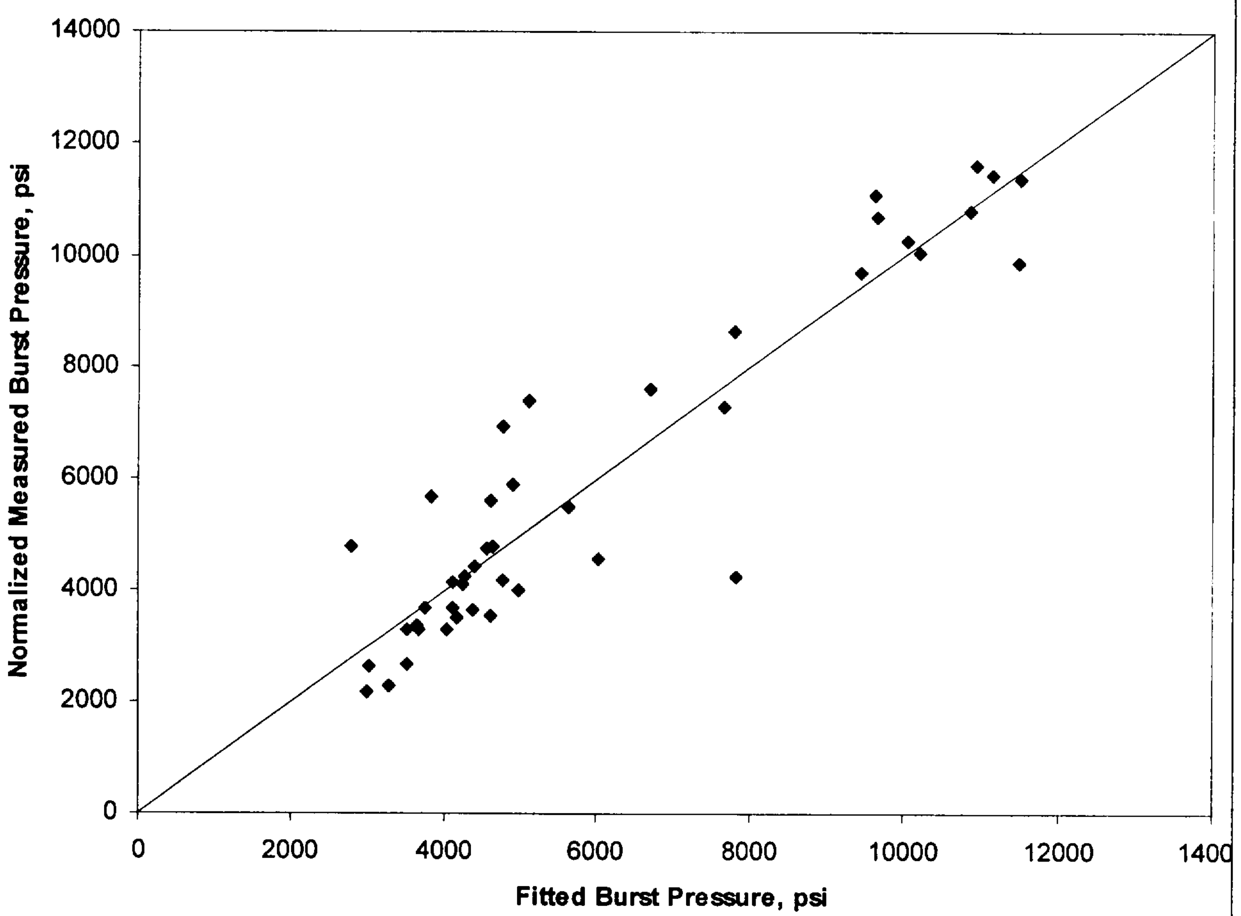


Figure 7
Normalized Measured Burst Pressures for ID Axial Cracks Versus Fitted Correlation with +Point™ Volts and +Point™ Length

Eddy Current Inspections – Introduction

The Technical Specification and NEI 95-6 inspection requirements are met for the Prairie Island Unit 1 steam generators. All tubes were inspected full length (except sleeved portion of tubes and row 1 and 2 U-bends) with the bobbin coil probe.

Special interest and critical areas such as tubesheet region or distorted support plate indications were examined with rotating coil technology probes.

Eddy Current Inspections - NRC Question on Setup

Provide a summary of the eddy current setup used by PINGP, Unit 1, for production analysis and for noise studies, highlighting the differences between the two setups. Describe the reasons for using these different setups. Discuss the potential advantages and disadvantages inherent in the different setups and how data and noise levels collected using the two set-ups can be compared.

Eddy Current Inspections - Prairie Island Response on Setup

Prairie Island production analysis is conducted with the phase rotation set at 15 degrees on the 40% ID EDM notch. The noise measurements are conducted with the phase rotation set at 35 degrees on the 100% EDM notch. The production setup is designed for the maximum sensitivity for detection of PWSCC at the incipient stage while minimizing the lift off noise variable.

The noise measurement setup is designed to eliminate variables between plants due to differences in manufacturers holding tolerances of the 40% ID EDM notch. Westinghouse noise studies have estimated a 5% error ban can be introduced when setting for noise measurements using the 40% ID EDM notch. For Prairie Island the difference between the two setup techniques is approximately 1 degree phase shift on the 100% EDM notch which is within the error ban of the software when measuring successive hits on the notch. If noise measurements were taken with the production setup the results would be non-conservative and result in lower observed noise levels that could not be directly compared with the results of other plants.

Current Prairie Island noise results were compared directly to the EPRI qualification data set average noise results to determine acceptability of the data on tube by tube basis using identical setup procedures for both the mid-range and high frequency probes. Prior noise studies performed and reported to the Industry and NRC Staff were conducted using the 40% ID EDM notch on all data sets and were intended to show that noise levels at one plant could be quite different than a similar design and vintage plant. Span (sensitivity) differences between the Prairie Island specific setup (2 divisions on the 40% OD EDM notch) and the EPRI ETSS's (96511 and 99997)

recommended setup (2 divisions on the 40% ID EDM notch) have no effect on noise studies and should only be considered as an enhancement to the POD at the Prairie Island site.

Noise characteristics were evaluated in the Prairie Island Unit 1 steam generator at 300 and 400 kHz with the mid range probe for all tubes and at 600 and 800 kHz for tubes inspected with the high frequency probe. A summary of noise data acquired previous to and during this inspection is summarized in Table 2. The Prairie Island values are the average of the noise levels at the apex of each tube. Individual tube noise measurements levels were measured over one probe rotation at the apex location (centered between 07C and 07H) and the noisiest tangent location.

U-Bend Average Noise Voltages

Mid Range Probe			High Freq Probe		
Plant	**300 VApp**	**300 VAvm**	**Plant**	**600 V_{App}**	**600 V_{Avm}**
ETSS 96511	1.09	0.4	ETSS 99997.1	1.27	0.37
PINGP 11 - Row 1	1.08	0.30	PINGP 11 - Row 1	0.67	0.24
PINGP 12 - Row 1	0.75	0.21	PINGP 12 - Row 1	0.49	0.19
PINGP 11 - Row 2	0.75	0.24	PINGP 11 - Row 2	0.49	0.19
PINGP 12 - Row 2	0.62	0.17	PINGP 12 - Row 2	0.38	0.12
* IP 2 - R2	1.40	0.67			
			Plant	**800 V_{App}**	**800 V_{Avm}**
Plant	**400 VApp**	**400 VAvm**	ETSS 99997.1	1.56	0.54
ETSS 96511	1.22	0.41	PINGP 11 - Row 1	0.84	0.22
PINGP 11 - Row 1	1.26	0.27	PINGP 12 - Row 1	0.48	0.19
PINGP 12 - Row 1	0.85	0.21	PINGP 11 - Row 2	0.52	0.15
PINGP 11 - Row 2	0.86	0.21	PINGP 12 - Row 2	0.52	0.11
PINGP 12 - Row 2	0.71	0.16	* IP 2 - R2	0.97	0.37

300 Vapp = 300 kHz peak to peak voltage at apex
300 Vavm = 300 kHz vertical maximum voltage at apex

Table 2
Average Voltage of Noise at U-bend Apex at Prairie Island, Indian Point 2 and the EPRI Appendix H Qualification Data Sets

Note that the Prairie Island average noise levels are less than the EPRI qualification data set averages, except for PINGP 11 – Row 1 which did require significant retests with the high frequency probe.

Eddy Current Inspections - NRC Question on Retests and Acceptance Criteria

Discuss the criteria for reinspection and rejection of tubes, the basis for this criteria, and the outcome of all reinspections (e.g., changes in measured parameters).

Eddy Current Inspections - Prairie Island Response on Retests and Acceptance Criteria

The site specific analysis procedure describes the use of the mid-range and high frequency probes as follows:

> *Upon completion of resolution on all low row U-bend examinations (both mid range and high frequency) the resolution analyst(s) shall calibrate and perform and record noise measurements in accordance with Reference 2.9 at 300 kHz and 400 kHz for the mid range probe and 600 kHz and 800 kHz for the high frequency probe. On any measurement that exceeds the average of the EPRI qualification on the initial examination the resolution analyst will report the run as BDA (This code requires retest due to bad data) with a Quality code of QEN(Quality Code – Excessive Noise). On any measurement that exceeds the average of the EPRI qualification on the follow-up examination of the mid range probe the resolution analyst will report the run as RHF (This code requires retest with a high frequency probe) with a Quality code of QEN. On any measurement that exceeds the average of the EPRI qualification on the follow-up examination of the high frequency probe the resolution analyst will report the run as TBP (This code, "To Be Plugged" is used for tubes in which data quality would possible hide a significant defect) with a Quality code of QEN.*

This is based on site-specific studies of noise performed on a variety of plants (Prairie Island 1 and 2, Point Beach 2, Kewaunee and Indian Point 2) and the EPRI qualification data sets prior to and during the conduct of the recent Prairie Island 1 eddy current inspection. Lacking industry or regulatory specific noise guidance, the site developed and implemented the above acceptance criteria. The predicted outcome was realized for the mid-range probe when only a few tubes in steam generator 11 (row 2) and steam generator 12 (rows 1 and 2) required additional testing with high frequency probe and nearly 50% of the tubes in steam generator 11 (row 1) required additional testing with the high frequency probe. Further, predictions that high frequency testing of noisy tubes (discovered during mid-range probe testing) would result in a reduction of the observed noise to levels below the acceptable level for the high frequency probe. The general trend was that tubes exhibiting excessive noise on the mid-range probe do not exhibit excessive noise on the high frequency probe. No tubes were rejected (required plugging) as a result of the subsequent high frequency probe testing of noisy tubes discovered during the mid-range probe testing. The measured noise levels in 11 SG row 1 U-bends are shown in Figure 8 for the mid-range probe at 300 kHz and in Figure 9 for the high frequency prove at 600 kHz. Data shows a significant reduction in noise levels with the high frequency probe.

Eddy Current Inspections - NRC Question on EPRI Qualification Data Set

It is the NRC staff's understanding that the criteria for reinspection or rejection of tubes is based on the Electric Power Research Institute's data set used for probe qualification for U-bend inspection. Provide information on the composition of the data set; that is, a description of the types of tubes, flaws, notches, artifacts, etc. Discuss how the data set is representative of the conditions at PINGP.

Eddy Current Inspections - Prairie Island Response on EPRI Qualification Data Set

The EPRI qualification data set contains one diagonal ID EDM notch 41% through wall, one circumferential ID EDM notch 27% through wall, 22 axial ID EDM notches ranging from 32% to 100% through wall and 2 tube pulls from the Trojan plant with ID axial cracks (PWSCC) 40% through wall. Two of the tubes have been heat treated. Three of the tubes contain bend tangent signals on the intradose, through the entire U-bend radius, at intervals similar to those identified in Prairie Island tube R1C52 in steam generator 12. Flaw signal characteristics and noise levels between the qualification data set and Prairie Island were found to be similar during the Prairie Island site validation performed in accordance with Revision 5 of the PWR Steam Generator Examination Guidelines in April 1999.

Typical noise levels in the EPRI Qualification Data sets for mid range and high frequency noise are shown in Table 3.

EPRI ETSS # 96511 Mid Frequency Noise Data, 300 kHz

Sample	***Apex V p-p***	***Apex V v-m***	***Tangent V p-p***	***Tangent V v-m***
Z5324	0.57	0.22	DATA NOT AVAILABLE	
TVA-1	0.75	0.33		
TVA-13	0.81	0.30		
TVA-23	0.68	0.24		
1019-I	1.26	0.37		
1019-3	1.51	0.73		
1019-4	1.59	0.73		
1019-1	1.21	0.46		
Z5300	1.05	0.50		
TSL-126	1.30	0.27		
TSL-15	1.33	0.28		
TSL-2	1.08	0.27		
TSL-10	0.58	0.19		
TSL-113	1.05	0.24		
TSL-115	1.20	0.24		
AVG	1.06	0.36	1.49	0.65
SD	0.32	0.17	0.63	0.28
95%	1.60	0.64	2.54	1.11
MIN	0.57	0.19	NA	NA
MAX	1.59	0.73	NA	NA

EPRI ETSS # 99997.1 High Frequency Noise Data, 600 kHz

Sample	***Apex V p-p***	***Apex V v-m***	***Tangent V p-p***	***Tangent V v-m***
Z5324	0.77	0.28	1.64	0.42
TVA-1	1.19	0.42	1.74	0.37
TVA-13	1.18	0.26	1.92	0.40
TVA-23	0.99	0.26	1.86	0.40
1019-I	1.48	0.48	2.93	1.22
1019-3	1.65	0.76	3.14	1.13
1019-4	1.57	0.93	1.97	0.68
1019-1	1.29	0.35	2.60	0.98
Z5300	1.18	0.33	2.07	0.45
TSL-126	1.44	0.20	1.64	0.34
TSL-15	1.38	0.30	1.95	0.39
TSL-2	1.33	0.29	1.19	0.49
TSL-10	0.83	0.26	1.67	0.56
TSL-113	1.38	0.19	2.16	0.79
TSL-115	1.37	0.20	2.11	0.69
AVG	1.27	0.37	2.04	0.62
SD	0.25	0.21	0.51	0.29
95%	1.68	0.72	2.88	1.10
MIN	0.77	0.19	1.19	0.34
MAX	1.65	0.93	3.14	1.22

Table 3
Typical Noise Levels for EPRI Qualification Data Sets

In the section on Structural Integrity Analysis, it was determined that the structurally significant inside diameter stress corrosion crack that should be detected is a 1.48 Volt indication that is 0.8 inches long.

As seen in Table 1, the smallest flaws that have been detected in the Prairie Island U-bends are a SAI at 1.12 Volts and 0.21 inches long and a SCI at 0.58 Volts and 0.7 inches long (74 degrees). When the range of noise in the apex in row 1 tubes in 11 SG is plotted, it is clear that some tubes are noisier than the EPRI average values (Noise values were checked at two frequencies at both peak to peak and vertical maximum values.) Those tubes exceeding the noise criteria were then evaluated with the high frequency probe. If noise criteria were still exceeded, the tube would have been plugged.

The noise criteria for the apex region are shown in Table 4. The noise in the region of the apex was evaluated against these criteria. Note that these criteria are less than the structurally significant flaw.

Prairie Island Unit 1 Noise Screening Criteria for Low Row U-bends

Mid Range Probe

EPRI ETSS	**300 VApp**	**300 VAvm**	**400 VApp**	**400 VAvm**
ETSS 96511	1.09	0.4	1.22	0.41

High Freq Probe

EPRI ETSS	**600 VApp**	**600 VAvm**	**800 V_{App}**	**800 V_{Avm}**
ETSS 99997.1	1.27	0.37	1.56	0.54

Table 4
Prairie Island Noise Screening Criteria for Low Row U-bends

11 SG contained the noisiest rows 1 and 2 U-bends. Figure 8 illustrates the noise levels in 11 SG row 1 U-bends. Those tubes exceeding the above noise criteria were retested with the high frequency probe. Figure 9 shows a decrease in the peak to peak noise levels. Also, Figures 8 and 9 include a plot of the phase angle calculated from the peak to peak volts and the vertical maximum volts for each tube.

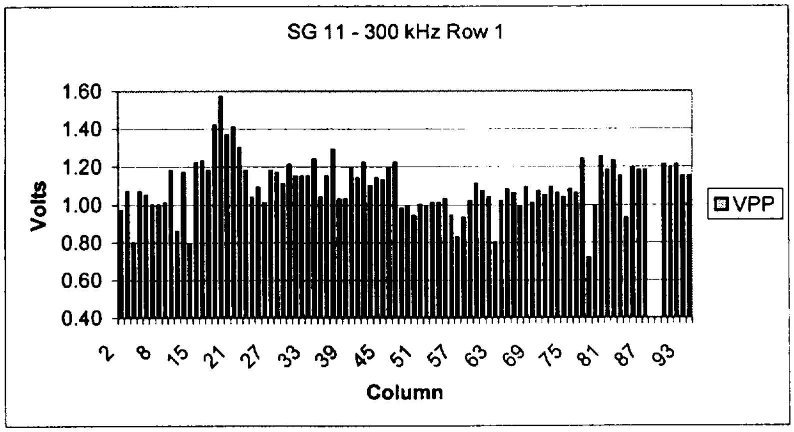
Eddy Current Inspections - NRC Question on Minimum Reliable Detection

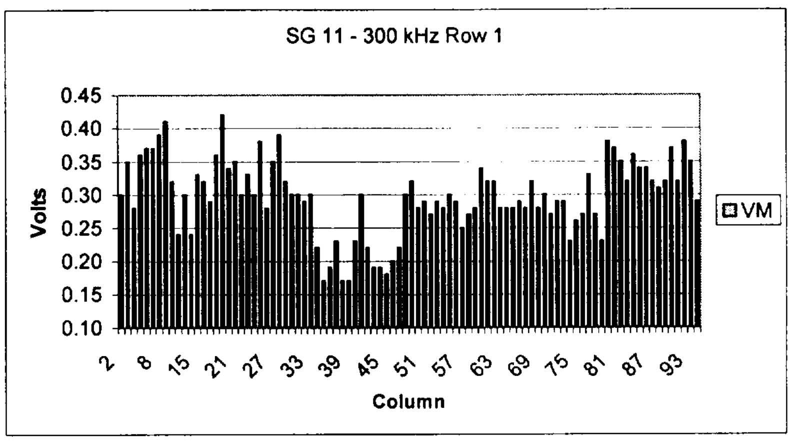
Discuss and provide the basis for your minimum reliable detection capabilities in terms of tube-by-tube factors such as signal-to-noise ratios and noise parameters, including volts peak-to-peak and vertical maximum. Include this information for tubes inspected with the midrange as well as for tubes inspected with both the midrange and high frequency probes.

Eddy Current Inspections - Prairie Island Response on Minimum Reliable Detection

Using the noise acceptance criteria from Table 4, a box can be postulated that limits maximum noise levels allowed. For the 300 kHz frequency, the noise box is a rectangle with a vertical height of 0.4 volts and a horizontal value of 1.09 volts.

To ascertain the minimum reliable detection, it can be seen from Table 1 that indications with voltage amplitudes as low as 0.58 volts can be detected. It is also noted from Table 1 that the Prairie Island U-bend indications have a phase angle greater than 20 degrees. Note from Figure 8, that the phase angle of nearly all the noise measurement data points is less than 20 degrees. This means a flaw will rise out of the noise as an analyst scrolls through the data making the indication detectable. Note also from Figures 8 and 9 that the peak to peak noise levels are reduced to less than 0.8 volts using the high frequency probe.





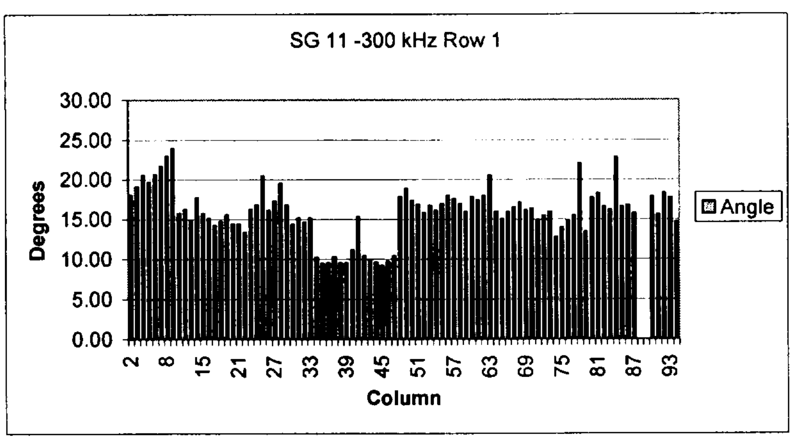
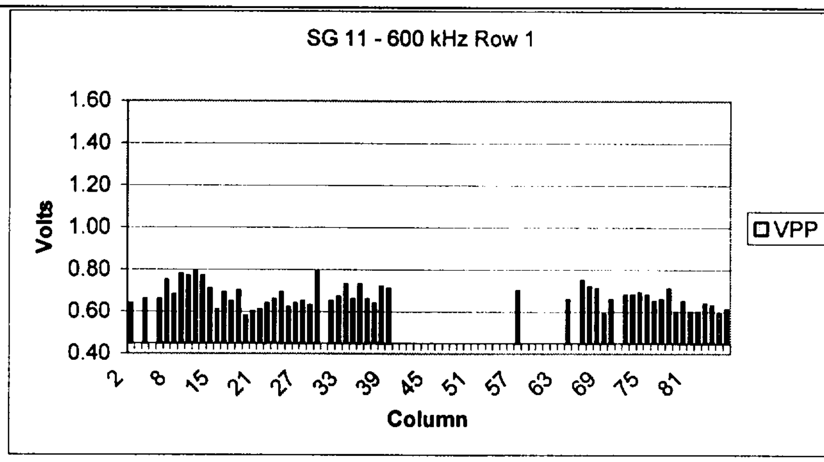
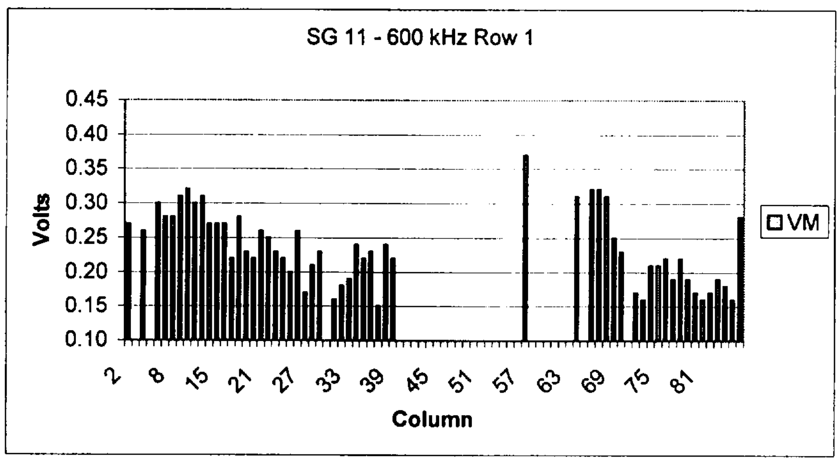


Figure 8
SG 11 Noise Levels – Mid Range Frequency





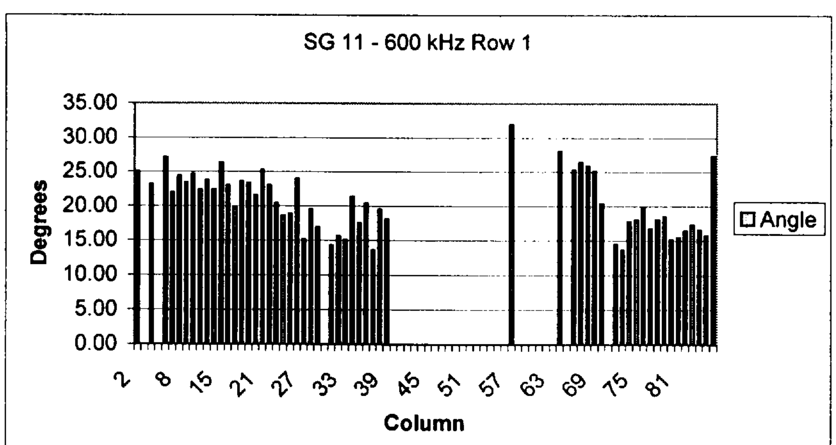


Figure 9
SG 11 Noise Levels – High Frequency

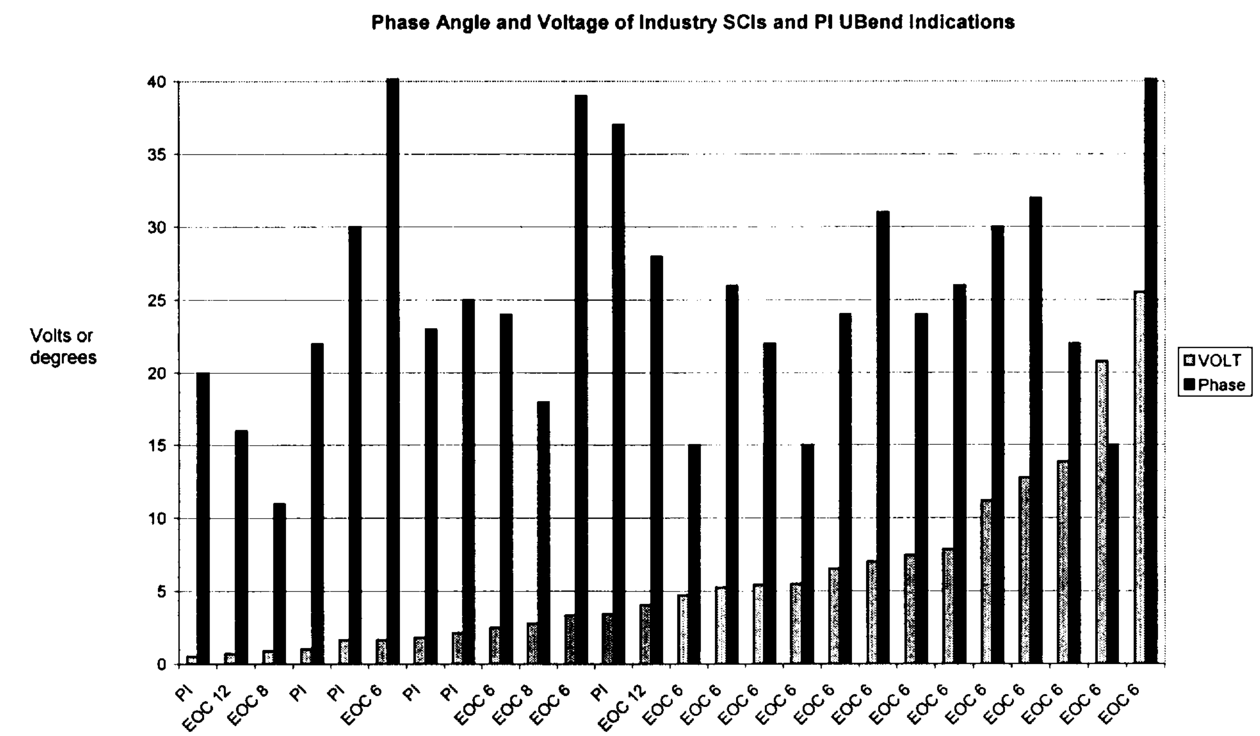


Figure 10
Phase Angle and Voltage of Industry SCIs and PI U-bend Indications

Figure 10 shows that phase angles of U-bend indications in the case of Prairie Island data are greater than 20 degrees and that the phase angles of the noise in Prairie Island u-bends is less than 20 degrees. Also note that Prairie Island is detecting low voltage signals compared to similar indications in the industry. Further note that the peak to peak noise values with the 600 kHz frequency is less than 0.85 volts whereas the voltage of an ID indication is expected to rise with the high frequency coil.

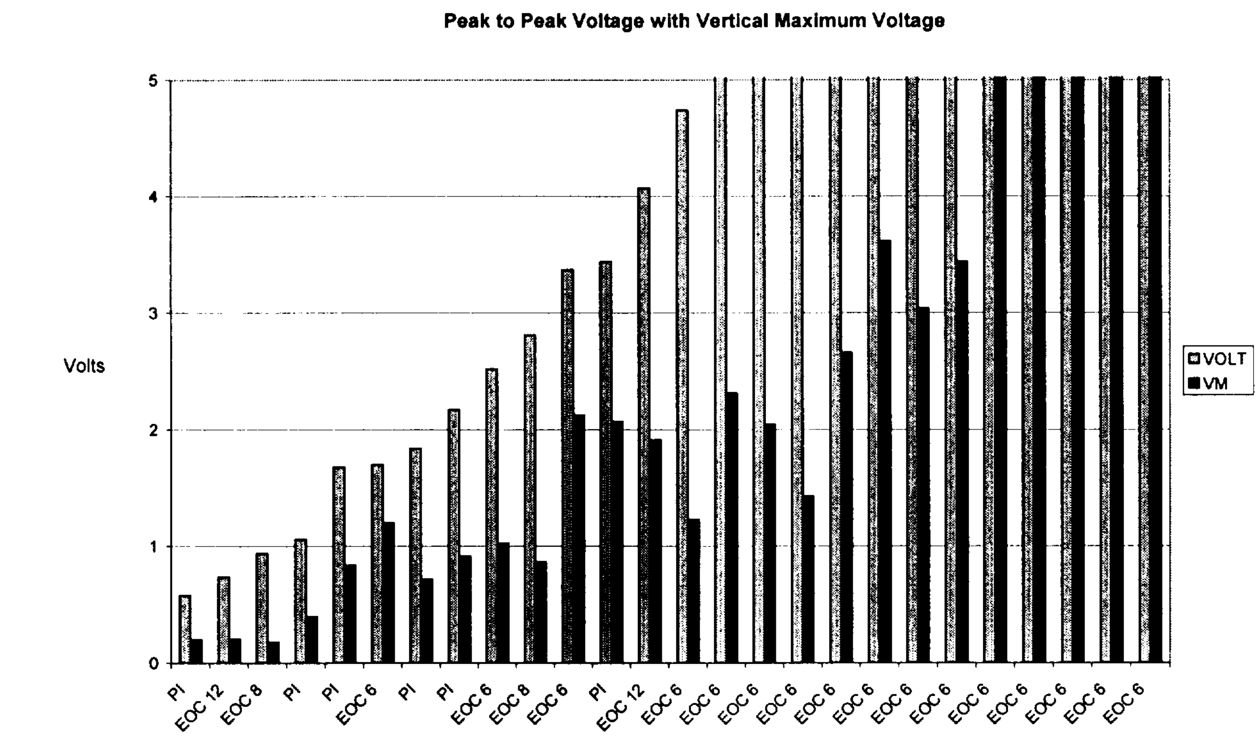


Figure 11
Peak to Peak Voltage with Vertical Maximum Voltage

Note in Figure 11 that the Prairie Island indications which have low amplitude vertical maximum voltages correspond to low peak to peak voltage indications much below the minimum structurally significant voltage of 1.48 volts.

It is readily apparent from the above data that a structurally significant flaw in the U-bend region of the Prairie Island steam generators can be easily detected because of the overall low noise values and because the phase angle of the noise values is also low.

Eddy Current Inspections - NRC Question on Most Adverse Flaw

Your analysis indicates that reliable detection of flaws with a peak-to-peak response exceeding 1.6 volts is sufficient to ensure that flaws of potential structural integrity significance are detected. Discuss, by example, the detectability of such a flaw in tubes with the most adverse noise conditions existing in the PINGP U-bend apex location. The example should consider a range of flaw vertical maximum voltage values ranging from 25 percent to 50 percent of the peak-to-peak voltage value (1.6 volts). The example should discuss the specific parameters and behaviors of the flaw and noise signals influencing the detectability of the flaw signal.

Eddy Current Inspections - Prairie Island Response on Most Adverse Flaw

The most adverse noise conditions result in the use of the high frequency probe and/or plugging of the tube. The phase angle of the Prairie Island noise in the U-bends is low, nearly horizontal and is due mainly to the probe motion. With a low phase angle (i.e. low maximum vertical voltage) real flaws will "come out of the noise" due to voltage and due to phase angle and be readily apparent to the eddy current analyst.

Eddy Current Inspections - NRC Question on Mag Bias Probes

Discuss if magnetically biased eddy current probes have been considered to address the noise levels in the U-bends.

Eddy Current Inspections - Prairie Island Response on Mag Bias Probes

The steam generator inspection used the magnetically biased probe this outage. It was used very sparingly for U-bend examinations (14 tubes in steam generator 11 and 7 tubes in steam generator 12) and only on those tubes which exhibited short duration permeability variations in accordance with the following analysis procedure definition:

PERMEABILITY VARIATION (PVN) - Condition where the data is interpretable but is effected by test coil impedance change due to a change in the materials inherent willingness to conduct magnetic flux lines over a short axial or circumferential duration (<0.3") such that critical flaw is still detectable (otherwise use TBP).

This more conservative inspection policy was put into practice for this inspection. Some concerns have been raised concerning the reduction in signal amplitude of magnetically biased probes compared to non-magnetically biased probes on ID EDM notch samples.

Dents, Flow Slot Hourglassing, and Secondary Side Inspections – NRC Question

Provide a summary of the location and magnitude of tube dents that are in the PINGP, Unit1, steam generators. Discuss how the number and size of these dents has changed over time.

Discuss the PINGP experience with dents or U-bend restrictions of eddy current probes. Provide in this context your definition of a dent.

Provide the methods, results, acceptance criteria, and conclusions relative to detection of flow slot hour-glassing.

Dents, Flow Slot Hourglassing, and Secondary Side Inspections – Prairie Island Response

Progression of Dents in 11 and 12 steam generators (as measured by the number of dent locations and the average voltage of all the dents each refueling inspection) is displayed in Figures 12 and 13. Dented condition is recorded when channel P1 is greater than or equal to 5.0 volts.

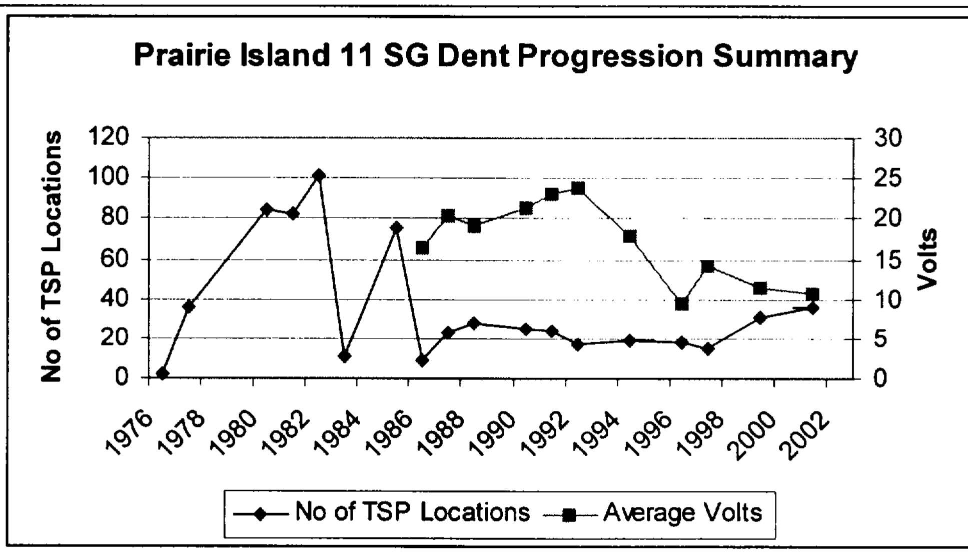


Figure 12
Prairie Island 11 SG Dent Progression Summary

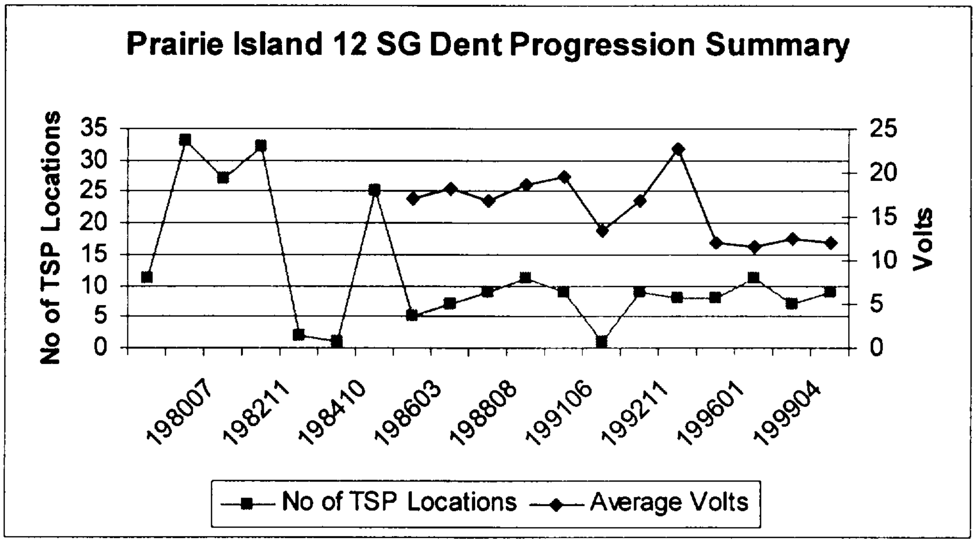
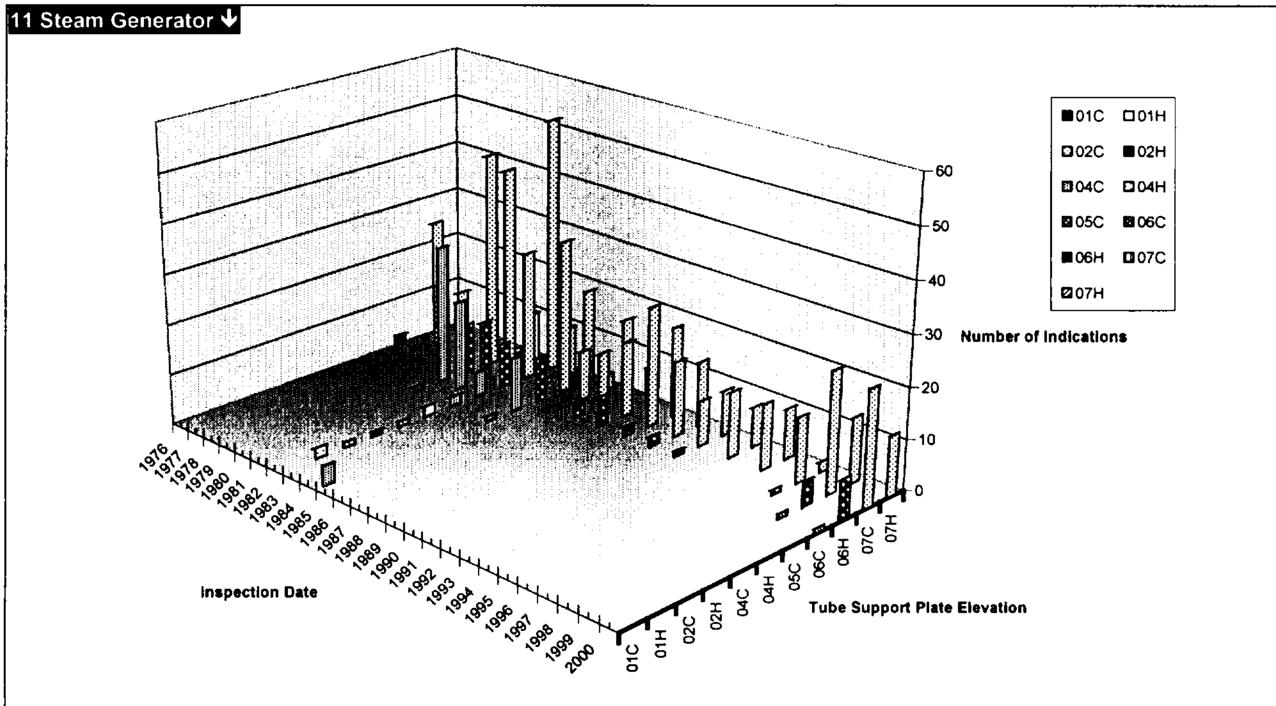


Figure 13
Prairie Island 12 SG Dent Progression Summary

Figure 14 shows the trend of the number of dents at each tube support plate elevation, separately for cold leg and hot leg. No dents have been found lower than the 6th tube support plate since 1986. In the 2001 inspection, one of the dents is in row 6, the other nine are in the outer periphery beyond row 40 .



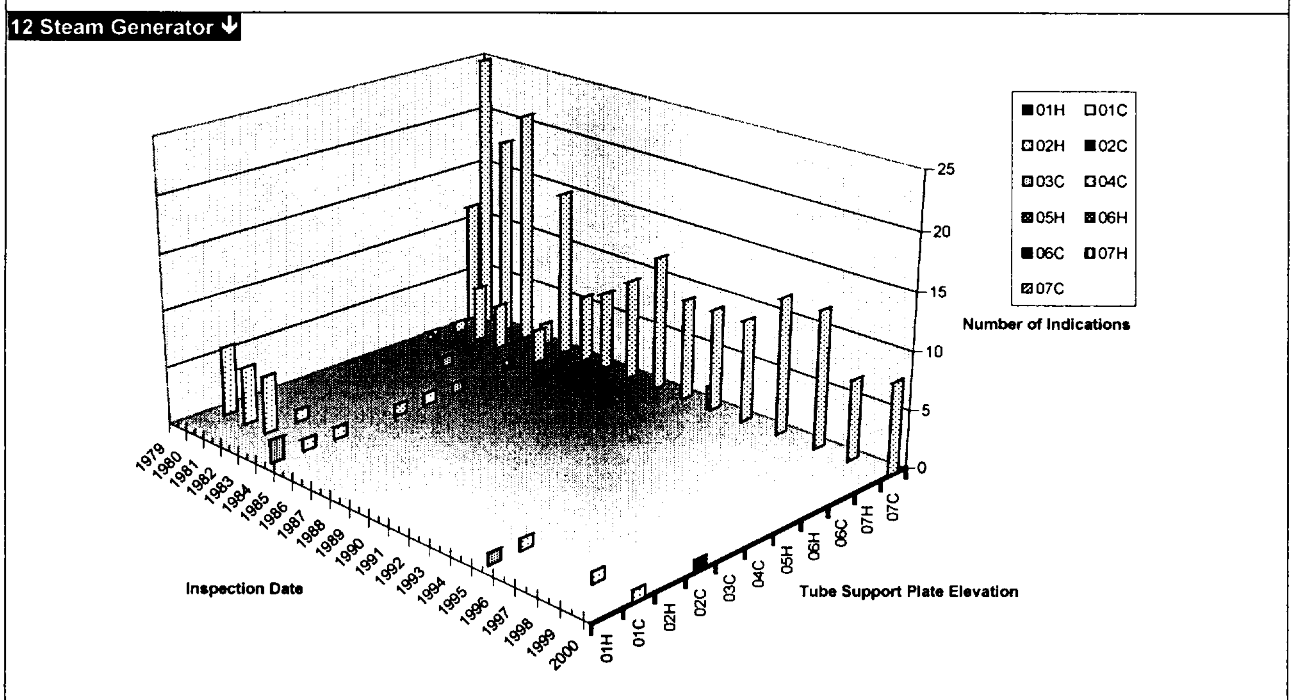


Figure 14
Prairie Island Dents per Inspection Year, Grouped by TSP Location

There is no noticeable hour glassing in any of the tube support plate flow slots in either steam generator by remote visual examination. Inspections are done with an upper bundle inspection camera via the tube lance region as seen from below. This method of evaluating for hourglass is not capable of precision down to 0.1 inch as proposed in the Indian Point 2 NRC Lessons Learned Document.

Root Cause Analysis

Root Cause Analysis – NRC Question on Hindsight Review

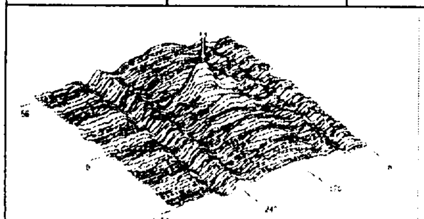
Discuss the results of your hindsight reviews of eddy current data performed on row 1 and row 2 tubes.

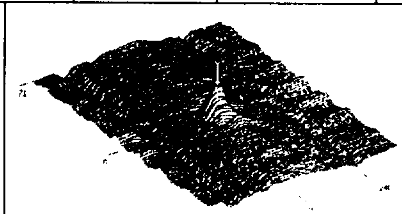
Root Cause Analysis – Prairie Island Response on Hindsight Review

Historical eddy current data on the U-bend indication in R1C52 were reviewed. The first rotating pancake coil examination of U-bends was done in Unit 1 in 1991. The circumferential ridges noted in the 2001 examination are visible in the 1991 c-scan. The large indication becomes visible on the strip chart in 1992. Within the accuracies of eddy current and the different calibration standards over the years, the indications are considered stable since 1994. Inspection with the +Point™ probe began in 1996. The circumferential ridges are visible in all inspections.

Table 4 shows voltages and phase angles from the look back at historical records. Note that the voltages and angles provide only a relative trend, not necessarily the same as the analysis of record.

	Inspection Date						
Location	**06/04/91**	**11/16/92**	**05/27/94**	**01/14/96**	**10/2/97**	**04/24/99**	**1/26/01**
07H +8.0	16.83v 183°	3.36v 21°	3.08v 14°	1.19v 20°	1.45v 14°	1.15v 25°	1.46v 22°
07H +7.5		2.57v 20°	1.10v 19°	0.75v 18°	0.84v 11°	0.67v 22°	0.79v 20°


1996


1999


2001

Table 4

Historical Eddy Current Review

This lookback demonstrates a very low growth rate, perhaps, negligible in the last 4 inspections.

Root Cause Analysis – NRC Question on Location Details

Provide a complete description of the location in the steam generators of the U-bend circumferential indications found in the February 2001 outage at PINGP.

Root Cause Analysis – Prairie Island Response on Location Details

Refer to Figure 16. The location of the circumferential indications (07H+~7.8 inches) is on the intradose of the U-bend about 0.7 inches from the apex on the cold leg side.

As seen Figure 15, it is not unusual to see circumferential indications scattered about in the U-bend region, some of which are on the intradose.

Measurement of residual stresses in U-bends at Penn State (EPRI NP-5282, Residual and Applied Stress Analysis of an Alloy 600 Row 1 U-bend) found that high tensile stresses did exist in the region of the bend tangent and extending above the bend tangent. Axial tensile stresses in the intradose region can initiate stress corrosion cracks, Measurements found that the OD of the intradose was in compression and that the ID of the intradose is in tension. Thus, it is possible that these indications in R1C52 do represent ID stress corrosion cracking at the deformed regions of the intradose and that the cracks would stop propagating when the region of compressive stresses is reached.

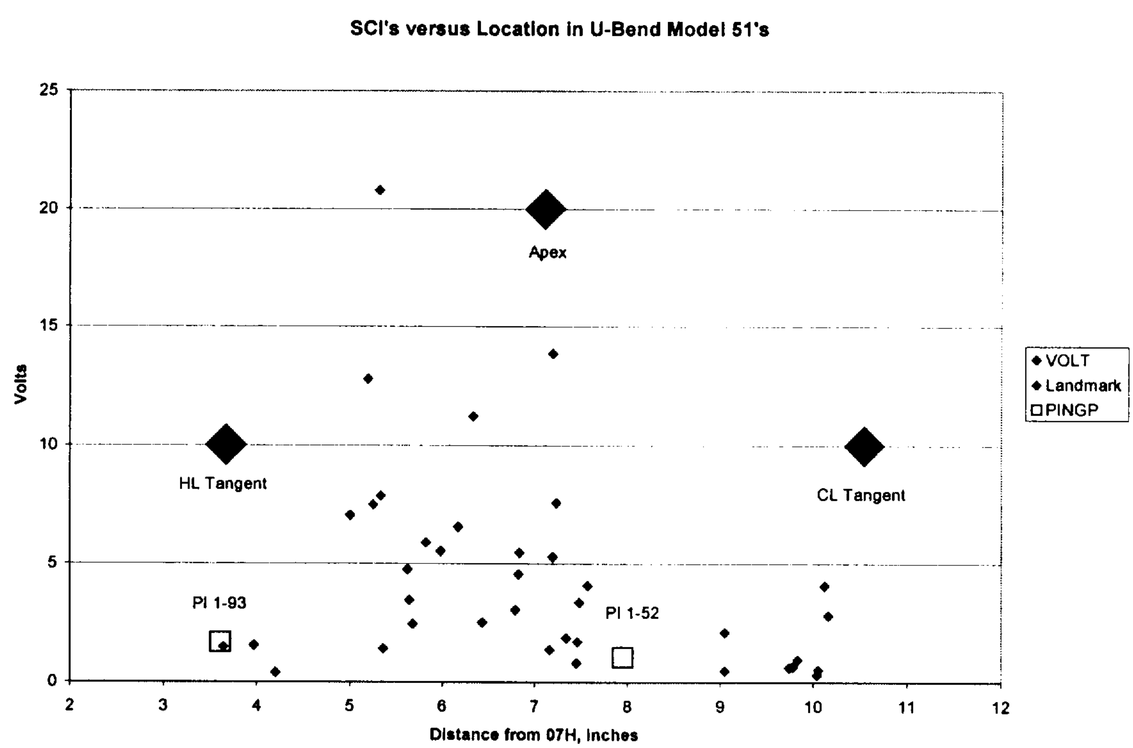
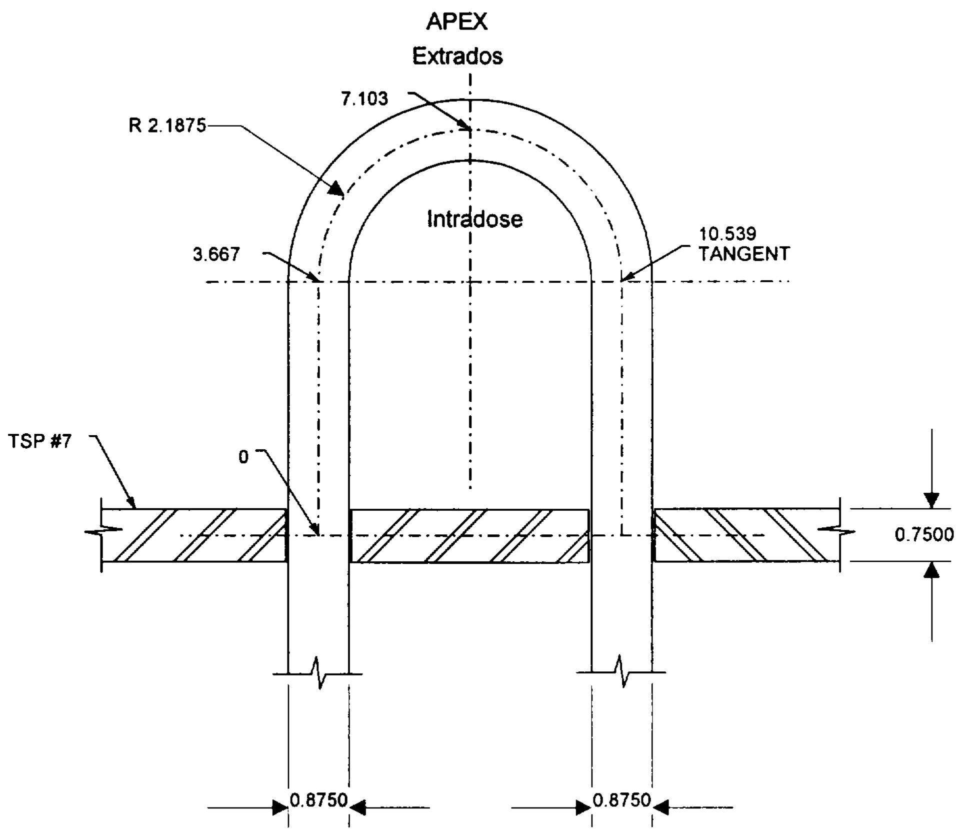


Figure 15
SCI's Versus Location in U-bend Model 51's



WESTINGHOUSE MODEL 51 STEAM GENERATOR			ROW 1 U BEND
PRAIRIE ISLAND NUCLEAR PLANT RED WING, MINNESOTA	DRAWN BY: KMK	SCALE 1/2" = 1'-0"	CR20011490
	CNTRL. NO.	DATE: 1-04-01	

Figure 16
Drawing CR20011490

Conclusion – NRC Question

Discuss how the data, analysis, and evaluations provided for the above questions can be used to support the acceptability of the steam generators at PINGP for the upcoming operating cycle.

Conclusion – Prairie Island Response

In the previous sections, data has been presented that:

1. Provides a basis for the ability to identify a structurally significant tube flaw.
2. Demonstrates low noise level in the Prairie Island U-bends.
3. Proves that the circumferential indication does not represent a new degradation mechanism.
4. Shows that the ridge existing in the intradose of the U-bend C-Scan of R1C52 also exist in an EPRI U-bend sample at the EPRI NDE Center.
5. Proposes a corrosion mechanism that (by plant experience) grows slowly and is limited by the complex stress states in the U-bend region.
6. Demonstrates Prairie Island has taken corrective action in response to the Indian Point 2 steam generator tube failure.

Indications which exceeded screening criteria were pressure tested in situ. There was no leakage at accident conditions. No tubes leaked or burst at 3 times normal operating pressure (in situ target pressure of 5256 psig). There was no identifiable primary to secondary side leakage of fission products during the previous operating cycle. All tubes with repairable indications were plugged or repaired. There is no issue with steam generator performance criteria in the Prairie Island Unit 1 steam generators. No tubes were identified during the condition monitoring process which exceeded structural and leakage performance criteria.

This conclusion is demonstrated by the following points:

- **Prairie Island has not discovered a new degradation mechanism with similarities to steam generator tube failure of recent notoriety.**

  The indications of interest identified in 12 steam generator R1C52 are two single circumferential indications located on the hot leg side of the U-bend region about one inch from the APEX. This is not a new type of indication or degradation. Figure 15 in the attachment shows that many circumferential indications at a variety of locations and voltages have been identified in recirculating steam generators since about 1991. The data is from and proprietary to EPRI.

- **Prairie Island understands the root cause of this degradation mechanism and/or eddy current indication as possible without removing the U-bend.**

Figure 17 shows Prairie Island R1C52 eddy current data. Figures 18 and 19 show the eddy current c-scan of an EPRI U-bend qualification data set with horizontal ridges similar to R1C52. Thus, the horizontal ridges are not unique nor is a circumferential indication on the intradose of row 1 U-bend in the region between the two tangents. It is postulated that high stresses from the tube bending process physically change the intradose and the primary water stress corrosion cracks grow until high residual stresses are relieved. The ridges are due to the bending process.

There is essentially no growth in R1C52 when evaluating previous RPC data back to 1991.

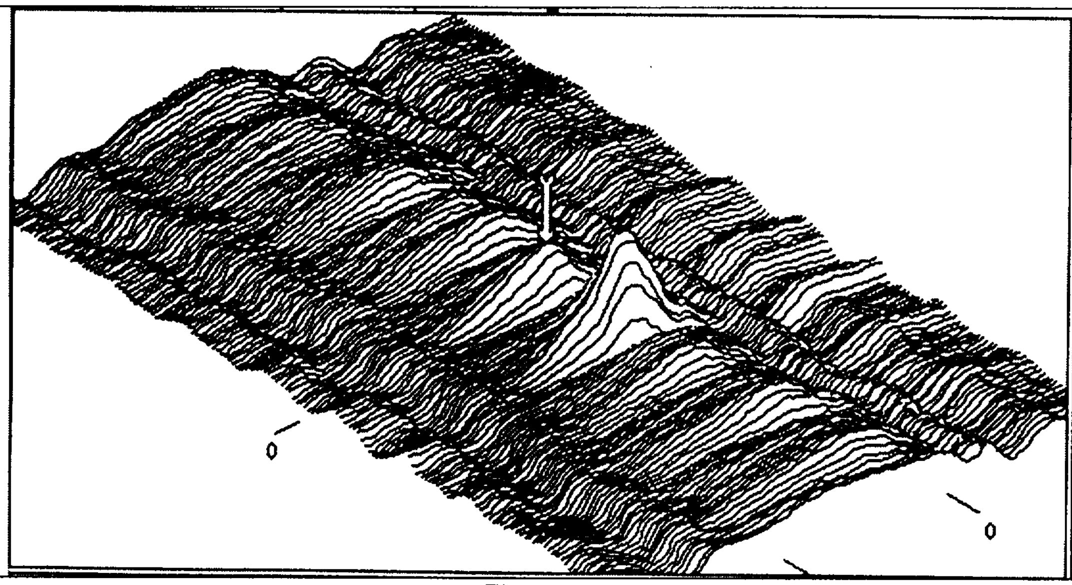


Figure 17
Eddy Current Data for Prairie Island R1C52

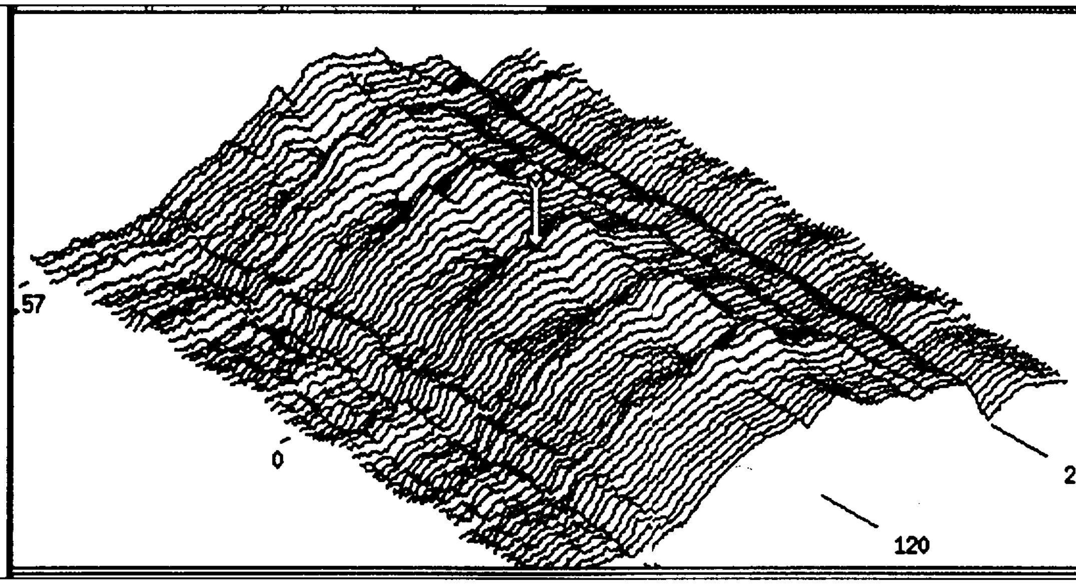


Figure 18
Eddy Current Data for EPRI U-bend Qualification Data Set: TVA-1

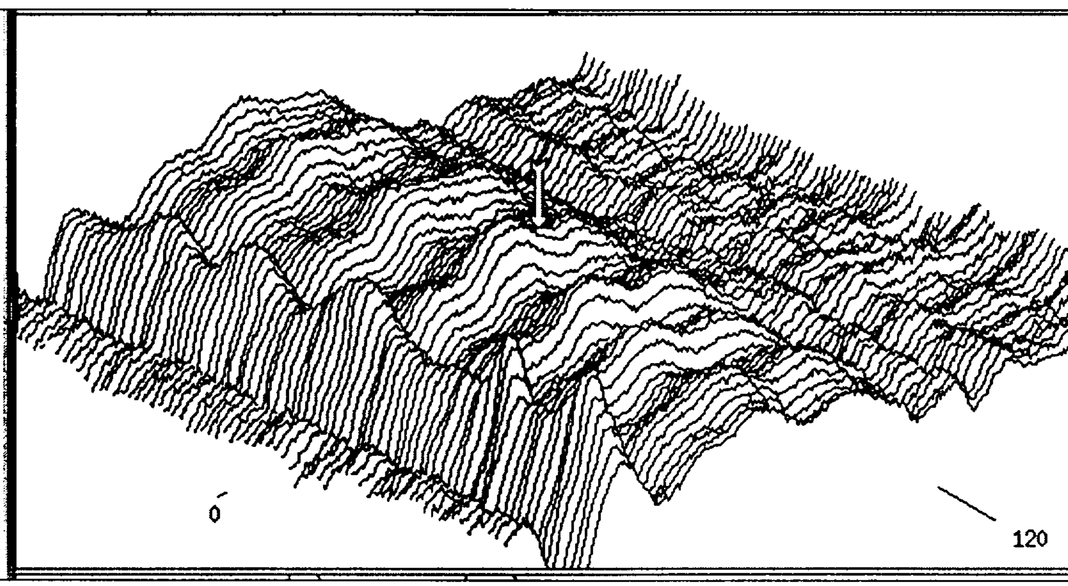


Figure 19
Eddy Current Data for EPRI U-bend Qualification Data Set: TSL-2

- **Prairie Island has taken corrective action in response to the Indian Point 2 steam generator tube failure of February 15, 2000.**

  The rows 1 and 2 U-bends which remain in service were heat treated in 2000 (Unit 2) and 2001 (Unit 1) to remove the residual stresses caused by the original bending process. Stress relief from this in situ heat treatment process has been demonstrated both in the laboratory and in the field to significantly reduce primary water stress corrosion cracking in the u-bend region.

  The eddy current analysis guidelines have imposed strict noise criteria in U-bends. A procedure has been developed to do further examination of U-bends with a high frequency probe in noisy tubes. Tubes have been plugged which exceed noise criteria.

  The latest EPRI primary to secondary leak guidelines have been implemented.

- **Prairie Island can detect indications representative of structurally significant flaws in the U-bends.**

  A structurally significant flaw in the U-bends at Prairie Island is about 1.5 volts peak to peak. Tubes which exceed 1.09 volts peak to peak noise are examined with a high frequency probe. If high frequency probe noise exceeds criteria, the tube is plugged.

- **The Prairie Island steam generators will maintain structural and leakage integrity until the next scheduled inspection.**

  In accordance with NEI 97-06, a preliminary operational assessment has been prepared for the Prairie Island Unit 1 steam generators. The draft operational assessment identified no short term or long term operability issues for the next cycle.