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NL# 00-085

July 7, 2000

Re: Indian Point Unit No. 2
Docket No. 50-247

Document Control Desk
US Nuclear Regulatory Commission
Mail Station P1-137
Washington, DC 20555-0001

Subject: Response to the Staff's Request for Additional Information (RAI) Regarding Steam Generator Operational Assessment Report (TAC No. MA9288)

Reference: 1) Con Edison Letter to NRC dated June 2, 2000
2) NRC Letter to Con Edison dated July 3, 2000
3) NRC Letter to Con Edison dated May 19, 2000

Pursuant to 10 CFR 50.54(f), Consolidated Edison Company of New York, Inc. (Con Edison) hereby provides a supplement to the U-bend PWSCC Condition Monitoring and Operational Assessment (CMOA), and the sludge pile ODSCC CMOA evaluations previously provided to the NRC via Reference 1. This supplement addresses three recently identified subjects: 1) the potential burst pressure effects stemming from the ANO-2 test program results, 2) the implications for the U-bend analysis of potentially undetected low voltage signals, and 3) the sensitivity of assumed POD (probability of detection) confidence levels to cycle length. The additional analyses contained within this supplement also specifically responds to Question 1 of the Staff's Request for Additional Information provided to us in Reference 2.

In Reference 3, the Staff provided a summary of its preliminary review of the Root Cause Evaluation for the steam generator tube failure, which occurred on February 15, 2000. A public meeting was held on May 3, 2000 to discuss the NRC's questions regarding the Root Cause Evaluation. Further, the Staff requested that Con Edison perform a review the transcript of the May 3, 2000 meeting and provide a written response to the topics of discussion and the questions raised during the meeting (as documented in the transcript).

Con Edison has completed its review of the May 3, 2000 meeting transcript, and believes that all pertinent questions have been satisfactorily addressed in subsequent correspondence to the Staff, and by the supplemental report provided by this letter. Specifically, Con Edison provided separate documentation relative to the Condition Monitoring and Operational Assessment reports, the steam generator tube examination program Requests for Additional Information, and the Root Cause Evaluation for the February 15, 2000 event.

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No new regulatory commitments are being made by Con Edison in this correspondence.

Should you or your staff have any concerns regarding this matter, please contact Mr. John McCann, Manager, Nuclear Safety & Licensing.

Sincerely,

Attachment

C

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Attachment

Indian Point 2 Supplement to U-bend PWSCC and Sludge Pile ODSCC CMOAs for Sensitivity to Cycle Length, POD and Burst Correlation

Consolidated Edison Company of New York, Inc.
Indian Point Unit No. 2
Docket No. 50-247
July 2000

Executive Summary

Indian Point 2 Supplement to CMOA

The attached supplement to the Condition Monitoring and Operational Assessment (CMOA) report is submitted as additional justification to permit restart of the Indian Point Unit 2 steam generators for the operating cycle specified in the CMOA (i.e. 0.85 EFPY). This material addresses the following questions raised during review of the CMOA as submitted on June 2, 2000.

1. The effect of the burst pressure margin issue resulting from the test program performed in support of ANO-2.
2. The effect of potential undetected low voltage signals on the U-Bend analysis.

In order to facilitate CMOA review, a very conservative approach was taken on all of the above issues. The operating cycle length of 0.85 EFPY as set forth in the CMOA meets the NEI-97-06 performance criteria in consideration of the issues being addressed here. Sensitivity analyses are also supplied which assume a shorter cycle length and evaluate the differential effects on the burst pressure margin.

Burst Pressure Margin Issue

Some recent preliminary tests conducted for ANO-2 appear to indicate that for certain specific crack profiles a difference in burst pressure may result from slow test pressurization rates applied for ligament tearing compared to more rapid pressurization rates applied for burst testing using current industry practices. This burst pressure difference initially was not expected since similar tests conducted by the industry over the last 25 years did not identify any significant burst pressure dependence on pressurization rate. The Indian Point 2 in-situ pressure tests would not be impacted by this issue as the tubes were pressurized at relatively slow rates including hold times at steam line break pressure differential and $3\Delta P_{NO}$ for all indications tested and also at high pressures for the more limiting indications which experienced leakage at these high pressures. Thus the IP-2 in-situ tests fully capture the potential effects of the ANO-2 test results. Nonetheless, as a sensitivity study we were asked to apply in this supplemental CMOA the Argonne National Laboratory ligament tearing model as if it applied to the tube burst condition. This is a very conservative approach and provides a clear lower bound since it assumes that all flaws would have no increase in burst pressure above that associated with ligament tearing. Employing the EPRI-recommended steam generator integrity guidelines for Operational Assessments of 90% probability at 50% confidence (90/50), the $3\Delta P_{NO}$ requirement is met for a cycle length of greater than 1.5 EFPY for an assumed row 3 U-bend indication and greater than 1.7 EFPY for an assumed sludge pile indication. Thus the use of the Argonne model as requested does not affect the calculations of the June 2 CMOA. It should be noted that as in the initial CMOA, a very conservative assumption has been employed that the row 3 performance will be similar to that encountered in row 2 during the past cycle. This is particularly conservative inasmuch as no indications were found in row 3 during this inspection, and none are projected to occur during the upcoming cycle. This being the case, the ANO-2 test results and the Argonne model have no bearing on the IP-2 Cycle 15 inspection interval.

Undetected Low Row U-Bend Indications

No row 3 U-bend indications were found in the EOC-14 inspection when the high frequency +Point probe was utilized to improve signal detectability in the U-bend region. However, the question was posed whether there could exist some low signal to noise ratio indications that may have appreciable depth that could remain undetected and potentially challenge structural integrity. Some detected indications in row 2 had maximum depths in the range of 60% to 70% through wall. Based on low voltage indications (about 1 volt or less) as the most difficult to detect in the presence of noise in the +Point data, voltage versus depth trends indicate that the potentially difficult to detect indications would be expected to be < 0.3 inch long with average depths less than about 45%, maximum depths of about 60% to 70% or less, and crack areas of < 0.1 % inch.

In the interest of further evaluating this concern, the depth-based POD employed in the original CMOA was augmented with a POD that also considered the effect of crack length and depth, i.e. crack area. When a crack area POD is utilized, the same POD is used for both the burst pressure and leak rate analyses. When a depth-based POD is applied, POD as a function of average depth is used for burst analyses and POD as a function of maximum depth is used for leakage analyses. The crack area POD provides a more accurate POD representation that can be applied for both burst and leakage analyses. The crack area POD results in increased detection probability for long cracks which influence the limiting burst pressure, while decreasing the detection probability for short cracks which are too small to influence the limiting burst pressure indication evaluation. The use of the crack area POD for tube integrity analyses more accurately reflects detection of the long and deep indications with resulting improvements in the evaluation of the acceptable operating cycle length. The result of these analyses were that the cycle length was increased in the low row U-bends as a result of employing the crack area based POD. Moreover, the results clearly demonstrate the conservatism obtained by applying the lower bound depth based POD in the original CMOA to establish an acceptable cycle length for Indian Point 2 Cycle 15.

Indian Point-2 Supplement to U-Bend PWSCC and Sludge Pile ODSCC CMOAs for Sensitivity to Cycle Length, POD and Burst Correlation

July 7, 2000

Revision 1

Prepared By

Westinghouse Electric Company
E-Mech Technology, Inc.

Indian Point-2 Supplement to U-Bend PWSCC and Sludge Pile ODSCC CMOAs for Sensitivity to Cycle Length, POD and Burst Correlation

July 7, 2000

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Indian Point-2 Supplement to U-Bend PWSCC and Sludge Pile ODSCC CMOAs for Sensitivity to Cycle Length, POD and Burst Correlation

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1.0 INTRODUCTION

This report provides a supplement to the U-Bend PWSCC CMOA of Reference 8.1 and the sludge pile ODSCC CMOA evaluations included in Reference 8.2. The additional assessments documented in this report include evaluations for: 1) burst pressure margins based on ligament-tearing rather than burst of the indication to provide a lower bound assessment, 2) U-bend POD considerations for potentially undetected low voltage indications in row 3, and 3) Cycle 15 operational assessment sensitivity analyses to demonstrate burst margins for operating periods until SG replacement assumed to be as short as four months or 0.333 EFPY. These cycle length sensitivity evaluations are performed for both the U-bend (Section 3) and sludge pile (Section 6) indications.

Some recent test results established in connection with an independent program conducted for ANO-2 found that when some specific crack profiles were tested by standard industry practice for burst testing and, alternatively, by using a slower pressurization rate to test for ligament-tearing, the slower pressurization rate resulted in a lower burst pressure than the test using the standard industry practice. This difference in burst pressure between the slow pressurization rates applied for ligament-tearing and the fast pressurization rates applied for burst testing was approximately 25% of the predicted burst pressure. This effect was identified for a single crack profile, with small variations of depths, simulating an ANO-2 tube crack, and is likely to be limited to a few specific crack profiles[1] assuming further evaluation confirms the initial test results. The burst pressure difference was not expected since similar test comparisons for throughwall cracks and uniform depth cracks did not identify any significant burst pressure dependence on pressurization rate. This issue is addressed in Section 5 of this supplement for U-bend indications and Section 7 for sludge pile indications by performing lower bound burst pressure margin analyses using ligament-tearing pressures as assumed burst pressures.

No row 3 U-bend indications were found in the EOC-14 inspection with the standard mid-range +Point probe or the high frequency +Point probe that was used to improve the signal to noise ratio in the U-bend. Assuming for the purposes of this analysis that indications are present in row 3 but were not detected, the indications with low voltages (i.e., lowest signal to noise ratio) would be the most likely undetected indications. Trends of +Point voltage with depth and crack area show that the low voltage indications having sufficient depth to be a potential tube integrity concern would be short cracks. The relatively higher likelihood of not detecting short cracks is also supported by the database used to develop the U-bend POD, as most of the indications not detected by all analysts in the detection testing were short (< 0.3 inch long). Short cracks are further evaluated relative to their potential for burst and also by developing a POD as a function of crack area to include length as well as depth effects in the POD for tube integrity analyses. These evaluations are included in Section 4.

Conclusions from the evaluations of this report are summarized in Section 2.

[1] Additional evaluations to determine the impact of this initial result are in the planning stage as of the date of this document.

2.0 CONCLUSIONS

This CMOA supplement provides additional analyses addressing 1) the applicability of current burst pressure correlations based on recent tests in connection with a program for ANO-2, 2) considerations on detection of low voltage or short indications, and 3) burst pressure margin sensitivity related to shorter cycle length. Recent test results simulating an ANO-2 indication with EDM notches have indicated a potential difference in the indication burst pressure dependent upon the rate of pressurization of the specimen. Slow rates of pressurization resulting in ligament-tearing led to a lower burst pressure than a fast pressurization rate test consistent with industry standards. This sensitivity to pressurization rate is in conflict with extensive test results for throughwall and uniform depth flaws for which no dependence on pressurization rate was identifiable. However, the lower burst pressure result indicates a potential issue with industry burst pressure correlations, which are based upon fast pressurization rate tests. This issue is conservatively addressed in this report by using a ligament-tearing model to define the lower bound for the burst pressure in the operational assessment analyses. The overall conclusions are given in Section 2.1 below. Section 2.2 provides a summary and conclusions for the topics addressed in this report.

2.1 Overall Conclusions

The principal topics addressed in this report are the burst pressure issue described above and the potential for undetected low voltage indications. Pending resolution of the industry-wide question on pressurization rate and effect on burst pressure described above, the operational assessments for an acceptable operating cycle length for Indian Point-2 have been reanalyzed using the ANL ligament-tearing correlation (Ref. 8.3) as a lower bound burst pressure. Presumed undetected low voltage indications would be expected to be smaller than the lowest voltage indications found in the 2000 inspection. Based on comparisons of signal voltage with crack depth and crack area, the largest potentially undetected low voltage indications would be less than about 0.3 inch long, with average depths up to about 45% and maximum depths up to 60% to 70%. The PODs used in the CMOA analyses are conservatively based on depth. PODs based on depth lead to equal PODs for short and long cracks of comparable depths. The length effects on POD can be more accurately incorporated into the operational assessments by developing POD as a function of crack area, which has a greater influence on detection than depth alone. A crack area based POD was developed for the U-bend utilizing the same data that was applied for the depth based POD. The crack area POD is applied to quantitatively assess the significance of length effects on detection in assessing an acceptable operating cycle. The confidence level applied in the cycle length analyses also has a large effect on the acceptable cycle lengths. The EPRI SG integrity guidelines recommend that the operational assessments results be evaluated at 90% probability and 50% confidence (i.e., 90/50). The acceptable operating cycle lengths from the CMOA analyses (References 8.1 and 8.2) have been obtained at 90/50 for the sludge pile and 95/95 for the U-bend. The more conservative confidence level was applied to the U-bend due to a more limited database for growth rates, NDE uncertainties and POD. The sensitivity to the confidence level applied for the cycle length evaluations is also assessed in this report. The increases in burst pressure margins for short cycle lengths are also evaluated.

Table 2-1 provides summary results for acceptable operating cycle lengths for the burst correlation applied (burst pressure or ligament-tearing), the POD applied (depth or crack area based) and the confidence level applied (90/50 or 95/95). For the EPRI recommended 90/50 confidence level and a depth based POD, the acceptable cycle length for the U-bend is 1.5 EFPY even when the lower bound

ligament-tearing model is applied. The corresponding result for the sludge pile is full cycle operation at 1.7 EFPY. When the burst pressure correlation rather than ligament-tearing correlation is applied at 90/50 confidence with a depth based POD, the acceptable operating cycle length is a full cycle for both the U-bend and sludge pile. When the crack area POD is applied to more correctly address relative detection between short and long cracks, the acceptable cycle length for both the U-bend and the sludge pile is full cycle operation even when ligament-tearing is applied as a lower bound burst pressure. This result clearly demonstrates the conservatism associated with applying the lower bound depth based POD to establish an acceptable cycle length for Indian Point-2 Cycle 15.

Analytical conservatisms are combined to estimate the shortest acceptable operating period for Indian Point-2 Cycle 15. The conservatisms combined include ligament-tearing rather than burst for comparison with the $3\Delta P_{NO}$ burst margin requirement, a depth-based rather than crack area based POD and 95/95 confidence levels rather than the EPRI guidelines recommended 90/50 confidence level. In addition, the U-bend analysis very conservatively assumes that the indications found in row 2 were found in row 3 to obtain a bounding estimate of postulated undetected BOC-15 indications for the cycle length evaluation. The expected condition is that cracking has not initiated in row 3 based on the absence of any row 3 indications in the EOC-14 inspection with the high frequency +Point probe.

When these conservatisms are combined, the cycle length which would satisfy the $3\Delta P_{NO}$ burst margin requirement is calculated to be 0.45 EFPY for the U-bends and 0.75 EFPY for the sludge pile. A sensitivity evaluation of a shorter cycle length of 0.333 EFPY was requested to assess the increase in the burst pressure margin compared to 0.85 EFPY. The results of this evaluation show that a cycle length of 0.333 EFPY would increase the burst pressure margin by only about 6% compared to a cycle length of 0.85 EFPY for Cycle 15.

2.2 Summary and Conclusions

Evaluation of Lower Bound Burst Pressure Margins Based on Ligament-Tearing Rather than Burst

Currently available test results indicate no significant dependence of the burst pressure of SG tubes on pressurization rate for:

1) Throughwall cracks and slits
2) Part-throughwall cracks and slits
3) Leak rates at SLB conditions for corrosion cracked specimens
4) ODSCC alternate repair criteria (ARC) specimens
5) PWSCC specimens

Pressurization effects seen in the ANO-2 test do not affect most crack geometries. Thus, if found to be a real effect, only a few irregular crack profiles are likely to be affected. Leak test results indicate that the pressurization effects do not occur at pressure differentials seen by the SG tubes under normal operating or design basis accident conditions. The pressurization rate issue results from applying an explicit definition that the burst margin must be demonstrated under steady state or near steady state conditions.

Based on the adequacy of the sludge pile database for growth, NDE uncertainties and POD, the EPRI SG integrity guidelines for applying 90% probability at 50% confidence can be applied for the CMOA analyses. At 90/50 confidence, the $3\Delta P_{NO}$ burst margin requirement is satisfied for the limiting indication at full cycle operation of 1.7 EFPY including the conservative use of the ligament-tearing

Based on the adequacy of the sludge pile database for growth, NDE uncertainties and POD, the EPRI SG integrity guidelines for applying 90% probability at 50% confidence can be applied for the CMOA analyses. At 90/50 confidence, the $3\Delta P_{NO}$ burst margin requirement is satisfied for the limiting indication at full cycle operation of 1.7 EFPY including the conservative use of the ligament-tearing model to represent burst. For more conservative 95/95 confidence levels, the $3\Delta P_{NO}$ burst margin requirement is satisfied at 0.75 EFPY for the ligament-tearing model representing burst and at about 1.0 EFPY when the burst correlation is applied. The effect of using ligament-tearing for burst rather than the burst correlation is to reduce the EOC burst pressure by about 335 to 380 psi dependent upon cycle length and confidence level.

Evaluation of Potentially Undetected Low Voltage Indications in the Row 3 U-bends

An evaluation of potentially undetected low voltage indications in the Row 3 U-bends was performed to assess the potential impact if low voltage indications were masked by signal noise resulting from magnetite or copper deposits and tube ovality. (The Reference 8.1 CMOA for the U-bends conservatively considered only Row 2 indications.) The lowest voltage indications found in the inspection ranged from 0.86 to about 1 volt and are associated with short cracks (< 0.3 inch long) having average depths up to about 45% and maximum depths up to about 60% to 70%. If it is postulated that row 3 indications were undetected, short cracks in this depth range would be the most probable undetected indications. The increased difficulties for detecting short cracks compared to long cracks would lead to lower PODs for short and potentially deep cracks. Short cracks tend to significantly reduce POD distributions developed as a function of depth. The influence of short crack detection on PODs can be accounted for in tube integrity analyses by applying POD as a function of crack area. For the U-bend analyses, the use of a crack area based POD (less conservative POD) increases the burst margins by more than 800 psi or about 13% compared to use of a depth based POD. An increase of 800 psi burst pressure for the limiting indication would lead to full cycle operation of 1.7 EFPY satisfying burst margin requirements. The use of the crack area POD more accurately reflects the better detection of long and deep cracks, as compared to short cracks of comparable depth, and improves operational assessments for acceptable operating cycle length compared to use of a depth only based POD. In particular, the results clearly demonstrate the conservatism obtained by applying the lower bound depth based POD to establish an acceptable cycle length for Indian Point-2 Cycle 15.

The following results support a determination that any assumed, undetected U-bend indications in row 3 with significant depth would be short cracks about < 0.3 inch long that would not impact structural or leakage integrity over the planned operating cycle for Indian Point-2.

- Based on low voltage indications (about 1 volt or less) as being the most difficult to detect in the presence of noise in the +Point data, voltage versus depth and crack area data trends indicate that the potentially difficult to detect indications would be expected to be < 0.3 inch long with average depths less than about 45%, maximum depths of about 60% to 70% or less and crack areas of < 0.1 %-inch.

- Even a 0.3 inch, 100% throughwall indication left in service would satisfy the burst margin requirement at 1.0 EFPY. The EOC length after one EFPY would be about 0.44 inch based on growth in length at 95% probability. The critical length of a 100% throughwall crack in a row 3 U-bend that satisfies $3\Delta P_{NO} = 4668$ psi is 0.53 inch for the nominal burst correlation and 0.46 inch at the lower 95% probability at 95% confidence on the burst correlation. Consequently, a 0.3 inch long

crack left in service would always satisfy burst margin requirements even after one EPFY of Cycle 15 operation.

- Indications with maximum depths <75% would not be expected to leak after 0.85 EFPY. The SLB leak rates at 0.85 EFPY for BOC maximum depths of 75% to 90% would be about 0.0055 to 0.24 gpm. For a cycle length of 0.45 EFPY, a BOC depth of 79% is required for leakage .The leak rates for 75% to 90% and 100% maximum BOC depths would be about 0.0048 to 0.31 gpm. For a 0.45 EFPY cycle length, eight undetected row 3 cracks having 90% maximum depth would be required to exceed the allowable 1.0 gpm leak rate limit. Since no row 3 indications were detected in the 2000 inspection, the likelihood of not detecting a sufficient number of short and deep cracks to exceed a 1.0 gpm leak rate limit is judged to be negligible.

Burst Pressure Margins for Short Operating Cycles

The sensitivity of the U-bend operational assessment burst pressure margins to cycle lengths as short as 0.333 EFPY (4 months) was evaluated. Margins are provided as the ratio of the limiting indication burst pressure to the $3\Delta P_{NO}$ margin requirement of 4668 psi. Since growth rates are modest for U-bend PWSCC, the increase in margin is not large for the shorter cycle. Going from a reference 0.85 EFPY cycle (Reference 8.1) to 0.333 EFPY, the U-bend burst margin ratio (1.0 is acceptable) increases from 1.06 to 1.13.

The sensitivity of the limiting burst pressures to uncertainties in the POD was also evaluated by statistical treatment of the uncertainties. The U-bend CMOA of Reference 8.1 assesses sensitivity to uncertainty in the POD distribution as a 5% depth shift from the reference POD distribution to represent a conservative assessment of the POD uncertainty. The POD uncertainty influence on the limiting burst pressure can be more accurately obtained by directly incorporating the POD uncertainty in the Monte Carlo analyses as performed in this assessment. For the U-bend analysis, an absolute shift in the nominal POD by 5% results in a decrease in the limiting burst pressure by about 344 psi for the 1.0 EFPY cases and about 366 psi for the 0.333 EFPY cases. The statistical treatment of the POD uncertainty in the Monte Carlo analysis reduces the limiting burst pressure by only about 43 psi for 0.85 EFPY and about 52 psi for 0.333 EFPY compared to use of the nominal POD.

2.3 Open Items

The following open items from the Reference 8.1 CMOA have been completed:

- Configuration control for the code version used in the CMOA has been completed.
- E-Mech Technology, Inc. has been approved as a qualified Westinghouse supplier.

As of the date of this report, the following are open items.

- An update of the computer code used for the analyses in this report has not been fully documented and placed in configuration control at the time of this report. Documentation of verification for the Westinghouse analyses is in process.

- The multi-cycle analyses described in this report were performed by E-Mech Technology, Inc. Verification signatures by E-Mech on the title page of this report reflect verification of the E-Mech analyses and not the complete report.

Table 2-1. Indian Point-2 U-bend and Sludge Pile Acceptable Operating Period Sensitivity to Burst Correlation, POD and Analysis Confidence Level

Burst Correlation	POD	Analysis Probability & Confidence Level	Acceptable Operating EFPY for Satisfying $3\Delta P_{NO}$ = 4668 psi	Comment
		U-Bend		
Burst Pressure	Depth with Uncertainty	90/50	> 1.7 1.7 = 5219 psi	EPRI confidence requirement
Burst Pressure	Depth with Uncertainty	95/95	> 1.0 1.0 = 4800 psi	Conservative confidence level
Burst Pressure	Crack Area with Uncertainty	95/95	> 1.7 1.7 = 5093 psi	Conservative confidence level with POD including crack length influence
Ligament-tearing	Depth with Uncertainty	90/50	> 1.5 1.5 = 4732 psi	Conservative ligament-tearing at EPRI confidence requirement
Ligament-tearing	Depth with Uncertainty	95/95	0.45 0.45 = 4684 psi	Conservative ligament-tearing and conservative confidence level
Ligament-tearing	Crack Area with Uncertainty	95/95	> 1.7 1.7 = 4674 psi	Conservative ligament-tearing with POD including crack length influence
		Sludge Pile		
Burst Pressure	Depth with Uncertainty	90/50	> 1.7 1.7 = 5023 psi	EPRI confidence requirement
Burst Pressure	Depth with Uncertainty	95/95	> 1.0 1.0 = 4866 psi	Conservative confidence level
Ligament-tearing	Depth with Uncertainty	90/50	> 1.7 1.7 = 4682 psi	Conservative ligament-tearing at EPRI confidence requirement
Ligament-tearing	Depth with Uncertainty	95/95	0.75 0.75 = 4669 psi	Conservative ligament-tearing and conservative confidence level

3.0 U-BEND OPERATIONAL ASSESSMENT SENSITIVITY TO CYCLE LENGTH

3.1 Evaluation of 0.333 EFPY Cycle Length

Based upon the Indian Point-2 commitment to initiate SG replacement by late 2000, the potential exists that the Cycle 15 operating cycle length until replacement could be as short as four months or 0.333 EFPY. A sensitivity analysis was requested, based on an assumed cycle length of 0.333 EFPY, to assess the impact of a shorter cycle length on burst margin. A shorter operating cycle increases the burst pressure margins against the $3\Delta P_{NO}$ = 4668 psi requirement. This section assesses burst pressure margin ratios of the limiting indication burst pressure to the $3\Delta P_{NO}$ requirement as a function of cycle length including a short 0.333 EFPY cycle length. The U-bend CMOA evaluated sensitivity to POD uncertainties by applying a 5% depth shift in the POD as an estimated worst case decrease in the POD. Sensitivity calculations are also included in this section for POD uncertainty by including the uncertainties in the POD correlation directly in the Monte Carlo operational assessment analyses.

3.2 Comparisons of Burst Margins for 0.85 EFPY and 0.333 EFPY Cycle Lengths

Table 3-1 provides sensitivity of the U-bend operational assessment burst pressure margins to cycle lengths as short as 0.333 EFPY (4 months) in order to assess the increase in burst margins for short cycle lengths. These tables are an extension of the reference analysis tables in the CMOA (Reference 8.1) to include 0.333 EFPY. Margins are provided as the ratio of the limiting indication burst pressure to the $3\Delta P_{NO}$ margin requirement of 4668 psi. Since growth rates are not large for the U-bend PWSCC, the increase in margin is modest for the shorter cycle. Going from the reference 0.85 EFPY cycle length to 0.333 EFPY, the U-bend burst margin ratio (1.0 is acceptable) increases from 1.06 to 1.13.

The U-bend CMOA of Reference 8.1 assesses sensitivity to uncertainty in the POD distribution as a 5% depth shift from the reference POD distribution. This was intended as a conservative assessment of the POD uncertainty. The POD uncertainty influence on the limiting burst pressure can be more accurately obtained by directly incorporating the POD uncertainty in the Monte Carlo analyses as performed in this assessment. The magnitude of the POD uncertainty on the log logistic POD distribution can be seen in Figure 3-1, which shows the nominal POD used in Reference 8.1 and the lower 95% confidence on the POD distribution. It is seen that the lower 95% confidence is about a 5% shift in the POD to deeper depths. Since the Monte Carlo analysis samples the total distribution, the effect of POD uncertainty on the limiting burst pressures can be expected to be much lower than obtained from the 5% shift sensitivity study. From Table 3-1, it is seen that the absolute shift in the nominal POD by 5% results in a decrease in the limiting burst pressure by about 344 psi for the 1.0 EFPY cases and about 366 psi for the 0.333 EFPY cases. The statistical treatment of the POD uncertainty in the Monte Carlo analysis reduces the limiting burst pressure by only about 43 psi for the 0.85 EFPY cases of Table 3-1 and about 52 psi for the 0.333 EFPY cases compared to use of only the nominal POD.

Overall, it is concluded that decreasing the Cycle 15 operating period from 0.85 to 0.333 EFPY results in a limiting indication burst pressure increase of about 300 psi with a resulting increase in the $3\Delta P_{NO}$ burst margin to the requirement of 4668 psi by about 6%. Statistical treatment of the POD uncertainties in the Monte Carlo analyses result in only a 1% reduction in the burst pressure margin compared to use of the nominal POD without uncertainties in the analyses as applied in the reference CMOA analyses of Reference 8.1.

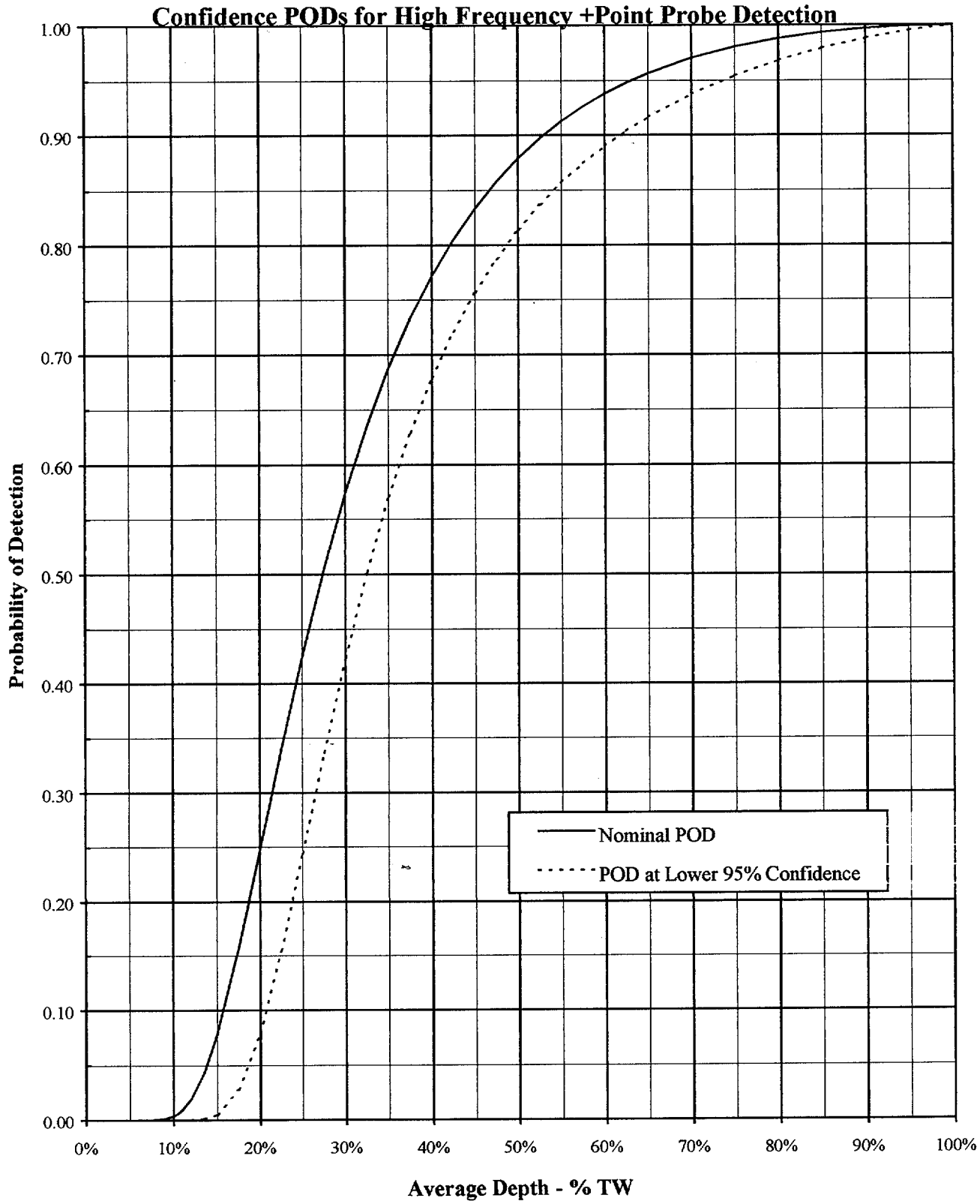
Table 3-1. Indian Point-2 U-Bend Cycle 15 Length Sensitivity Analyses (400 kHz Profiles)[1] for Projected Burst Pressures and Leak Rate[2] Results for the Limiting SG 24

Assumes Row 3 Indications Same as Detected Row 2 Indications

Operating EFPY	POD	Limiting Burst Pressure (psi)	Burst Pressure Margin Ratio[3]	SLB Leak Rate (gpm)	SLB Burst Probability	$3\Delta P_{NO}$ Burst Probability
95% Probability/95% Confidence						
1.0	Reference	4840	1.04	0.0	3.23×10^{-3}	4.10×10^{-2}
1.0	POD Shift by +5%	4496	0.96	0.0	6.35×10^{-3}	6.01×10^{-2}
0.85	Reference	4937	1.06	0.0	3.23×10^{-3}	3.61×10^{-2}
0.85	Reference with Unc.[4]	4894	1.05	0.0	3.81×10^{-3}	3.82×10^{-2}
0.75	Reference	5001	1.07	0.0	3.20×10^{-3}	3.36×10^{-2}
0.333	Reference	5253	1.13	0.0	2.51×10^{-3}	2.43×10^{-2}
0.333	Reference with Unc.[3]	5201	1.11	0.0	3.00×10^{-3}	2.61×10^{-2}
0.333	POD Shift by +5%	4887	1.05	0.0	5.18×10^{-3}	3.74×10^{-2}
0.333	POD Shift by -5%	5664	1.21	0.0	1.11×10^{-3}	1.53×10^{-2}
90% Probability/50% Confidence						
1.0	Reference	5670	1.21	0.0	2.97×10^{-3}	4.07×10^{-2}
0.333	Reference	6058	1.30	0.0	2.36×10^{-3}	2.42×10^{-2}
0.333	Reference with Unc.[3]	5980	1.28	0.0	2.76×10^{-3}	2.57×10^{-2}

1. The reference 8.1 growth rates are based on the 400kHz probe profiles
2. Acceptance criteria: $3\Delta P_{NO}$ = 4668 psi at operating temperature, SLB leak rate = 1 gpm summed over all degradation mechanisms. Burst probability guidelines: $\Delta P_{SLB} = 4\times10^{-2}$, $3\Delta P_{NO} = 8\times10^{-2}$ summed for all degradation mechanisms in limiting SG.
3. Ratio of Calculated Limiting Burst Pressure to $3\Delta P_{NO}$ = 4668 psi acceptance criteria.
4. Uncertainties on the POD included in the Monte Carlo analyses.

Figure 3-1. Indian Point-2 Comparison of Nominal and Lower 95% Confidence PODs for High Frequency +Point Probe Detection



4.0 U-BEND OPERATIONAL ASSESSMENT SENSITIVITY TO POD

The U-bend operational assessment of Reference 8-1 defines lower bound PODs as a function of average depth or maximum depth. The development of these PODs does not explicitly account for the crack length effect on detection. By including short and long indications in the PODs as a function of depth, the POD is conservative for long cracks, as the short cracks included in the POD tend to have deeper depths for undetected indications than long cracks.

This section addresses the potential for short and deep undetected U-bend indications, and their potential effects on tube integrity. The assumed undetected indications (for purposes of this analysis) are likely to have low voltages, as the low voltage indications are more difficult to separate from the signal noise response. The trends of indication voltage with crack depth are defined in Section 4.1. Tube integrity considerations for the assumed short (<0.3 inch) cracks are evaluated in Section 4.2. As a demonstration of the sensitivity of the POD to short cracks, the POD of Reference 8.1 including all crack lengths is compared in Section 4.3 to the POD that would result if only crack lengths ≥ 0.3 inch were included in the POD. To include crack length effects on POD directly in the tube integrity analyses, a POD as a function of crack area is developed in Section 4.4 applying the same database used to develop the Reference 8.1 POD as a function of depth only. Section 4.5 provides EOC burst pressure predictions based on applying the POD as a function of crack area rather than crack depth. Conclusions from this evaluation are given in Section 4.6.

4.1 Indication Voltage Trends with Crack Depth and Crack Area

Short indications (< 0.3") can have low voltage (about 1 volt or less) responses since the effective coil field for a +Point probe is about 0.15 to 0.20 inch and the probe tends to respond to both the flaw and undegraded tubing as it passes through the indication. For this reason, RPC calibrations standards are recommended to be 0.5 inch long so that the probe can be easily centered within the EDM notch without end effects influencing the calibration voltage and depth. The voltage versus depth trends for the U-bend indications can be used to assess the range of depths associated with low voltage indications. Figure 4-1 shows the U-bend indication voltages (data from Table 3-5 of Reference 8.1) for the 2000 inspection, 400 kHz evaluation as a function of average and of maximum depth. The 400 kHz data is applied, rather than the 800 kHz data, since the sizing techniques applied for the U-bend were developed from dented TSP experience relating 300 to 400 kHz data to destructive exam results. Figure 4-1 includes the regression fits to the data.

The lowest voltages for the detected indications are in the range of about 0.8 to 1.2 volt. The average depths for the low voltage indications range from about 14% to 45% and the maximum depths range from 38% to 55% with a single maximum depth indication at 74% (R2C69, crack 2). The 74% maximum depth for R2C69 is likely an overestimate since the post in situ value even at 800 kHz for this indication was only about 55% maximum depth. The more likely maximum depth associated with indications of about 1 volt would be about 60%. The voltages for other indications about 40% average depth were more than 1.6 volt indications and would be expected to be detectable above noise levels in the U-bend since these indications were detected with the mid-range +Point probe as well as the 800 kHz high frequency probe. All of the indications < 1.7 volt had crack lengths had crack lengths < 0.3 inch.

Since crack length as well as depth influences detectability, the most appropriate quantity for evaluating POD including length effects would be crack area based on average depth times length. The burst effective length and associated average depth would be the preferred measure of crack area for a POD evaluation since this reflects the deepest segments of the crack and ignores the shallow tails. Figure 4-2 shows the trends of +Point peak to peak volts versus burst effective crack area. For the present analyses, crack area is computed as the depth fraction (i.e., 0.5 = 50% depth) times the length in inches and annotated as %-inch for units. The resulting correlation is better defined than that obtained for volts as a function of depth alone. All indications up to about 1.2 volt have a crack area of < 0.1 % inch. Thus the expected crack area for undetected indications would have a crack area < 0.1 % inch. As shown in Section 4.4, the POD is expected to increase rapidly with crack area to about 0.8 at a crack area of 0.1 % inch.

Based on the above assessments of low voltage indications (about 1 volt or less) as the most difficult to detect, the difficult to detect indications would be expected to be < 0.3 inch long with average depths less than about 45%, maximum depths of about 60% or less and crack areas of < 0.1 % inch. Indications of this range are further evaluated in Sections 4.2 to 4.5.

4.2 Burst Margins and SLB Leak Rates for Short (0.3 Inch) BOC Crack Lengths

This section assesses EOC burst margins and SLB leak rates for assumed potentially undetected short (0.3 inch) indications left in service in the row 3 U-bends at BOC-15. Examples of detected short indications are the indications found in tubes R2C87 and R2C85, which were evaluated in Table 9-2 of the U-bend CMOA, Reference 8.1. The multiple indications in R2C87 ranged from burst effective lengths and average depths of 0.25 inch, 48.0% average depth to 0.31 inch, 44.3% average depth, and associated burst pressures after 1.0 EFPY of 5887 and 5958 psi, respectively. This results show a burst pressure margin of 26% above the $3\Delta P_{NO}$ = 4668 psi burst margin requirement. No SLB leakage was found for these indications after 1.0 EFPY.

From the U-bend growth distribution in the CMOA (Reference 8.1), the growth in length at 95% cumulative probability is about 0.14 inch per EFPY. The EOC length for a 0.30 inch indication after one EFPY would be about 0.44 inch. The critical length of a 100% throughwall crack in a row 3 U-bend that satisfies $3\Delta P_{NO}$ = 4668 psi is 0.53 inch for the nominal burst correlation and 0.46 inch at the lower 95% probability at 95% confidence for the burst correlation. Consequently, a 0.3 inch long crack left in service would always satisfy burst margin requirements even after one EPFY of Cycle 15 operation.

Low level leakage at SLB conditions could result from very deep, short cracks that are potentially undetected and left in service. Indications with maximum depths of about 60% to 70%, as typical of about 1 volt undetected indications, would not leak after a cycle length of 0.85 EFPY. To assess the maximum depth that would have to be undetected to result in leakage at 0.85 EFPY, the profile of crack 3 for R2C87 (burst effective length of 0.31 inch) was scaled to varying maximum depths between 70% and 100% at BOC-15, and leakage analyses performed after 0.85 EFPY. The profiles with maximum depths <75% did not leak after 0.85 EFPY. The SLB leak rates at 0.85 EFPY for BOC maximum depths of 75%, 90% and 100% would be about 0.0055, 0.24 and 0.46 gpm. For a cycle length of 0.45 EFPY, a BOC depth of 79% is required for leakage and the leak rates for 75%, 90% and 100% maximum BOC depths would be about 0.0048, 0.13 and 0.31 gpm. For a 0.333 EFPY cycle length, the corresponding leak rates would range from about 0.002 to 0.28 gpm. For a 0.45 EFPY cycle length, eight undetected row 3 cracks having 90% maximum depth would be required to exceed the allowable

1.0 gpm leak rate limit. Since no row 3 indications were detected in the 2000 inspection, the likelihood of not detecting a sufficient number of short and deep cracks to exceed a 1.0 gpm leak rate limit is negligible.

4.3 POD Comparisons for All Crack Lengths with Crack Lengths ≥ 0.3 Inch Long

The lower bound POD distributions recommended for Indian Point-2 U-bend analyses with the high frequency +Point probe include data for short and long cracks. The database used to develop this POD included 47 laboratory and pulled tube indications with flaws in axial dents together with NDD intersections that were analyzed by four field analysts. Nine indications were not detected by one or more of the four analysts. Of the 9 indications without detection by all analysts, 7 indications had lengths ranging from 0.030 to 0.213 inch, 1 was 0.300 inch and 1 was 0.817 inch (28% average depth). The limited detection for the short cracks clearly dominates the low POD obtained for all the data. This is consistent with the conclusions from the voltage trend analyses described above in Section 4.1. The U-bend CMOA also includes a POD versus depth curve developed for dented TSP intersections. In this database, 8 indications were not detected by one or more analysts, and 7 of the 8 undetected indications had crack lengths < 0.3 inch. Thus, the undetected contributions to the POD for dented TSP intersections are also dominated by short cracks.

A general sensitivity of the POD to short cracks can be demonstrated by comparing the POD obtained for all data to a POD obtained by eliminating all indications < 0.30 inch long. This comparison is shown in Figure 4-3. The POD above 30% average depth is substantially improved when short cracks are not considered. The reduction in POD below 25% depth is an artifact of eliminating the shallow, short cracks that were detected by only a fraction of the analysts tested. A more appropriate method to incorporate crack length effects in the POD is to define the POD as a function of the crack area as described in the following section.

4.4 POD as a Function of Crack Area

For eddy current NDE, detection would be more sensitive to the area of the flaw than to depth alone. A POD as a function of crack area reflects limited detection for short cracks and improves the POD application for tube integrity analyses. The POD is therefore developed as a function of crack area to quantitatively incorporate crack length effects on detection into the tube integrity analyses. The database used to determine the PODs as a function of depth is applied to obtain the POD versus crack area. The deepest section of the crack is reflected in the burst effective length and depth and represents the appropriate quantity to define POD dependence.

The resulting POD as a function of burst effective crack area is shown in Figure 4-4. The POD increases rapidly to about 0.67 at crack areas as small as 0.05 and reaches 0.95 at 0.275 %-inch crack area. For a 0.6 inch indication that could be long enough to challenge structural integrity at EOC conditions, an indication of 46% average depth would be detected at 95% probability. This indication would satisfy structural integrity after more than 0.85 EFPY Cycle 15 operation. As expected, short cracks would be deeper to obtain the same POD as long cracks. For a 0.3 inch long crack, the average depth could be up to 92% to obtain a 0.95 POD.

The POD as a function of crack area given in Figure 4-4 is applied in this report to incorporate crack length effects in the tube integrity analyses. With the single cycle analysis methods applied in the CMOA analyses of Reference 8.1, the burst effective crack areas are calculated for all indications prior to applying the POD adjustment to obtain the calculated undetected population.

4.5 Burst Margin Comparisons for PODs Dependent On Crack Depth and Crack Area

The single cycle analysis methods were modified to permit calculations with POD given as either a function of depth or crack area. When a crack area POD is utilized, the same POD is used for both the burst pressure and leak rate analyses. When a depth based POD is applied, POD as a function of average depth is used for burst analyses and as a function of maximum depth is used for leakage analyses. The crack area POD provides a more accurate POD representation that can be applied for both burst and leakage analyses. The crack area POD results in increased detection probability for long cracks which influence the limiting burst pressure, while decreasing the detection probability for short cracks which are too small to influence the limiting burst pressure indication evaluation. The use of the crack area POD for tube integrity analyses more accurately reflects detection of the long and deep indications with resulting improvements in the evaluation of the acceptable operating cycle length.

Operational assessment results comparing the reference POD as a function of depth with the crack area POD are given in Table 4-1. The crack area POD leads to increases in the limiting burst pressure by more than 650 psi. Because of this increase in the limiting indication EOC burst pressure, a full cycle operating period of 1.7 EFPY satisfies burst margin requirements even at 95/95 confidence levels for the analysis. Shorter operating periods increase the burst margins. These results demonstrate the potential increases in acceptable cycle lengths obtained by more accurately reflecting crack length effects in the POD. Moreover, the results clearly demonstrate the conservatism obtained by applying the lower bound depth based POD to establish an acceptable cycle length for Indian Point-2 Cycle 15.

4.6 Conclusions

This evaluation was performed to assess the potential impact if low voltage indications were masked by signal noise resulting from magnetite or copper deposits and tube ovality. The lowest voltage indications found in the inspection ranged from 0.86 to about 1 volt and are associated with short cracks (< 0.3 inch long) having average depths up to about 45% and maximum depths up to about 60% to 70%. If it is postulated that row 3 indications were undetected, short cracks in this depth range would be the most probable undetected indications. The increased difficulties for detecting short cracks compared to long cracks would lead to lower PODs for short and potentially deep cracks. Short cracks tend to significantly reduce POD distributions developed as a function of depth. The influence of short crack detection on PODs can be accounted for in tube integrity analyses by applying POD as a function of crack area. For the U-bend analyses, the use of a crack area based POD increases the burst margins by more than 650 psi or about 14% compared to use of a depth based POD. An increase of 650 psi burst pressure for the limiting indication would lead to full cycle operation of 1.7 EFPY satisfying burst margin requirements. The use of the crack area POD more accurately reflects the better detection of long and deep cracks, as compared to short cracks of comparable depth, and improves operational assessments for acceptable operating cycle length compared to use of a depth only based POD. In particular, the results clearly demonstrate the conservatism obtained by applying the lower bound depth based POD to establish an acceptable cycle length for Indian Point-2 Cycle 15.

The following results support a conclusion that any assumed, undetected U-bend indications in row 3 with significant depth would be short cracks about < 0.3 inch long that would not impact structural or leakage integrity over the planned operating cycle for Indian Point-2.

- Based on low voltage indications (about 1 volt or less) as the most difficult to detect in the presence of noise in the +Point data, voltage versus depth trends indicate that the potentially difficult to detect indications would be expected to be < 0.3 inch long with average depths less than about 45%, maximum depths of about 60% to 70% or less and crack areas of < 0.1 % inch.

- Even a 0.3 inch, 100% throughwall indication left in service would satisfy the burst margin requirement at 1.0 EFPY. The EOC length after one EFPY would be about 0.44 inch. The critical length of a 100% throughwall crack in a row 3 U-bend that satisfies $3\Delta P_{NO}$ = 4668 psi is 0.53 inch and 0.46 inch at the lower 95% probability at 95% confidence. Consequently, a 0.3 inch long crack left in service would always satisfy burst margin requirements even after one EPFY of Cycle 15 operation.

- Indications with maximum depths <75% would not be expected to leak after 0.85 EFPY. The SLB leak rates at 0.85 EFPY for BOC maximum depths of 75% to 90% would be about 0.0055 to 0.24 gpm. For a cycle length of 0.45 EFPY, a BOC depth of 79% is required for leakage and the leak rates for 75% to 90% and 100% maximum BOC depths would be about 0.0048 to 0.31 gpm. For a 0.45 EFPY cycle length, eight undetected row 3 cracks having 90% maximum depth would be required to exceed the allowable 1.0 gpm leak rate limit. Since no row 3 indications were detected in the 2000 inspection, the likelihood of not detecting a sufficient number of short and deep cracks to exceed a 1.0 gpm leak rate limit is negligible.

- POD as a function of crack area is applied to incorporate crack length effects in the tube integrity analyses. The crack area POD reflects the improved detectability of long and deep indications compared to short indications of comparable depths.

Table 4-1. Indian Point-2 Cycle 15 U-Bend POD Sensitivity Analyses (400 kHz Profiles) for Projected Burst Pressures and Leak Rate(1) Results for the Limiting SG 24
Assumes Row 3 Indications Same as Detected Row 2 Indications

Operating EFPY	POD	Limiting Burst Pressure (psi)	Burst Pressure Margin Ratio(2)	SLB Leak Rate (gpm)	SLB Burst Probability	$3\Delta P_{NO}$ Burst Probability
95% Probability/95% Confidence						
1.70	Crack Area POD without Uncertainty	5093	1.09	0.0	5.51×10^{-4}	3.43×10^{-2}
0.85	Reference	4937	1.06	0.0	3.23×10^{-3}	3.61×10^{-2}
0.85	Ref. with Unc. (3)	4894	1.05	0.0	3.81×10^{-3}	3.82×10^{-2}
0.85	Crack Area POD without Uncertainty	5676	1.22	0.0	1.35×10^{-4}	1.76×10^{-2}
0.85	Crack Area POD with Uncertainty	5543	1.19	0.0	1.87×10^{-4}	1.91×10^{-2}
0.333	Reference	5253	1.13	0.0	2.51×10^{-3}	2.43×10^{-2}
0.333	Ref. with Unc.(3)	5201	1.11	0.0	3.00×10^{-3}	2.61×10^{-2}
0.333	Crack Area POD without Uncertainty	5993	1.28	0.0	1.08×10^{-4}	1.11×10^{-2}
0.333	Crack Area POD with Uncertainty	5856	1.25	0.0	7.8×10^{-5}	1.22×10^{-2}
90% Probability/50% Confidence						
0.85	Reference	5670	1.22	0.0	2.97×10^{-3}	3.54×10^{-2}
0.85	Crack Area POD without Uncertainty	6760	1.45	0.0	5.0×10^{-5}	1.72×10^{-2}
0.85	Crack Area POD with Uncertainty	6620	1.42	0.0	9.0×10^{-5}	1.87×10^{-2}
0.85	Ref. with Unc. (3)	5677	1.22	0.0	3.53×10^{-3}	3.78×10^{-2}
0.333	Reference	6058	1.30	0.0	2.36×10^{-3}	2.42×10^{-2}
0.333	Ref. with Unc.(3)	5980	1.11	0.0	2.76×10^{-3}	2.57×10^{-2}
0.333	Crack Area POD without Uncertainty	7100	1.52	0.0	4.0×10^{-5}	1.08×10^{-2}
0.333	Crack Area POD with Uncertainty	6940	1.49	0.0	1.0×10^{-5}	1.17×10^{-2}

1. Acceptance criteria: $3\Delta P_{NO}$ = 4668 psi at operating temperature, SLB leak rate = 1 gpm summed over all degradation mechanisms. Burst probability guidelines: $\Delta P_{SLB} = 4\times10^{-2}$, $3\Delta P_{NO} = 8\times10^{-2}$ summed for all degradation mechanisms in limiting SG.
2. Ratio of Calculated Limiting Burst Pressure to $3\Delta P_{NO}$ = 4668 psi acceptance criteria.
3. Uncertainties on the POD included in the Monte Carlo analyses.

Figure 4-1. Indian Point-2: U-Bend Indication 400 kHz Peak to Peak Volts versus Crack Depth Trends

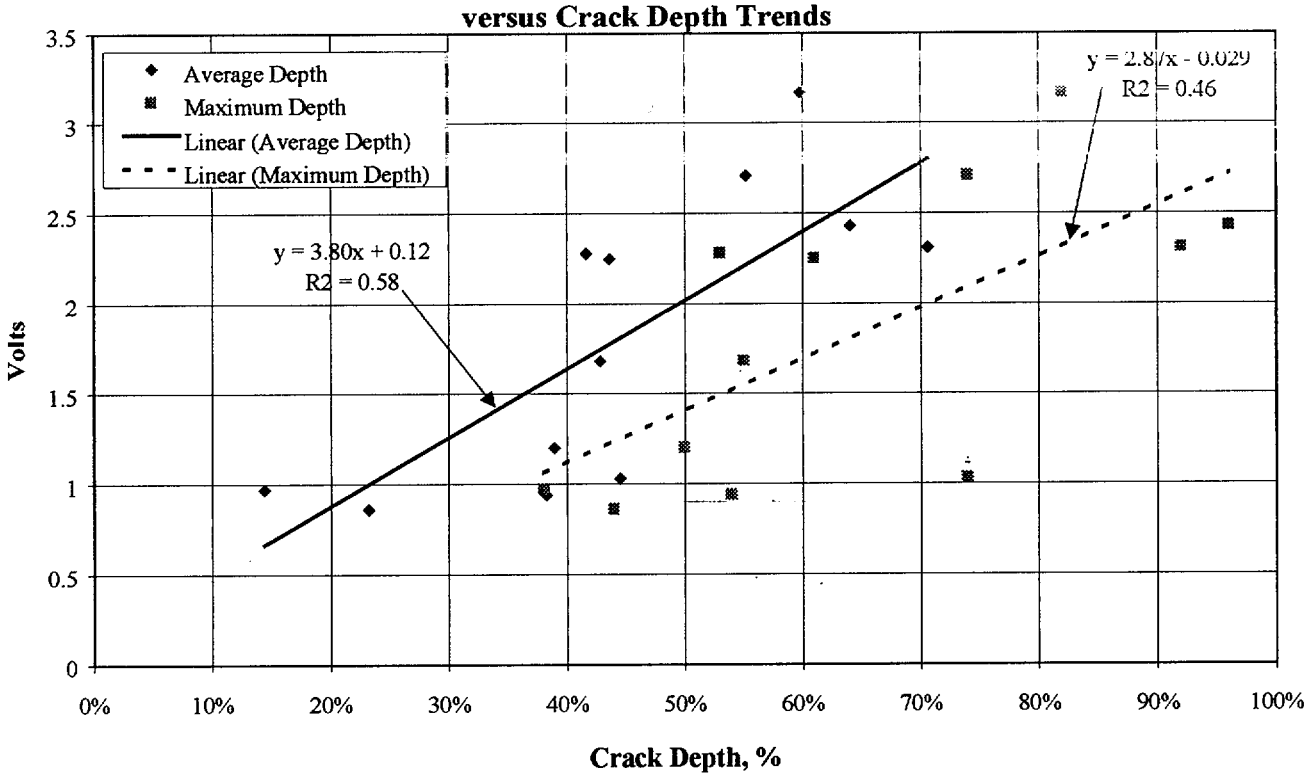


Figure 4-2. Indian Point-2: U-Bend Indication 400 kHz Peak to Peak Volts versus Burst Effective Crack Area (length x avg. depth) Trends

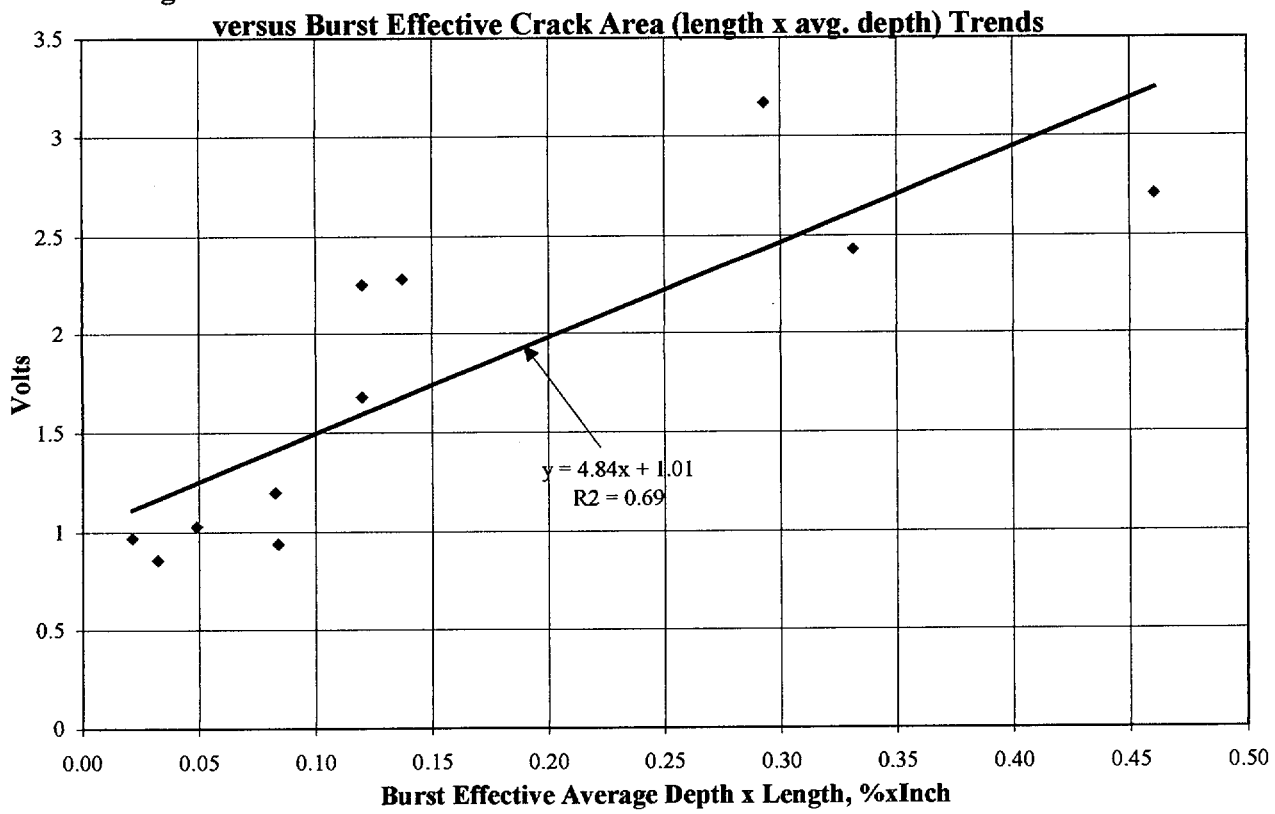


Figure 4-3. Indian Point-2: Comparison of POD vs. Average Depth for All Indications and Only for >= 0.3 Inch Long Indications

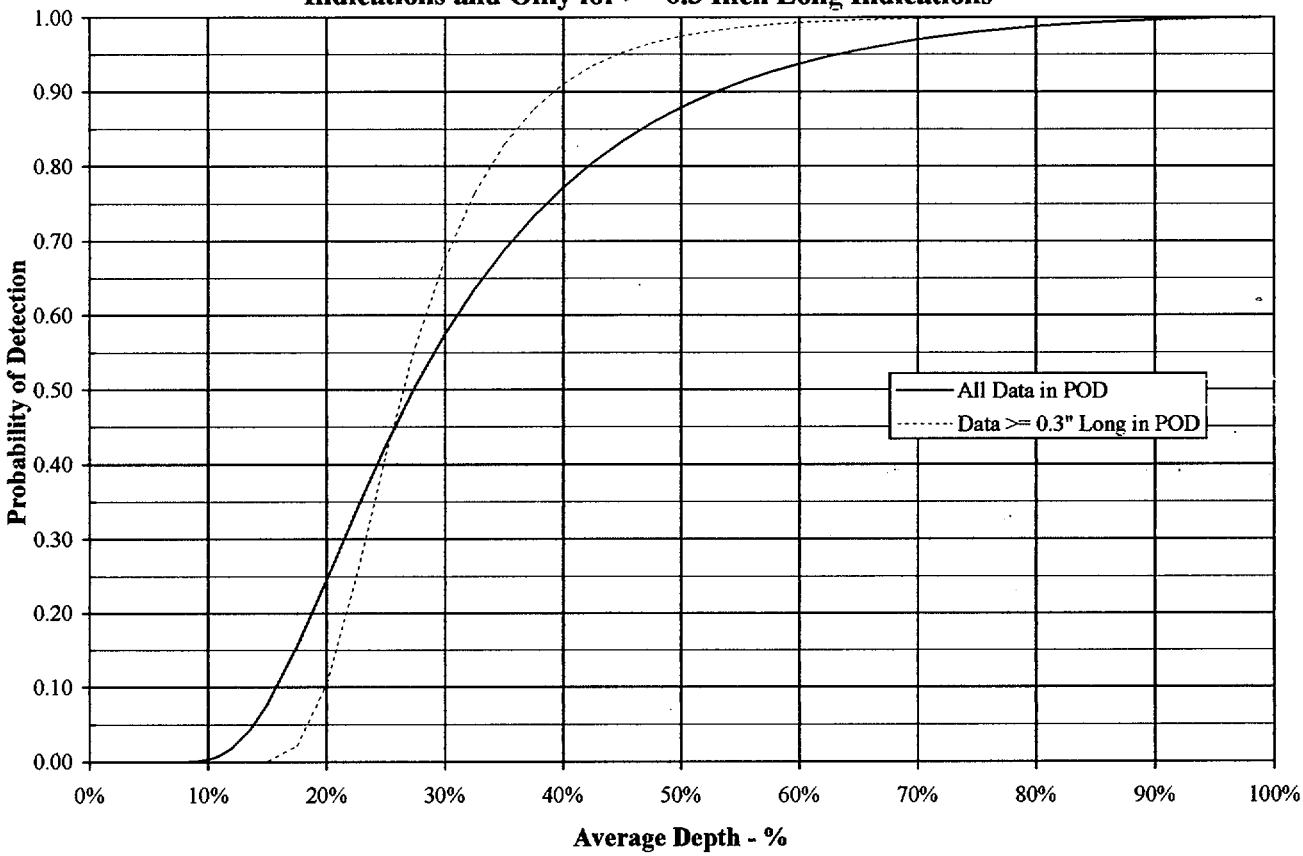
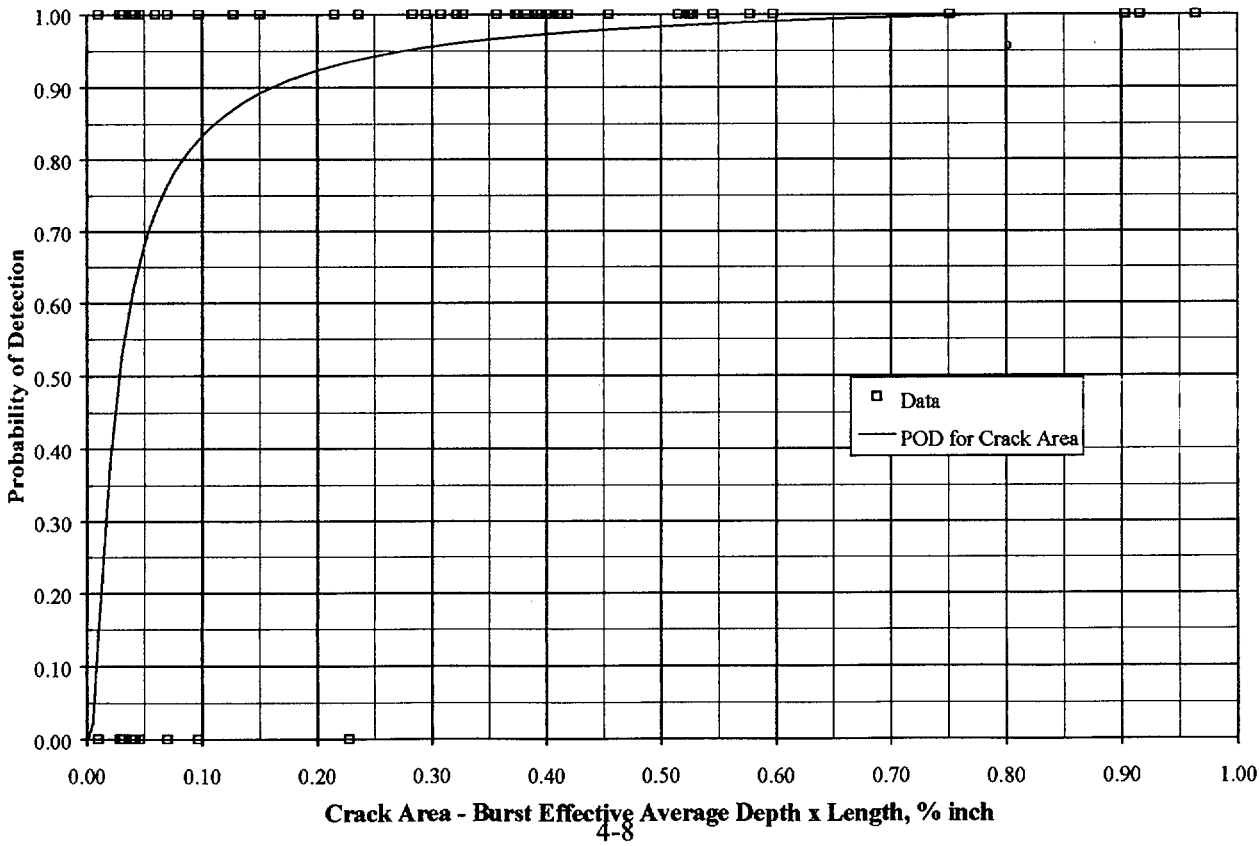


Figure 4-4. Indian Point-2: U-Bend POD vs. Burst Effective Crack Area

Crack Area = % average depth times length in inches



5.0 U-BEND OPERATIONAL ASSESSMENT SENSITIVITY TO BURST CORRELATION

5.1 Burst Correlation Issue

In an ANO-2/NRC meeting of June 8, 2000, new test results comparing burst pressures following ligament-tearing were compared with standard burst pressure test results obtained using a bladder with high pressurization rates. The burst pressures following ligament-tearing were found to be less than the burst pressures obtained using the industry standard burst pressure test techniques. The results of these tests raise potential questions on the adequacy of partial depth burst pressure correlations relative to adequately representing all flaw geometries. This potential issue is addressed in this section for potential implications on the operational assessment. The Indian Point-2 in situ pressure tests would not be impacted as the tests were pressurized at relatively slow rates with hold times for the more limiting indications having leakage at high pressures. The ANO-2 test results were for a single crack profile. For this profile, the results indicate the possibility that some crack shapes with slow pressurization rates (ligament-tearing tests) may result in lower burst pressures than the data included in industry burst pressure correlations. Fast and slow pressurization rate tests, as described below, have previously been performed for throughwall cracks and uniform depth cracks with no significant differences in the resulting burst pressures. Based on these results, no effects of pressurization rate had been expected, and the ANO-2 test result indicates a potentially "new" phenomenon for industry acceptance. Available time since the June 8 meeting has not permitted additional efforts to understand whether the ANO-2 test results require an industry reassessment of how burst pressure tests are performed. The ANO-2 flaw was about 1.4 inch long with two deep sections separated by a shallow ligament, such that when the shallow ligament tore, the resulting throughwall length did not permit a higher burst pressure than the ligament-tearing pressure. If this test result is confirmed to indicate a pressurization rate influence on burst pressures, it is anticipated to effect only long cracks (likely significantly longer than an acceptable length for a throughwall flaw such as about 0.6 inch for U-bend indications) with highly irregular crack shapes.

The ANO 2 test results do present an anomaly relative to the results of SG tube burst testing that has been performed during the last quarter century. Specific tests have been performed to verify that the testing processes do not result in an artificial increase in the burst pressure from strain-rate effects. However, the issue here is whether there is some other time-dependent phenomenon active when a complex crack profile is involved. The testing database mostly consists of throughwall slits and rectangular shaped profiles for developing analytical models for predicting burst pressure.

During the last 25 years, a large number of burst tests have been performed under a variety of conditions and for a variety of degradation morphologies. The results for a variety of conditions are summarized in the following paragraphs.

Throughwall Cracking

The definitive work in throughwall cracking was performed by Laborelec (Paul Hernalsteen, Reference 8.4) wherein as series of specimens were tested to failure using large plant pumps at the Schelle fossil power plant in Belgium. The tests were performed without benefit of any lining to prevent leakage from the specimens. The pressure was gradually raised until unstable crack extension was attained. The results from those tests over a wide range of crack lengths confirmed the supposition that burst pressures were greater than had been reported by Westinghouse (Reference 8.5) from tests conducted at high rates and using a plastic bladder to prevent leakage prior to crack extension. They also confirmed that burst

pressures were slightly lower than had been reported by others (Reference 8.5), including Laborelec, using that used a metal foil, like stainless steel, to line the plastic bladder to prevent its expulsion through the crack opening.

Other testing performed by Laborelec (Reference 8.4) did confirm that burst pressures could be artificially increased by about 15% by increasing the pressurization rate by three orders of magnitude, say 200 psi/s to 200000 psi/s. Hernalsteen also reported reductions in measured burst pressure by about 5% by decreasing the pressurization rate from say 200 psi/s to 20 psi/sec, but concluded that the result was due to creeping deformation of the liner and foil and crack flanks and not extension of the crack in the tube specimen.

Additional data were reported by EdF (Reference 8.6) for throughwall cracks with lengths of 0.276" (18 & 435 psi/s), 0.591" (18 to 234 psi/s), and 1.18" (17 to >242 psi/s). The results of the tests performed to obtain that data demonstrated that there was no dependence of the burst pressure on the pressurization rate.

Finally, the data reported by the Battelle National Laboratory in Reference 8.7 were obtained at a rate of 30 psi/s. These burst test results are not at variance with data obtained from other test programs at other laboratories, including Westinghouse, Combustion Engineering and Framatome.

Part-Throughwall Cracking

Data for a variety of tube sizes and various depth rectangular notches were reported in Reference 8.7. These data were obtained at pressurization rates of about 30 psi/s and have been used with results from other test programs from other laboratories, including Westinghouse, which typically use significantly higher pressurization rates.

Data for 0.250" long EDM notches from 60 to 90% deep at pressurization rates of "Quasi-steady" to 3200 psi/s indicate no significant dependence on the ligament-tearing pressure for 7/8" diameter by 0.050" thick Alloy 600 MA SG tubes (Reference 8.8).

ODSCC ARC Burst Tests

Burst tests were performed at several different laboratories in three countries, the United States, Belgium and France. Although the testing procedures were different, the test results were similar. Tests performed in the US were at a pressurization rate of about 1500 to 2000 psi/s, while those in France were at a maximum of 500 psi/s and those in Belgium were most likely performed at a rate of about 200 psi/s. The US and Belgian results were quite similar, despite being at the most different pressurization rates, while the French burst test results were uniformly about 425 psi higher on average than the US and Belgian results. The implication is that there is no effect of the pressurization rate.

PWSCC ARC and Other Burst Tests

Testing programs similar to those for ODSCC ARC applications have been conducted at multiple laboratories, e.g., see References 8.9 and 8.10, for PWSCC cracked tubes. The tests were of both laboratory specimens and pulled tube sections. The results from the different laboratories were not discernibly different, implying no noticeable effect of pressurization rate. However, not as much information is known about test differences for PWSCC specimens as for ODSCC specimens.

Leak Rate Tests at SLB Conditions

A substantial body of leak test data at SLB conditions has been obtained with no indications of time dependent ligament-tearing at the associated pressure differential of about 2560 psi. Leak tests are conducted with hold times at pressure ranging from a few minutes to 10 – 20 minutes.

Conclusions

The results from the previous discussions indicate no significant dependence of the burst pressure of SG tubes on pressurization rate for:

1) Throughwall cracks and slits,
2) Part-throughwall cracks and slits,
3) Leak rates at SLB conditions for corrosion cracked specimens,
4) ODSCC ARC specimens, and,
5) PWSCC specimen (although the review here were not as extensive as for the ODSCC specimen data).

From the above available burst test data, the effects seen in the ANO-2 test do not affect most crack geometries. Thus, if found to be a real effect, only a few irregular crack profiles are likely to be affected. Leak test results indicate that the pressurization effects do not occur at pressure differentials seen by the SG tubes under normal operating or design basis accident conditions. The pressurization rate effects are only applicable to the definition of the test conditions required to demonstrate the $3\Delta P_{NO}$ burst margin. The pressurization rate effects become an issue by applying a requirement that the burst margin must be demonstrated under near steady state conditions.

Pending a technical resolution of the ANO-2 test results issue on burst pressure analyses, the potential impact on Indian Point-2 acceptable operating lengths is assessed using bounding assumptions as described in the following section.

5.2 General Considerations on Burst versus Ligament-Tearing Correlation

A database to fully assess the impact of the ANO-2 test results is not currently available. To provide a lower bound impact of these test results, ligament-tearing pressures can be used to define a minimum burst pressure in place of the burst pressure correlation. This approach is applied for the Indian Point-2 assessments of this section. The U-bend operational assessment analyses are performed using the ANL ligament-tearing correlation as a burst pressure correlation. This is a very conservative approach and provides a clear lower bound since it assumes that all flaws would have no increase in burst pressure above the longest ligament-tearing pressure. Even without data, less conservative approximations could be performed. For example, if the resulting ligament-tearing pressure and length would result in a higher burst pressure for a throughwall flaw at the ligament-tearing length, this increase in burst pressure would be a more accurate lower bound burst pressure. However, the most conservative assumption of treating the ligament-tearing pressure from the ANL model as a burst pressure is applied herein.

The ANL ligament-tearing model is taken from Reference 8.3. The basic model is the ligament-tearing pressure for a rectangular flaw is given by,

$$P_t = P_0 \frac{1}{m_p}$$

where P_0 is the non-degraded burst pressure of the tube and m_p is a stress intensity magnification factor or a burst pressure reduction factor. The burst pressure reduction factor, m_p, from the ANL model is,

$$m_p = \frac{1 - \alpha \frac{h}{m}}{1 - h},$$

where h is the relative depth of the crack and α is,

$$\alpha = 1 + \beta h^2 \left(1 - \frac{1}{m}\right),$$

where β is 0.852. The factor m is the reduction factor for a throughwall crack and is given by,

$$m = 0.614 + 0.386 e^{-1.25\lambda} + 0.418\lambda,$$

where λ is the normalized crack length given by,

$$\lambda = \frac{0.9089\, L}{\sqrt{R_m t}},$$

where L is the crack length, R_m is the tube mean radius and t is the tube wall thickness

The non-degraded burst pressure is estimated as,

$$P_0 = 0.595 \left(S_y + S_u\right) \frac{t}{R_m}.$$

The mean relative error of the inverse of m_p was found to be -0.0218 and the relative standard deviation was 0.0849 for 94 data points or 93 degrees of freedom. By relative error, the error term, ε, is,

$$\varepsilon = \frac{\Delta \, 1/m_p}{1/m_p}$$

where the Δ indicates the difference formed by subtracting the estimated value from the true value. Thus, a negative error value means that the estimated value is greater than the true value.

5.3 Single Cycle Analysis Comparisons of Burst Margins for Burst and Ligament-Tearing

The single cycle analysis results reported in other sections of this supplement and in the CMOAs of References 8.1 and 8.2 are based on using a burst pressure correlation to obtain the limiting indication burst pressure distribution for comparison with the $3\Delta P_{NO}$ burst margin requirement. To bound the

ligament-tearing versus burst pressure issue described above, the analyses were repeated using the ANL ligament-tearing model as a burst pressure model. That is, the calculated pressure for ligament-tearing is conservatively assumed to be the burst pressure for the indication.

The results of the single cycle analyses are given in Table 5-1. The table includes results based on the burst pressure correlation, results based on using the ANL ligament-tearing model as a burst correlation, results with and without including uncertainty in the POD distribution, and results using the crack area POD of Section 4. For the U-bend analyses, the operating cycle length evaluation is based on applying analysis results at 95% probability and 95% confidence, which is considerably more conservative than the EPRI SG integrity guidelines (Reference 8.11) requirement of 90/50 confidence levels. The more conservative confidence requirement is applied due to the limited database for the U-bend for growth, NDE uncertainties and POD.

From the Table 5-1 results at 0.45 EFPY, the ligament-tearing model reduces the limiting indication burst pressure by about 450 psi compared to use of the burst pressure correlation. The conservative application of the ligament-tearing model to represent burst pressure at 0.45 EFPY results in a limiting indication burst pressure of 4684 psi which meets the $3\Delta P_{NO} = 4668$ psi burst pressure margin requirement. This represents the most limiting and most conservative assessment of the acceptable operating cycle length for Indian Point-2 Cycle 15. The ligament-tearing model reduces the acceptable cycle length from 1.0 EFPY for the burst correlation to 0.45 EFPY. If the EPRI confidence level requirement of 90/50 is applied rather than the more conservative 95/95 level, the table results show that a full operating cycle length of 1.7 EFPY meets the burst margin requirement even when the ligament-tearing model is applied for burst. Similarly, if the crack area POD of Section 4 is applied to more accurately account for short crack lengths in the POD, a full cycle length of 1.7 EFPY is acceptable with the ligament-tearing model. Shortening the operating cycle length from 0.45 to 0.333 EFPY, increases the burst pressure margin ratio from 1.00 to 1.02 for the ligament-tearing model with POD uncertainty included in the analysis.

5.4 Multi-Cycle Analysis Comparisons of Burst Margins for Burst and Ligament-Tearing

An evaluation was performed to determine the effect of using a more conservative ligament-tearing equation rather than a burst pressure relationship on operational assessment results obtained with the multi-cycle Monte Carlo simulation approach. The multi-cycle approach is to use a semi-empirical ligament-tearing equation developed by Cochet, et. al. that is sometimes referred to as the Framatome equation. Historically this equation has been found to provide conservative calculations compared to burst pressures of Alloy 600 steam generator tubing with axial crack degradation. Over the past several years, a ligament-tearing equation, originally developed by Kiefner et. al. for natural gas pipelines, has been used in structural integrity studies of degraded steam generator tubing at Argonne National Laboratories. This latter equation, now referred to as the ANL equation, represents ligament-tearing and is more conservative than the Cochet equation. The multi-cycle Monte Carlo code was modified to use the ANL ligament-tearing equation. Benchmarking calculations for the large leakage event were repeated followed by operational assessment calculations for Row 3 U-Bends. Similar calculations were made for Row 2 U-Bends since this is a reference case, even though Row 2 U-Bends will not remain in service.

Use of the ANL ligament-tearing equation, instead of the Framatome equation has a larger impact on leakage integrity than structural integrity. For example, in the benchmark case of the large leakage

event at EOC 14, use of the ANL equation increased the calculated probability of burst at NOP for a Row 2 U-bend at EOC 14 from 4% to 5.4% while the probability of large leakage at NOP increased from 8.1% to 26%. The projected consequences of a given degree of degradation are projected to be more adverse with the ANL equation.

When applied in analyses of projected Row 3 U-bend behavior, the ANL equations lead to decreases in projected worst case burst pressures of about 600 psi. The projected 95/95 SLB leak rate remained at 0.00 gpm for an operating cycle length of 1.0 EFPY and beyond. Even with a worst case degraded tube pressure evaluated at the lower 95th percentile, maintenance of a $3\Delta P_{NO}$ structural integrity performance criteria is projected for an operating cycle length beyond 1.0 EFPY.

If projections for Row 2 U-bends are taken as a bounding case for Row 3 behavior in Cycle 15, then use of the ANL equation and a worst case degraded tube pressure evaluated at the lower 95th percentile, maintenance of a $3\Delta P_{NO}$ structural integrity performance criteria is projected for an operating cycle length of about 0.6 EFPY. Results of the multi-cycle analyses for Row 2 at 0.6 EFPY are given in Table 5-2. Projected 95/95 leak rates are 0.00 gpm beyond a cycle length of 1.0 EFPY. It should be noted that the use of the lower 95th percentile worst case burst pressure is more conservative than the EPRI Tube Integrity Assessment Guidelines structural margin goal of 0.08 probability of exceeding $3\Delta P_{NO}$. In the cases of interest to Indian Point, the difference is several hundred psi. At 0.6 EFPY, the calculated $3\Delta P_{NO}$ burst probability is 0.064.

Almost all burst test data at high and low rates of loading show that use of the Framatome equation is conservative. There are no test data on pulled tube or laboratory specimens with axial cracks that show non-conservative results. Use of a more conservative equation for projections of Row 3 behavior demonstrates that required leakage and structural integrity margins would be met for an operating interval length of 1.0 EFPY and more. Additional conservatism generated by considering projected Row 2 behavior as an absolute bound to Row 3 leakage and structural integrity supports an operating interval of 0.6 EFPY when the more conservative ANL ligament-tearing model is applied.

5.5 Conclusions

Currently available test results indicate no significant dependence of the burst pressure of SG tubes on pressurization rate for:

1) Throughwall cracks and slits,
2) Part-throughwall cracks and slits,
3) Leak rates at SLB conditions for corrosion cracked specimens,
4) ODSCC ARC specimens, and,
5) PWSCC specimen

Pressurization effects seen in the ANO-2 test do not affect most crack geometries. Thus, if found to be a real effect, only a few irregular crack profiles are likely to be affected. Leak test results indicate that the pressurization effects do not occur at pressure differentials seen by the SG tubes under normal operating or design basis accident conditions. The pressurization rate effects are only applicable to the definition of the test conditions required to demonstrate the $3\Delta P_{NO}$ burst margin. Since the ASME code requirement for a safety factor of 3 applies to the ultimate tensile stress limit, no time dependence is

required by the code. The pressurization rate effects become an issue only by applying an explicit definition that the burst margin must be demonstrated under quasi-steady state conditions.

Pending a technical resolution of the ANO-2 test results issue on burst pressure analyses, the potential impact on Indian Point-2 acceptable operating lengths is assessed using a lower bound based on applying the ANL ligament model as a burst pressure model. This is equivalent to the conservative assumption that all indications would have burst behavior like the ANO-2 test results. A less conservative application of the ligament-tearing model would be to use ligament-tearing to calculate the throughwall length and then apply a throughwall burst pressure correlation to calculate the resulting burst pressure. This analysis method would significantly increase the burst pressure for U-bend burst effective crack lengths less that about 0.6 inch which envelopes all but one indication found in the 2000 inspection. For example, row 3 U-bend throughwall lengths satisfying the $3\Delta P_{NO}$ requirement are 0.53 inch at 50/50 confidence and 0.46 inch at 95/95 confidence. Consequently, indications resulting in ligament-tearing to $\leq$ 0.46 inch, which would generally be less than the crack length, would satisfy the burst margin requirements.

As expected, the application of a ligament-tearing model in place of a burst pressure model leads to significant reductions in the limiting burst pressures calculated for the operational assessment. The limiting burst pressures calculated for the U-bend using the ANL ligament-tearing model are about 450 psi lower than obtained from a burst pressure correlation. This results in a reduction of the operating cycle length at 95/95 confidence levels from 1.0 EFPY for the burst correlation to 0.45 EFPY when applying ligament-tearing as a lower bound for the burst pressure. This 0.45 EFPY result conservatively combines the lower bound ligament-tearing model, 95/95 confidence levels rather than the EPRI guideline requirement of 90/50 and applies the lower bound depth based POD rather than the crack area POD which more correctly accounts for the more limited detection of short cracks. If either 90/50 confidence levels or the crack area POD are applied in the evaluation, a full cycle operating length of 1.7 EFPY satisfies the $3\Delta P_{NO}$ burst margin requirement. Shortening the cycle length from 0.45 to 0.333 EFPY for the ligament-tearing model at 95/95 confidence results in an increase in the burst pressure margin ration from 1.00 to 1.02.

Table 5-1. Indian Point-2 Cycle 15 U-Bend Burst Correlation Sensitivity Analyses (400 kHz Profiles) for Projected Burst Pressures and Leak Rate[1] Results for the Limiting SG 24
Assumes Row 3 Indications Same as Detected Row 2 Indications

EFPY	Burst Correlation	POD	Limiting Burst Pressure (psi)	Burst Pressure Margin Ratio[2]	SLB Leak Rate (gpm)	SLB Burst Probability	$3\Delta P_{NO}$ Burst Probability
95% Probability/95% Confidence							
1.7	Burst	Crack Area POD with Uncertainty	5093	1.09	0.0	5.51×10^{-3}	3.43×10^{-2}
1.7	Lig. Tearing	Crack Area POD with Uncertainty	4674	1.00	0.0	6.63×10^{-3}	5.47×10^{-2}
1.0	Burst	Ref. with Unc. [3]	4800	1.03	0.0	4.18×10^{-3}	4.27×10^{-2}
0.45	Burst	Reference	5196	1.11	0.0	2.51×10^{-3}	2.60×10^{-2}
0.45	Burst	Ref. with Unc. [3]	5125	1.10	0.0	3.21×10^{-3}	2.86×10^{-2}
0.45	Lig. Tearing	Reference	4741	1.02	0.0	3.46×10^{-3}	4.49×10^{-2}
0.45	Lig. Tearing	Ref. with Unc. [3]	4684	1.00	0.0	4.93×10^{-3}	4.83×10^{-2}
0.45	Burst	Crack Area POD with Uncertainty	5796	1.24	0.0	1.08×10^{-4}	1.16×10^{-2}
0.45	Lig. Tearing	Crack Area POD with Uncertainty	5357	1.15	0.0	1.08×10^{-4}	2.30×10^{-2}
0.333	Burst	Reference	5253	1.13	0.0	2.51×10^{-3}	2.43×10^{-2}
0.333	Burst	Ref. with Unc.[3]	5201	1.11	0.0	3.00×10^{-3}	2.61×10^{-2}
0.333	Lig. Tearing	Reference	4806	1.03	0.0	3.95×10^{-3}	4.16×10^{-2}
0.333	Lig. Tearing	Ref. with Unc. [3]	4758	1.02	0.0	4.79×10^{-3}	4.44×10^{-2}
0.333	Burst	Crack Area POD with Uncertainty	5856	1.25	0.0	1.08×10^{-4}	1.11×10^{-2}
0.333	Lig. Tearing	Crack Area POD with Uncertainty	5450	1.17	0.0	6.30×10^{-5}	2.00×10^{-2}
90% Probability/50% Confidence							
1.7	Burst	Ref. with Unc. [3]	5219	1.12	0.0	5.23×10^{-3}	6.32×10^{-2}
1.7	Lig. Tearing	Ref. with Unc. [3]	4732	1.01	0.0	7.10×10^{-3}	9.91×10^{-2}
0.45	Burst	Ref. with Unc. [3]	5909	1.27	0.0	2.94×10^{-3}	2.81×10^{-2}
0.45	Lig. Tearing	Ref. with Unc. [3]	5419	1.16	0.0	4.58×10^{-3}	4.80×10^{-2}
0.45	Burst	Crack Area POD with Uncertainty	6860	1.47	0.0	1.68×10^{-5}	1.16×10^{-2}
0.45	Lig. Tearing	Crack Area POD with Uncertainty	6530	1.40	0.0	3.00×10^{-5}	2.25×10^{-2}
0.333	Burst	Ref. with Unc.[3]	5980	1.28	0.0	2.76×10^{-3}	2.57×10^{-2}
0.333	Lig. Tearing	Ref. with Unc. [3]	5491	1.18	0.0	4.47×10^{-3}	4.41×10^{-2}
0.333	Burst	Crack Area POD with Uncertainty	6940	1.49	0.0	1.00×10^{-5}	1.17×10^{-2}

Table 5-1. Indian Point-2 Cycle 15 U-Bend Burst Correlation Sensitivity Analyses (400 kHz Profiles) for Projected Burst Pressures and Leak Rate[1] Results for the Limiting SG 24

Assumes Row 3 Indications Same as Detected Row 2 Indications

EFPY	Burst Correlation	POD	Limiting Burst Pressure (psi)	Burst Pressure Margin Ratio[2]	SLB Leak Rate (gpm)	SLB Burst Probability	$3\Delta P_{NO}$ Burst Probability
0.333	Lig. Tearing	Crack Area POD with Uncertainty	6934	1.49	0.0	3.67×10^{-3}	1.71×10^{-2}

1. Acceptance criteria: $3\Delta P_{NO}$ = 4668 psi at operating temperature, SLB leak rate = 1 gpm summed over all degradation mechanisms. Burst probability guidelines: $\Delta P_{SLB} = 4 \times 10^{-2}$, $3\Delta P_{NO} = 8 \times 10^{-2}$ summed for all degradation mechanisms in limiting SG.
2. Ratio of Calculated Limiting Burst Pressure to $3\Delta P_{NO}$ = 4668 psi acceptance criteria.
3. Uncertainties on the POD included in the Monte Carlo analyses.

Table 5-2. Indian Point-2 Multi-Cycle Analysis Summary of Projected Row 2 Structural and Leakage Integrity Figures of Merit for Cycle 15 Operation(1)

Parameter	Reference Input 1.0 EFPY Operating Interval Framatome Equation	Reference Input 0.6 EFPY Operating Interval ANL Equation
Probability of Burst at Normal Operation	0.08%	0.14%
Probability of Large Leakage at Normal Operation	0.26%	0.65%
Probability of Burst at Steam Line Break	0.45%	0.69%
Probability of Large Leakage at Steam Line Break	0.93%	-
Probability of Burst at 3 Times Operating Pressure, 3ΔP	5.8%	6.4%
Probability of Large Leakage During In Situ Testing	7.8%	-
Median Minimum Degraded Tube Burst Pressure, psi	7047	6650
95th Percentile Minimum Degraded Tube Burst Pressure, psi	4661	4600
Chance of More Than 1 Burst at 3ΔP	nil(2)	nil

1. Acceptance criteria: $3\Delta P_{NO}$ = 4668 psi at operating temperature, SLB leak rate = 1 gpm/SG summed over all degradation mechanisms. Burst probability guidelines: $\Delta P_{SLB} = 4x10^{-2}$, $3\Delta P_{NO} = 8x10^{-2}$ summed for all degradation mechanisms in limiting SG.
2. nil = no occurrences in 10,000 simulations

6.0 SLUDGE PILE OPERATIONAL ASSESSMENT SENSITIVITY TO CYCLE LENGTH

6.1 Evaluation of 0.333 EFPY Cycle Length

As discussed in Section 3.1, the Indian Point-2 commitment to initiate SG replacement by late 2000 could shorten the Cycle 15 operating cycle length until replacement to as short as four months or 0.333 EFPY. This section assesses burst pressure margin ratios of the limiting indication burst pressure to the $3\Delta P_{NO}$ requirement as a function of cycle length including a short 0.333 EFPY cycle length. The sludge pile CMOA analyses of Reference 8.2 evaluated sensitivity to POD uncertainties by applying a 5% depth shift in the POD as an estimated worst case decrease in the POD. Sensitivity calculations are also included in this section for POD uncertainty by including the uncertainties in the POD correlation directly in the Monte Carlo operational assessment analyses.

6.2 Comparisons of Burst Margins for 0.85 EFPY and 0.333 EFPY Cycle Lengths

Table 6-1 provides sensitivity of the sludge pile operational assessment burst pressure margins to cycle lengths as short as 0.333 EFPY (4 months). These tables are an extension of the reference analysis tables in the CMOA (Reference 8.2) to include 0.333 EFPY. Margins are provided as the ratio of the limiting indication burst pressure to the $3\Delta P_{NO}$ margin requirement of 4668 psi. At the required 90/50 confidence level, the burst pressure margin increases from 1.12 to 1.27 based upon decreasing the cycle length from 1.70 to 0.333 EFPY. At the more conservative 95/95 confidence level, the burst pressure margin increases from about 1.0 to 1.17 upon decreasing the cycle length from 1.7 to 0.333 EFPY.

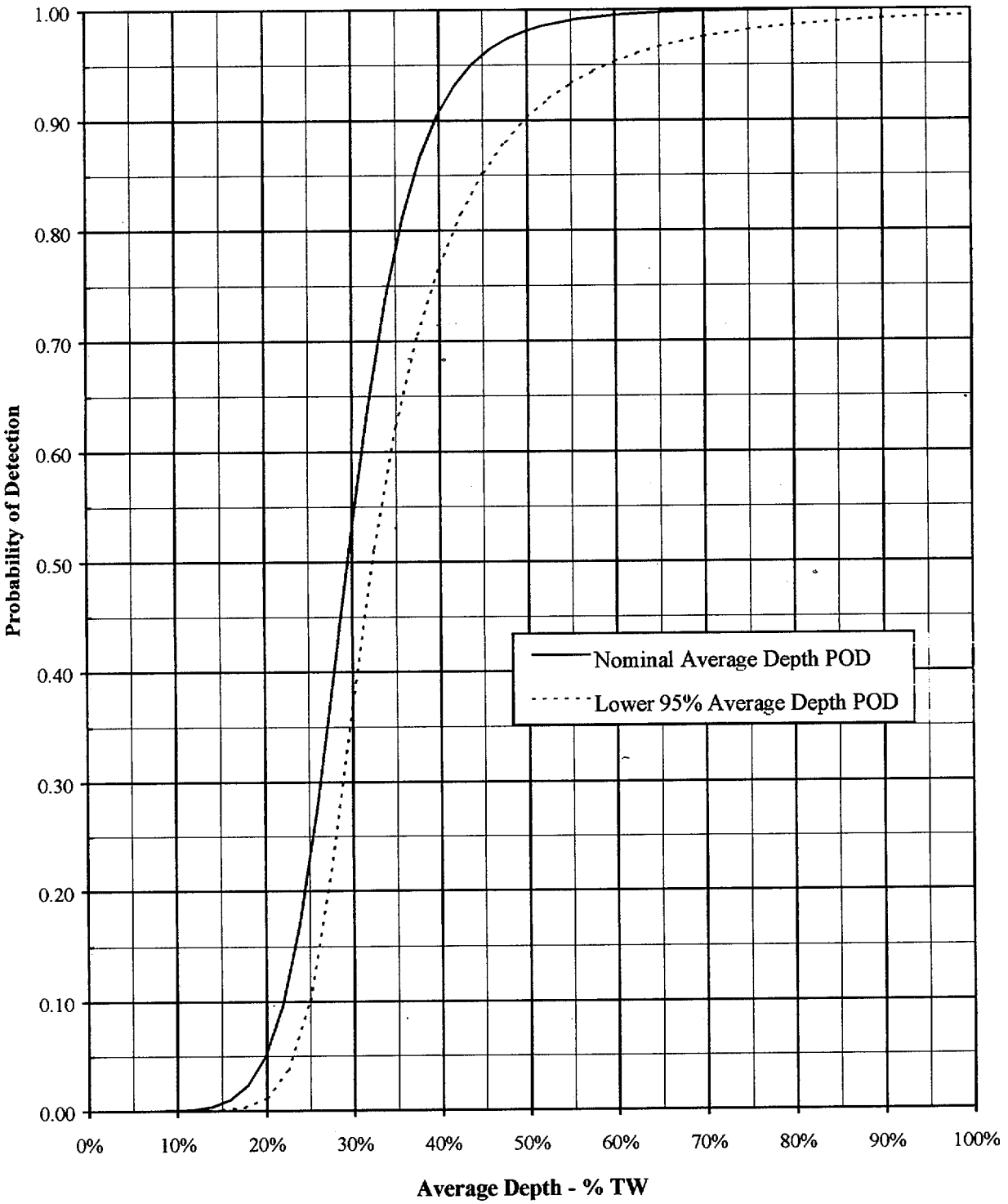
The sludge pile CMOA analyses of Reference 8.2 assess sensitivity to uncertainty in the POD distribution as a 5% depth shift from the reference POD distribution. This was intended as a conservative assessment of the POD uncertainty. The POD uncertainty influence on the limiting burst pressure can be more accurately obtained by directly incorporating the POD uncertainty in the Monte Carlo analyses as performed in this assessment. The magnitude of the POD uncertainty on the POD distribution can be seen in Figure 6-1, which shows the nominal POD used in Reference 8.2 and the lower 95% confidence on the POD distribution. It is seen that the lower 95% confidence is about a 3% shift in the POD at < 30% depth and increases to about a 10% shift at 50% depth. Since the Monte Carlo analysis samples the total distribution, the effect of POD uncertainty on the limiting burst pressures can be expected to be lower than obtained from the 5% shift sensitivity study. From Table 6-1, it is seen that the absolute shift in the nominal POD by 5% at 0.333 EFPY results in a decrease in the limiting burst pressure by almost 300 psi at 95/95 confidence. The statistical treatment of the POD uncertainty in the Monte Carlo analysis at 0.333 EFPY reduces the limiting burst pressure by about 150 psi at 90/50 confidence and about 215 psi at 95/95 confidence. As expected, the statistical treatment of POD uncertainties reduces the POD sensitivity compared to the more conservative 5% shift in the POD. Additional analyses addressing the sensitivity to POD uncertainties are included in Section 7.

Table 6-1. Indian Point-2 Cycle 15 Sludge Pile Length Sensitivity Analyses for Projected Burst Pressure and Leak Rate[1] Results for the Limiting SG 22

Operating EFPY	POD	Limiting Burst Pressure (psi)	Burst Pressure Margin Ratio[2]	SLB Leak Rate (gpm)	SLB Burst Probability	$3\Delta P_{NO}$ Burst Probability
90% Probability/50% Confidence						
1.7	Reference	5240	1.12	0.0	1.06×10^{-3}	7.86×10^{-2}
0.333	Reference	5940	1.27	0.0	2.50×10^{-4}	2.94×10^{-2}
0.333	Reference[3]	5786	1.24	0.0	3.37×10^{-4}	2.18×10^{-2}
95% Probability/95% Confidence						
1.7	Reference	4661	0.998	0.0	1.29×10^{-3}	8.07×10^{-2}
1.0	Reference	5093	1.09	0.0	3.49×10^{-4}	3.06×10^{-2}
0.333	Reference	5447	1.17	0.0	1.94×10^{-4}	1.38×10^{-2}
0.333	Reference[3]	5231	1.12	0.0	4.53×10^{-4}	2.30×10^{-2}
0.333	POD Shift	5151	1.10	0.0	2.79×10^{-4}	3.28×10^{-2}
0.333	POD Shift by -5%	5951	1.27	0.0	1.18×10^{-4}	6.55×10^{-3}

1. Acceptance criteria: $3\Delta P_{NO}$ = 4668 psi at operating temperature, SLB leak rate = 1 gpm summed over all degradation mechanisms. Burst probability guidelines: $\Delta P_{SLB} = 4\text{x}10^{-2}$, $3\Delta P_{NO} = 8\text{x}10^{-2}$ summed for all degradation mechanisms in limiting SG.
2. Ratio of Calculated Limiting Burst Pressure to $3\Delta P_{NO}$ = 4668 psi acceptance criteria.
3. Uncertainties on the POD included in the Monte Carlo analyses.

Figure 6-1. Indian Point-2 Comparison of Nominal and Lower 95% Sludge Pile PODs for Average Depth, +Point Detection



7.0 SLUDGE PILE OPERATIONAL ASSESSMENT SENSITIVITY TO BURST CORRELATION

The current applicability of the burst pressure correlation, given recent test results reported for an ANO-2 indication, has been discussed in Section 5 for U-bend indications. As a lower bound estimate of the limiting indication burst pressure for this issue, the ANL ligament-tearing correlation is applied as a burst correlation as described in Section 5.2. The same conservative analysis approach is applied to the sludge pile indications in this section.

7.1 Single Cycle Analysis Comparisons of Burst Margins for Burst and Ligament-tearing

The results of the analyses comparing EOC burst pressures for burst based on the burst pressure correlation and for the conservative assumption that ligament-tearing represents burst are given in Table 7-1. The analyses include calculations for the reference POD used in the sludge pile CMOA analyses of Reference 8.2 and with the uncertainty in POD included in the analyses. For the burst pressure correlation, the effect of including POD uncertainties is a reduction in the burst pressure of about 225 psi. For ligament-tearing, the effect of including POD uncertainties is about 230 psi.

For the sludge pile indications, the reference analyses for establishing an acceptable operating cycle length are based on the EPRI SG integrity guideline requirements for 90% probability and 50% confidence. The available database for growth, NDE uncertainties and POD, as described in Reference 8.2, supports application of the EPRI confidence levels for the operational assessment. From Table 7-1, the $3\Delta P_{NO}$ burst margin requirement is satisfied for the limiting indication at 90/50 confidence for full cycle operation of 1.7 EFPY including the conservative use of the ligament-tearing model to represent burst. The burst pressure margins increase substantially for the shorter operating cycles planned for Cycle 15.

The influence of applying the higher 95/95 confidence levels is to reduce the EOC burst pressure by about 550 psi. When these more conservative confidence levels are applied, the burst margin requirement is satisfied with the ligament-tearing model at 0.75 EFPY.

The effect of using ligament-tearing for burst rather than the burst correlation is to reduce the EOC burst pressure by about 335 to 380 psi dependent upon cycle length and confidence level.

7.2 Conclusions

Based on the adequacy of the sludge pile database for growth, NDE uncertainties and POD, the EPRI SG integrity guidelines for applying 90% probability at 50% confidence can be applied for the CMOA analyses. At 90/50 confidence, the $3\Delta P_{NO}$ burst margin requirement is satisfied for the limiting indication at full cycle operation of 1.7 EFPY including the conservative use of the ligament-tearing model to represent burst. For more conservative 95/95 confidence levels, the $3\Delta P_{NO}$ burst margin requirement is satisfied at 1.0 EFPY for the ligament-tearing model representing burst and at about 1.0 EFPY when the burst correlation is applied. The effect of using ligament-tearing for burst rather than the burst correlation is to reduce the EOC burst pressure by about 335 to 380 psi dependent upon cycle length and confidence level.

Table 7-1. Indian Point-2 Cycle 15 Sludge Pile Burst Correlation Sensitivity Analyses for Projected Burst Pressures and Leak Rates[1] for the Limiting SG 22

Assumes Row 3 Indications Same as Detected Row 2 Indications

EFPY	Burst Correlation	POD	Limiting Burst Pressure (psi)	Burst Pressure Margin Ratio[2]	SLB Leak Rate (gpm)	SLB Burst Probability	$3\Delta P_{NO}$ Burst Probability
90% Probability/50% Confidence							
1.7	Burst	Ref. with Unc. [3]	5023	1.08	0.0	2.13×10^{-3}	9.75×10^{-2}
1.7	Lig. Tearing	Ref. with Unc. [3]	4682	1.00	0.0	3.53×10^{-3}	1.4×10^{-1}
0.75	Burst	Ref. with Unc. [3]	5571	1.19	0.0	6.45×10^{-4}	3.23×10^{-2}
0.75	Lig. Tearing	Ref. with Unc. [3]	5201	1.11	0.0	1.14×10^{-3}	5.37×10^{-2}
0.333	Burst	Ref. with Unc. [3]	5786	1.24	0.0	3.37×10^{-4}	2.15×10^{-2}
0.333	Lig. Tearing	Ref. with Unc. [3]	5405	1.16	0.0	1.02×10^{-3}	3.75×10^{-2}
95% Probability/95% Confidence							
1.0	Burst	Ref. with Unc. [3]	4866	1.04	0.0	1.00×10^{-3}	4.40×10^{-2}
0.75	Burst	Reference	5230	1.12	0.0	1.70×10^{-4}	2.20×10^{-2}
0.75	Burst	Ref. with Unc. [3]	5015	1.07	0.0	7.88×10^{-4}	3.35×10^{-2}
0.75	Lig. Tearing	Reference	4907	1.05	0.0	5.54×10^{-4}	3.79×10^{-2}
0.75	Lig. Tearing	Ref. with Unc. [3]	4669	1.00	0.0	1.63×10^{-3}	5.50×10^{-2}
0.333	Burst	Reference	5447	1.17	0.0	1.70×10^{-4}	1.28×10^{-2}
0.333	Burst	Ref. with Unc. [3]	5231	1.12	0.0	4.53×10^{-4}	2.36×10^{-2}
0.333	Lig. Tearing	Reference	5127	1.10	0.0	4.41×10^{-4}	2.31×10^{-2}
0.333	Lig. Tearing	Ref. with Unc. [3]	4896	1.05	0.0	1.18×10^{-3}	3.85×10^{-2}

1. Acceptance criteria: $3\Delta P_{NO}$ = 4668 psi at operating temperature, SLB leak rate = 1 gpm/SG summed over all degradation mechanisms. Burst probability guidelines: $\Delta P_{SLB} = 4\times10^{-2}$, $3\Delta P_{NO} = 8\times10^{-2}$ summed for all degradation mechanisms in limiting SG.
2. Ratio of Calculated Limiting Burst Pressure to $3\Delta P_{NO}$ = 4668 psi acceptance criteria.
3. Uncertainties on the POD included in the Monte Carlo analyses.

8.0 REFERENCES

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