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July 27, 2000

Re: Indian Point Unit No. 2
Docket No. 50-247
NL-00-099

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

Subject: Responses to the NRC's Request For Additional Information Regarding Steam Generator Operational Assessment Report (TAC No. MA9288)

Reference: 1) USNRC Letter to A. A. Blind from J. A. Zwolinski, "Staff Concerns and Request for Additional Information Regarding the Steam Generator Operational Assessment, Indian Point Nuclear Generating Unit No. 2 (TAC No. MA9288)," dated July 20, 2000.

Pursuant to 10 CFR 50.54(f), Consolidated Edison Company of New York, Inc. (Con Edison) hereby provides responses to Questions 1, 2, 3, 4, 5 and 6 of the Staff's Request for Additional Information (RAI) identified within the Reference 1.

These responses continue to demonstrate that very conservative approaches have been taken in the Condition Monitoring and Operational Assessment (CMOA) Report submitted on June 2, 2000 and the supplement to the CMOA Report submitted on July 7, 2000. In particular, we emphasize that a very conservative underlying approach for the development of this operational assessment has been employed, in that row 3 has been analyzed as if the indications detected in row 2 had been detected in row 3. In fact, no indications were detected in row 3 at Indian Point 2, nor were they expected. Analysis and experimental data have shown that the maximum stresses imposed in row 3 are smaller than that of row 2, and the degree of maximum strain in row 3 is also less than that imposed in row 2. As described in previous submittals, our analysis of the existing stresses on the U-bends in row 3, our understanding of the material properties of the tubes in row 3, and the contribution of stress to primary water stress corrosion cracking, clearly provide the basis for our conclusion that there

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should be no primary water stress corrosion cracks in row 3. In addition, industry experience has been that the number of flaws detected in row 3 is significantly reduced from that of row 2 which is, in turn, reduced from that of row 1. Hence, this approach is very conservative. Even with this approach, an operating cycle equivalent to 0.85 EFPY has been demonstrated, which is in excess of that required to reach the steam generator replacement outage planned to begin before the end of the current year.

The attached responses to the RAIs also include requested sensitivity studies. These sensitivity studies for the requested 5% shift in depth or 50% shift in area correspond to a deterministic confidence level of about 95%. The requested sensitivity studies employing the 10% shift in depth or 100% shift in area are equivalent to a 99% confidence level, which is far in excess of that discussed in NEI-97-06 or in DG-1074.

It should also be noted that new NDE techniques involving the use of a 800 kHz probe were developed and employed, for the first time in the industry, to improve the signal to noise ratio in the low row U-bends. The use of this technique substantially enhanced the ability to detect defects such as primary water stress corrosion cracks. This new technology provided a significant improvement over the equipment and techniques that were available in 1997. Even though there was substantial evidence that the new techniques increased detectability in row 2, this improved technique did not detect any indications in row 3. In addition, tubes without detectable degradation in both row 2 and row 3 were subjected to in-situ testing and met the performance criteria, thereby providing additional assurance that there are no undetected flaws of sufficient magnitude to challenge the accepted industry performance criteria. In summary, the previously submitted CMOA and supplement, as well as the attached responses to the RAIs, continue to support the conclusion that the Indian Point 2 steam generators are safe to operate for the requested operating period.

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

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

Sincerely,

Attachment

C: Mr. Hubert J. Miller
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ATTACHMENT

RESPONSES TO THE RAI QUESTIONS FROM NRC LETTER DATED JULY 20, 2000

CONSOLIDATED EDISON COMPANY OF NEW YORK, INC.
INDIAN POINT UNIT NO. 2
DOCKET NO. 50-247
JULY 2000

NRC RAI Letter dated July 20, 2000

Question 1

The July 7, 2000, submittal from Consolidated Edison Company of New York, Inc. (the licensee) refers to the consideration of an uncertainty distribution that was applied to the depth-based and area-based probability of detection (POD) curves for the low row U-bends. Confirm whether the staff's understanding is correct that the assumed uncertainty distribution refers to the full uncertainty range of the nominal fit to the data. Provide a chart illustrating the 95 percent confidence bounds on the nominal POD fit to the crack area data (similar to that done in Figure 6-1 for the nominal fit to average crack depth).

Reply

The staff's understanding is correct that the POD uncertainty distributions presented in the July 7 submittal represent the full uncertainty range of the nominal fit to the data. The calculations given in the submittal and identified as POD with uncertainty include Monte Carlo sampling of the POD uncertainty distribution in the analyses. These calculations process the POD uncertainties with the same Monte Carlo sampling process as applied for other parameters (NDE uncertainties, growth, burst correlation, etc.) that have defined distributions. Inclusion of POD uncertainties in the analyses provides a consistent and correct basis for determining the POD uncertainty effects on the limiting indication burst pressure.

Figure RAI-1-1 provides the requested plot of the nominal and lower 95% confidence POD fit to the crack area data. The plot also includes the lower 99% confidence POD curve. The lower 99% confidence curve is included to permit comparisons of a defined confidence level with the Question 3 request to provide sensitivity analyses for a 50% and 100% shifts of the nominal crack area based POD function.

However, it should be noted that:

1) The use of the 800 kHz plus point probe provided the state of the art detection capability for indications in rows 2, 3 and 4;

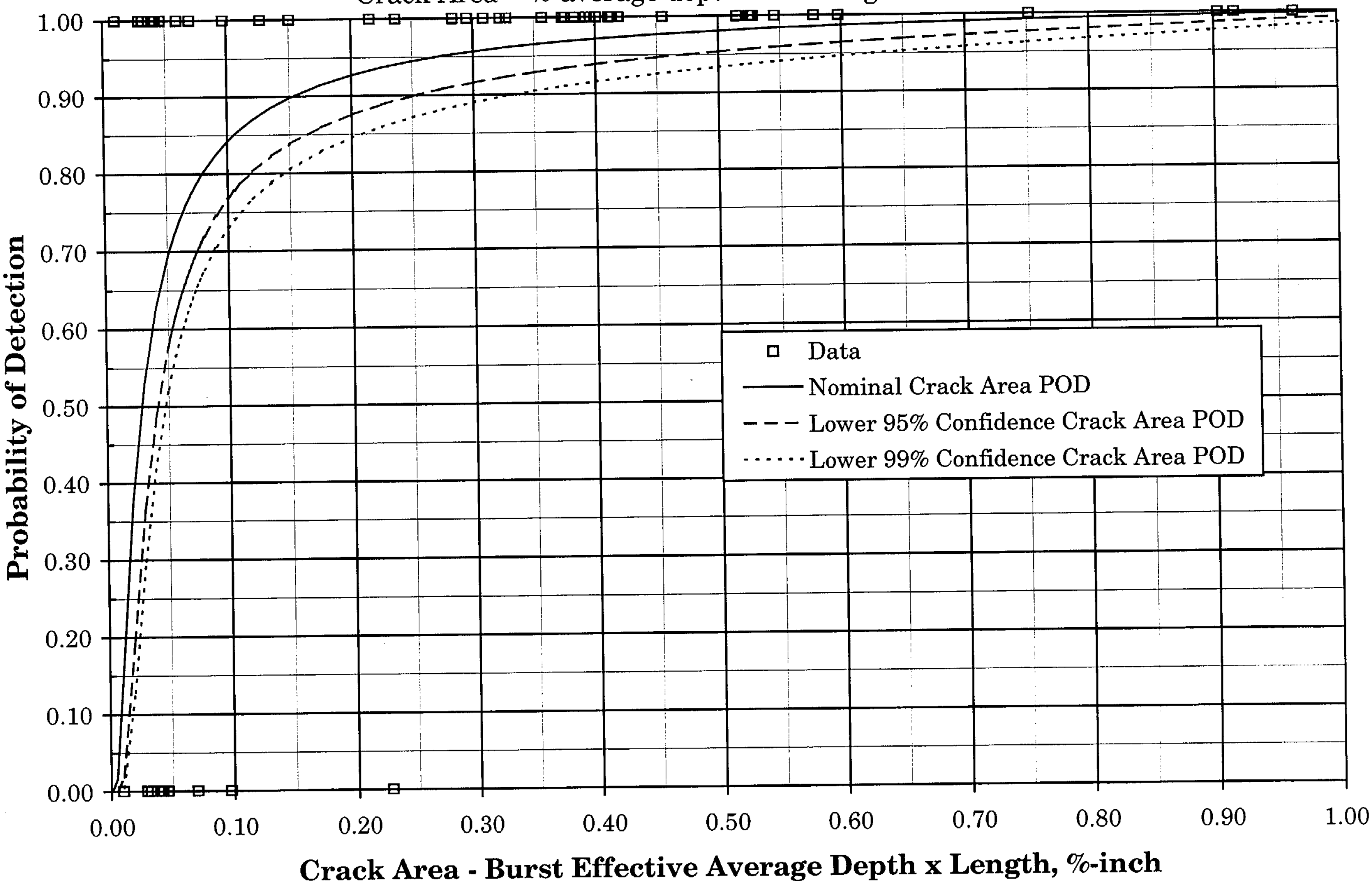
2) All the row 2 tubes have been plugged and are out of service, but the Operational Assessment assumed that row 2 indications occurred in row 3 and were repaired to provide a conservative bounding analysis on when the next inspection must be performed; and

3) The 800 kHz probe detected no indications in any row 3 tube. This is consistent with industry experience.

The combination of having no indications in row 3 while assuming the row 2 indications occurred in row 3 provides a highly conservative model as the basis for the CMOA analyses.

Figure RAI-1-1. Indian Point-2: POD vs. Burst Effective Crack Area Nominal, Lower 95% and Lower 99% Confidence Levels

Crack Area = % average depth times length in inches)



NRC RAI Letter dated July 20, 2000

Question 2

In its June 2, 2000 submittal, the licensee had previously provided the analysis sensitivity results for an assumed +5% shift of the depth-based POD in terms of percent through-wall. What is the sensitivity of the June 2 analysis to a 10% shift?

Reply

The 5% and 10% shifts in the nominal depth-based POD function are obtained by adding 5% and 10% average depth to the nominal depth at each POD value. This provides a lateral shift in the POD by 5% and 10% depth to more conservative POD functions. In Figure RAI-2-1, the nominal and shifted PODs are compared with the average depth POD uncertainty distribution evaluated at the lower 95% and lower 99% confidence levels. The POD with a 5% depth shift is in good agreement (about 1 to 2% in POD higher above 45% depth) with the POD evaluated at the lower 95% confidence level. However, including this POD in the Monte Carlo analyses is equivalent to deterministically applying the lower 95% POD for all indications. This practice is much more conservative than the required evaluation of the burst distribution at a 95/95 confidence level including POD uncertainties in the analysis. The POD with a 10% average depth shift is more conservative than the POD at the lower 99% confidence level for crack depths less than 50% and slightly less conservative (1 to 2% on POD) for crack depths above 55%. It should be noted that analyses at 99% or greater confidence levels are unprecedented in the level of conservatism (statistical 99% and even more conservative for deterministic 99% POD applications) for SG tube integrity analyses by any existing NRC or EPRI or other industry guidelines. As a result, such analyses are not considered applicable or necessary for assessing the Indian Point-2 acceptable operating cycle length.

The Monte Carlo results for the case with a 10% shift in the POD distribution are shown in Table RAI-2-1 along with the corresponding results for the reference POD distribution (depth-based) and the distribution with a 5% shift. The reference POD and 5% shift results are the same as given in Table 9-3 of the June 2 submittal for the limiting SG (SG-24) and an operating period of 1 year. The reduction in burst pressure at 95/95 confidence due to increasing the POD shift from 5% to 10% is nearly the same (about 350 psi) as for the case with 5% shift from the reference distribution; i.e., shifting the POD distribution beyond 5% towards larger depths does not result in a more rapid change in burst pressure. The larger burst pressure reductions for the deterministic POD shifts of 5% and 10% are much larger than the relatively small 40 psi reduction obtained by treating the POD uncertainty statistically in the Monte Carlo analyses and evaluating the combined burst pressure distribution at 95/95 confidence. As noted above, the results presented for the case with the deterministic 10% shift in the POD distribution results in applying the POD at more than a deterministic 99% confidence level. This is well beyond the scope required to determine a reasonably justifiable inspection interval.

Table RAI 2-1

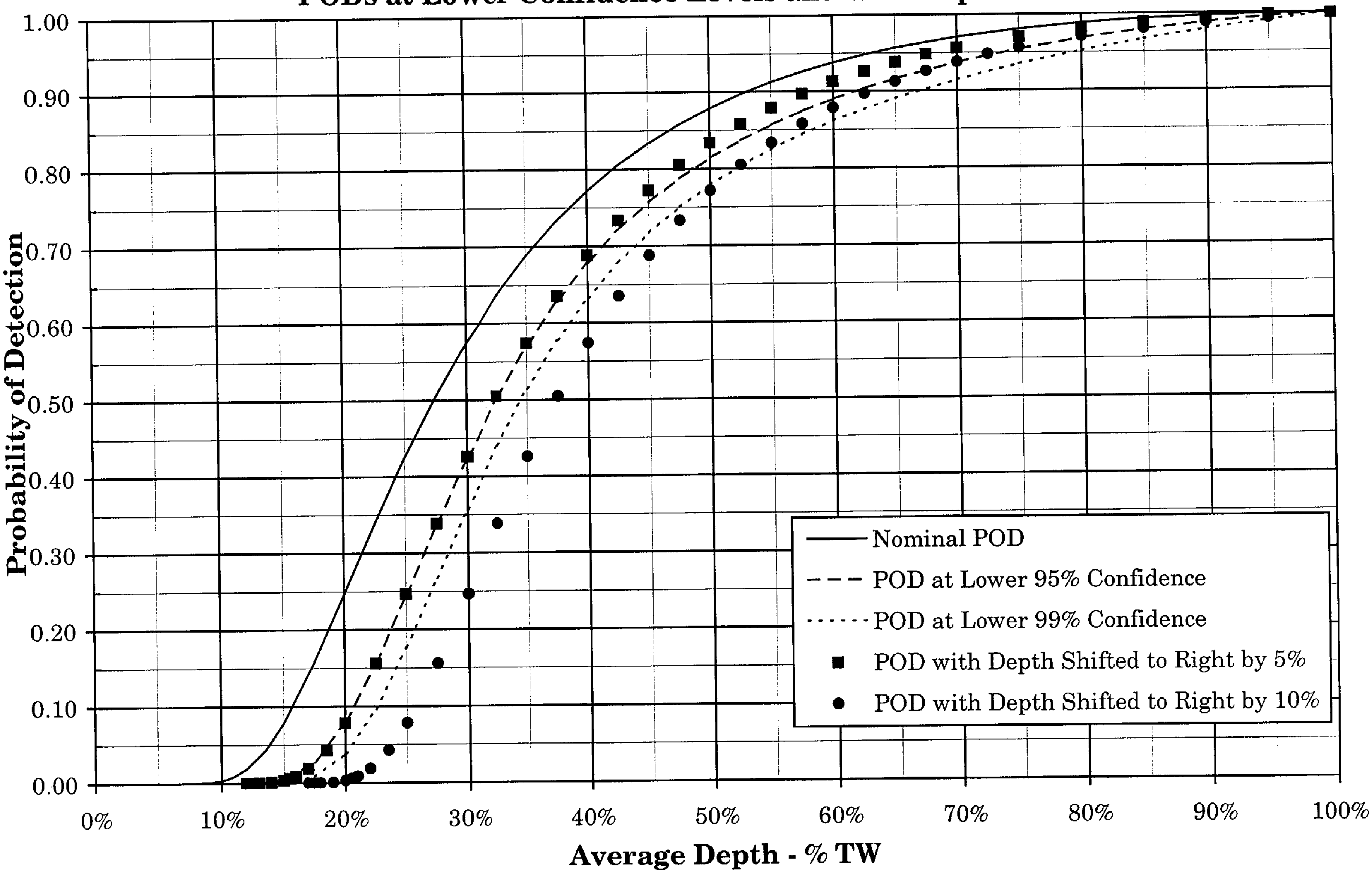
Indian Point-2 Cycle 15 SG Depth-Based POD Sensitivity Analyses Projected Burst Pressures and Leak Rate[1] for the Limiting SG 24 - 400 kHz Profiles

Operating EFPY	POD	Limiting Burst Pressure (psi)	SLB Leak Rate (gpm)	SLB Burst Probability	$3\Delta P_{NO}$ Burst Probability
1.0	Reference Depth-Based POD Distribution	4840	0.0	3.23×10^{-3}	4.10×10^{-2}
	Reference POD with Uncertainty	4800	0.0	4.18×10^{-3}	4.27×10^{-2}
	POD Shift +5%	4496	0.0	6.35×10^{-3}	6.01×10^{-2}
	POD Shift +10%	4137	0.0	1.08×10^{-2}	8.96×10^{-2}

Note:

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.

Figure RAI-2-1. Indian Point-2: POD vs. Average Crack Depth Including PODs at Lower Confidence Levels and with Depth Shifts



NRC RAI Letter dated July 20, 2000

Question 3

In its July 7 submittal, the licensee did not describe the sensitivity of the supplemental analysis results to a shift in the nominal crack area-based POD function. Provide the sensitivity of the analysis results to a 50% and 100% shift of the nominal area-based POD function in terms of crack area for a given POD value.

Reply

The July 7 submittal did not separately portray sensitivity of the analyses to a shift in the nominal crack area-based POD function since the POD uncertainties were directly imbedded in the Monte Carlo analyses. The June 2 submittal did not include the POD uncertainty distribution directly in the analyses; alternatively, a POD shift of 5% (equivalent to about a 95% confidence level on the POD as noted in the Question 2 response) was applied to demonstrate sensitivity to POD uncertainty. However, the requested sensitivity analyses are included below in this question response.

The 50% and 100% shifts in the nominal area-based POD function are obtained by multiplying the nominal area at each POD value by factors of 1.5 and 2.0, respectively. This provides a lateral shift in the POD conceptually similar to that for the 5% and 10% shifts in the POD for Question 2 above. In Figure RAI-3-1, the nominal and shifted PODs are compared with the POD uncertainty distribution evaluated at the lower 95% and lower 99% confidence levels. The crack area POD with a 1.5 factor shift is in good agreement (1% on POD) with the POD evaluated at the lower 95% confidence level.

Just as with question 2, including this POD in the Monte Carlo analyses is equivalent to deterministically applying the lower 95% POD for all indications. This practice is much more conservative than the required evaluation of the burst distribution at 95/95 including POD uncertainties in the analysis.

The crack area POD with a 2.0 factor shift is more conservative than the POD at the lower 99% confidence level for crack areas less than 0.25 and slightly less conservative (1 to 2% on POD) for crack areas above 0.25. The row 2 indications found in the year 2000 inspection have crack areas of 0.03 to 0.14 %-inch for the 8 smaller indications and 0.29 to 0.46 %-inch for the 3 largest indications. Analyses at 99% or greater confidence levels are unprecedented in the level of conservatism for SG tube integrity analyses required by any NRC or EPRI guidelines, and are not considered appropriate for assessing the Indian Point-2 acceptable operating cycle length.

Leak and burst results based on the crack area POD distribution shifted by factors of 1.5 and 2 are shown in Table RAI-3-1 along with the corresponding results for the reference crack area POD distribution. The results shown are for the limiting SG (SG-24) and are based on an operating period of 0.85 EFPY. As noted above, the POD distribution with a 1.5 factor shift is a good approximation to the distribution at the lower 95% confidence level and the distribution with a 2.0 factor shift is comparable to the distribution at the lower 99% confidence level. The burst pressure reduction from the statistical treatment of uncertainties in the Monte Carlo analyses is about 240 psi, whereas the conservative shift in the crack area POD by a deterministic 1.5 factor results in a burst pressure decrease of about 640 psi. This difference demonstrates the significance of correctly including the POD uncertainty distribution directly in the Monte Carlo analyses. The 95/95 limiting burst pressures for both the 1.5 and 2.0 deterministic factors still meet the $3\Delta P_{NO}$ limit of 4668 psi. Burst probabilities at SLB and $3\Delta P_{NO}$ conditions are also within the recommended limits for both sensitivity cases. As noted above, the distribution with a 2.0 factor shift is not realistic and does not contribute to meaningful SG integrity evaluations.

Table RAI 3-1

Indian Point-2 Cycle 15 U-Bend Crack Area POD Sensitivity Analyses Projected Burst Pressures and Leak Rate[(1)] for the Limiting SG 24 - 400 kHz Profiles

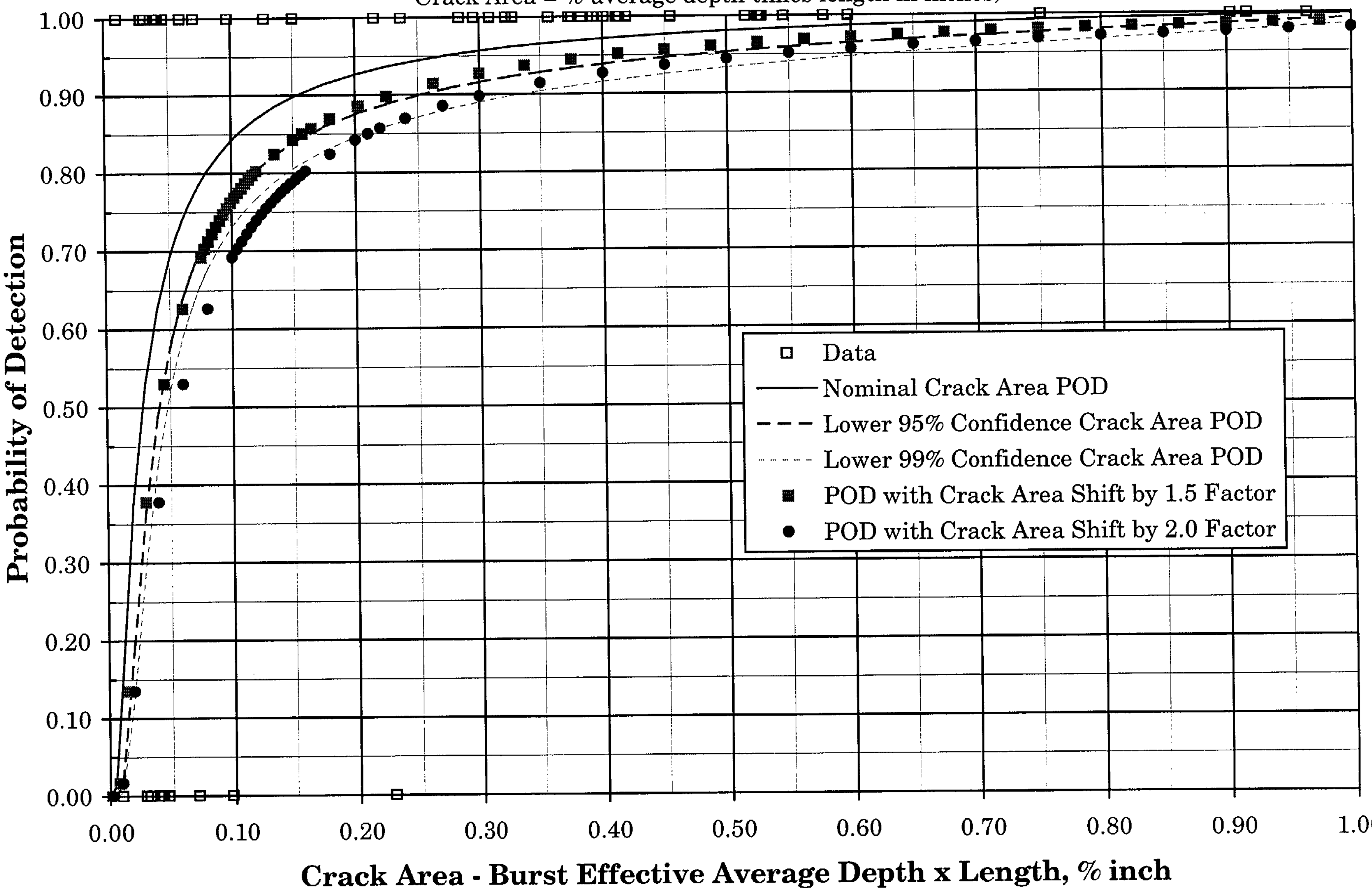
Operating EFPY	POD	Limiting Burst Pressure 95%/95% (psi)	SLB Leak Rate 95%/95% (gpm)	SLB Burst Probability	$3\Delta P_{NO}$ Burst Probability
0.85	Reference Crack Area POD Distribution	5676	0.0	1.35×10^{-4}	1.76×10^{-2}
	Reference Crack Area POD Distribution with Uncertainty	5543	0.0	1.87×10^{-4}	1.91×10^{-2}
	Shifted with a 1.5 factor	5035	0.0	1.82×10^{-3}	3.09×10^{-2}
	Shifted with a 2.0 factor	4731	0.0	1.44×10^{-3}	4.47×10^{-2}

Note:

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: $\Delta P_{SLB} = 4x10^{-2}$, $3\Delta P_{NO} = 8x10^{-2}$ summed for all degradation mechanisms in limiting SG.

Figure RAI-3-1. Indian Point-2: POD vs. Burst Effective Crack Area Including PODs at Lower Confidence Levels and with Crack Area Shifts

Crack Area = % average depth times length in inches)



NRC RAI Letter dated July 20, 2000

Question 4

Describe the sensitivity of the analysis results to the assumed flaw size measurement error distributions. This sensitivity should consider a 50% and 100% increase in standard deviation compared to what was assumed in WCAP-15128, "Depth-Based SG Tube Repair Criteria for Axial PWSCC at Dented TSP Intersections."

Reply

The NDE sizing uncertainties applied for U-bend indication operational assessments are based on sizing qualification data generated for dented TSP intersections. To acknowledge and account for potential differences in sizing uncertainties for U-bends and dented intersections and to consider the influences of deposits on the tubes, the standard deviations of the dented intersection data were conservatively increased by 25% above the WCAP-15128 uncertainties for all CMOA analyses. The standard deviations of the error distributions applied for average depth, maximum depth and length are then 9.8%, 17.7% and 0.174 inches, respectively. These uncertainties are absolute values added to the measured depths rather than a percentage of the measured value. A further increase in these standard deviations makes the sizing uncertainty very unrealistic for the indications influencing the operating cycle. For example, a 100% increase, the standard deviation for average depth becomes about 15.6%, which is excessively large for data with a reasonable signal to noise ratio. In the cycle length analyses, the NDE uncertainty is applied to all flaws equally and does not discriminate between the indications with high signal to noise ratios (better sizing accuracy) and low signal to noise ratios. As shown in the response to Question 5, the indications at R2C69, R2C71 and R2C72 have the dominant influence on the operating cycle length evaluation through the POD adjustment for undetected indications. These indications, particularly R2C69 and R2C72, have significantly better signal to noise (S/N) ratios than R2C5; thereby, justifying that the sizing uncertainties for these indications should approach that of WCAP-15128 (i.e., the basis for applying a 25% increase in the NDE uncertainties for the CMOA analyses). The (S/N) ratios for R2C69 and R2C72 are > 4 for peak to peak voltages and R2C71 is about 2.5 compared to a S/N ranging from 1.5 to 2 for R2C5. Given these considerations, there is no basis to apply a 100% increase in the uncertainties for these three indications.

The Monte Carlo results using NDE sizing uncertainties obtained by increasing the standard deviation by 50% and 100% are shown in Table RAI-4-1 along with the corresponding results for the case using the reference NDE sizing uncertainties. The results shown are for the limiting SG (SG-24) and are based on an operating period of 0.85 EFPY. For the case with a 50% increase in the standard deviation, the 95/95 burst pressure is reduced by 95 psi to 4799 psi, which continues to meet the $3\Delta P_{NO}$ limit of 4668 psi. The burst probability at the SLB and $3\Delta P_{NO}$ conditions (4.02×10^{-3} and 4.32×10^{-2}) are well within the recommended limits of 4.0×10^{-2} and 8.0×10^{-2}, respectively. The increase in the uncertainty from a 50% factor to a 100% factor results in a further decrease in the limiting indication burst pressure by about 75 psi, but this increase in the uncertainties has no basis.

Table RAI 4-1

Indian Point-2 Cycle 15 U-Bend NDE Sizing Uncertainty Sensitivity Analyses Projected Burst Pressures and Leak Rate(1) Results for the Limiting SG 24 - 400 kHz Profiles

Uncertainties in POD included in the Monte Carlo Analyses

Operating EFPY	NDE Sizing Uncertainty	Limiting Burst Pressure (psi)	Burst Pressure Margin Ratio(2)	SLB Leak Rate (gpm)	SLB Burst Probability	$3\Delta P_{NO}$ Burst Probability
0.85	Reference Depth Sizing Uncertainty(3)	4894	1.05	0.0	3.18×10^{-3}	3.82×10^{-2}
	50% increase in WCAP-15128 standard deviation	4799	1.02	0.0	4.02×10^{-3}	4.32×10^{-2}
	100% increase in WCAP-15128 standard deviation	4623	0.99	0.0	5.11×10^{-3}	5.13×10^{-2}

Notes:

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: $\Delta P_{SLB} = 4x10^{-2}$, $3\Delta P_{NO} = 8x10^{-2}$ 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. Includes 25% increase in WCAP-15128 NDE sizing uncertainties.

NRC RAI Letter dated July 20, 2000

Question 5

In the June 2 submittal, the licensee provided a sensitivity study that suggests that the use of 800 KHz sizing measurement instead of 400 KHz measurements reduces the end-of-cycle minimum burst pressure by only 2%. This appears inconsistent with the significantly higher flaw sizes calculated with data from the 800 KHz eddy current probe and that estimated burst pressures based on the 800 KHz measurements are an average of 18% lower than those based on the 400 KHz measurements. Provide an explanation for this apparent significant discrepancy.

Reply

The use of the 400 kHz data for determining end-of-cycle minimum burst pressure is appropriate. Although neither the 400 kHz nor the 800 kHz probe is fully qualified for sizing in the U-bends, there is considerably more industry experience with the 400 kHz probe. An NDE sizing data base is available for 400 kHz, and was used. Moreover, as discussed below, there is no significant difference in acceptable cycle length when the 800 kHz data is used instead of the 400 kHz data. This is because the increased crack depth determined with the 800 kHz probe is off-set by the higher local POD value at those points.

The apparent inconsistency noted in the question results from comparisons of the limiting burst pressures shown for 400 kHz and 800 kHz profiles in Tables 6-3 and 9-3 of the June 2, 2000 submittal. Table 6-3 shows the burst pressures calculated as a part of the condition monitoring evaluation and the results apply to single indications. Table 9-3 shows the limiting burst pressures for all SG-24 (the limiting SG) indications obtained as a part of the operational assessment. The limiting burst pressure for operational assessment is determined by the POD group indications, which are composed of fractional indications obtained by applying the POD factor to account for indications potentially missed during the inspection. The process of combining the fractional indications into POD groups has been previously described in detail. Briefly, the individual indications that make up a POD group are represented at their fractional value of (1/POD-1) such that the sum of the fractional indications for a POD group sums to 1.0 indication. The indications are selected in the order of their depth (average depth for burst and maximum depth for leakage) such that the 1st POD group has the deepest indications, the 2nd POD group the next set of deeper cracks, etc. The (1/POD-1) factors for each indication in the POD group have a significant effect on the calculated limiting burst pressure for a SG, in addition to the burst pressures for the individual indications in the group.

The limiting burst pressures for the Indian Point-2 U-bend SG analyses are determined by POD Group 1, which contains the deepest and the longest indications. Table RAI-5-1 shows the (1/POD-1) fractional part for the indications that make up POD Group 1 for 400 kHz and 800 kHz measurements. Also shown in the table are the burst adjusted average depths and lengths for each indication as well as the 95/95 confidence burst pressures for the individual indications after a year of operation (calculated under the assumption that the indication had not been repaired). As 800 kHz data are not available for R2C5 Crack 1, 400 kHz data was used with the 800 kHz data for other indications; however, since this indication represents only 0.5% of POD Group 1, it has an insignificant effect on the limiting SG burst pressure. Among the other indications that make up POD Group 1 for the 400 kHz and 800 kHz data, the 95/95 burst pressures (after one year of operation) for the 800 kHz profiles are on the average 15% below that for the 400 kHz profiles since the 800 kHz profiles have deeper depths. Except for R2C69 Crack 2, the burst-adjusted crack lengths are essentially the same for both sets of profiles.

If the composition of the POD Group 1 indications for the 400 kHz and 800 kHz data were the same, then the limiting burst pressure for the SG can also be expected about 15% lower for the 800 kHz data. However, since the 800 kHz profiles are deeper, the POD values for them are higher and, therefore, contribute lower (1/POD-1) fractional values. Crack #1 in tubes R2C71, R2C72 and R2C69 have a burst pressure in the range about 3000 to 4100 psi and, therefore, have a dominant effect on lowering the burst pressure for POD Group 1. The (1/POD-1) fractions for these three indications in the 800 kHz group are only 38% to 80% of that in the 400 kHz group. That is, the deeper and longer indications make a smaller fractional contribution to the POD group indications for the 800 kHz group, which largely offsets the decrease in burst pressure for the deeper 800 kHz profiles. Therefore, because of the differences in the POD application effects, the reduction in the limiting SG burst pressure from using 800 kHz data is significantly less than that implied from burst pressures for single indications.

Table RAI 5-1

Comparison of POD Group 1 Indication Compositions for 400 kHz and 800 kHz Profiles and their Limiting Burst Pressures

Indication	400 kHz Profiles				800 kHz Profiles				Ratio of 800 to 400 Data		
	Burst Adjusted Average Depth (%)	Burst Adjusted Length (in)	(1/POD-1) Fraction Ratio	Indication 95/95 Burst Pressure (psi) (1)	Burst Adjusted Average Depth (%)	Burst Adjusted Length (in)	(1/POD-1) Fraction Ratio	Indication 95/95 Burst Pressure (psi) (1)	Burst Adjusted Average Depth Ratio	(1/POD-1) Fraction Ratio	95/95 Burst Pressure Ratio(1)
R2C5 Crack 1	87.4	2.05	0.0048	1249	87.4(2)	2.05(2)	0.0048(2)	1249	1	1	1
R2C71 Crack 1	64.0	0.57	0.0494	3744	75.6	0.58	0.0187	3226	1.182	0.379	0.862
R2C72 Crack 1	59.8	0.54	0.0676	4084	62.8	0.56	0.054	3687	1.050	0.799	0.903
R2C69 Crack 1	55.2	0.91	0.0942	3898	64.7	0.97	0.0468	2988	1.171	0.497	0.767
R2C69 Crack 2	44.5	0.11	0.2073	7166	48.8	0.27	0.1508	5573	1.096	0.727	0.778
R2C69 Crack 3	38.2	0.23	0.3444	6494	61.1	0.23	0.0613	5162	1.599	0.178	0.795
R2C4 Crack 1	23.2	0.17	0.2323(3)	7949	33.0	0.12	0.3517(4)	7707	1.424	1.343	0.970
R2C74 Crack 1	15.7	0.14	0(5)	8077	39.4	0.16	0.3119	6929	2.509	-	-

Notes:

1. EOC burst pressures based on an operating period of 1 year and a lower bound flow stress value of 75.7 ksi.
2. There is no 800 kHz data for R2C5 (1997 data) and the profile was taken to same as that obtained with 400 kHz signal.
3. Actual (1/POD-1) value for R2C4 is 1.7637, 0.2323 of it is included in POD Group 1 (fraction needed to bring the cumulative fraction to one)
4. Actual (1/POD-1) value for R2C4 is 0.5485, 0.3517 of it is included in POD Group 1 (fraction needed to bring the cumulative fraction to one)
5. R2C74 is not a part of POD Group 1 for 400 kHz data.

NRC RAI Letter dated July 20, 2000

Question 6

Discuss in detail the basis for the assumption that the material flow stress is invariant with the initial non-strain hardened material properties. What is the sensitivity of the analysis results to consideration of the 95/95 lower tolerance limit material certification test results data for the tubes at Indian Point 2, adjusting for temperature and strain hardening? Alternatively, what is the sensitivity of the analysis to the consideration of the uncertainty distribution associated with the material certification data with appropriate adjustments for temperature and strain hardening?

Reply

The application of a constant material flow stress in the U-bend CMOA analyses is not based on an assumption that the flow stress is invariant with the initial non-strain hardened material properties. The intent of the constant flow stress assumption in the analyses is that a lower bound value can be applied for U-bend analyses that will yield more conservative burst pressures and burst probabilities than use of a strain hardened material property distribution. The constant value was applied since the constant flow stress values trace to lower bound row 1 ratios between U-bend and straight leg burst pressures. The flow stress analyses given in Section 5.6 of the U-bend CMOA (June 2 submittal) were included to estimate the correction to row 3 for the constant flow stress value. In this response, the CMTRs for IP2 are used to develop the straight leg and U-bend material property distributions to demonstrate the conservatism in the use of the constant flow stress in the reference analyses. This response corresponds to the alternate analysis noted above in RAI Question 6 in that the sensitivity of the analysis is provided for the uncertainty distribution associated with the material certification data adjusted for temperature and strain hardening.

The IP2 SG CMTRs were analyzed for the Row 2 and Row 3 tubes. Based on the Huntington Alloys certifications, sixty different heats of material were utilized for the 368 row 2 tubes, and forty-four different heats of material were utilized for the 368 row 3 tubes (92 per SG). The populations of material heats for rows 2 and 3 are not unique; that is, a number of heats of material were utilized for both row 2 and row 3 tubes. Since the CMTRs identified the quantity of tubes made from each heat (but not the SG location of tubes made from a specific heat), tube quantity weighted mean S_y, S_u and S_f were calculated, along with the variance about the mean for each property. The resulting row 2 and row 3 material properties from the CMTRs are given in Table RAI-6-1 as the straight leg properties.

Using the heat specific S_y and S_u values, stress-strain curves were constructed for each heat based on the typical stress-strain curve provided in Figure 5-9 of the U-bend CMOA (June 2 submittal). Section 5.6 of the U-bend CMOA provides total strain values of 19%, 12% and 9% for the rows 1,2 and 3 U-bend, respectively. Each of the heat specific $\sigma-\varepsilon$ curves was entered at the 12% strain level for row 2 and the 9% strain level for row 3, and the corresponding stress was read to represent the strain hardened yield strength for the heat. This is shown graphically on Figure RAI-6-1 using a composite $\sigma-\varepsilon$ curve based on the row 3 mean S_y and S_u. For both the unstrained and strain hardened conditions, LTL (lower 95/95) values for S_f were calculated using the methodology contained in WCAP-12522. Table RAI-6-1 summarizes the results of this analysis for the U-bend properties. The IP-2-specific (rows 2 and 3) material properties are slightly lower than the WCAP-12522 reference values. The effect of strain hardening is shown to be consistent with the analysis included in section 5.6 of the U-bend CMOA; that is, strain-hardening adjustment factors of 1.21 and 1.18 on the flow stress are shown to apply for the row 2 and row 3 tubes, respectively.

Material properties in the U-bend cannot be measured using standard practices due to the curvature of the tubing. Estimates can be obtained by developing a correlation between material hardness and yield strength using straight length tubing with measured material properties, performing hardness measurements for the bent U-bend material and applying the correlation to estimate the U-bend yield strength. This process was applied in Reference RAI-6-1 to estimate the yield strength for three row 1 tubes of 7/8 inch diameter. The ratios of the U-bend extrados at the apex to straight length yield strength obtained from these tests ranged from 1.65 to 1.75 for the row 1 tubing.

Burst pressures have also been measured to obtain the ratio of burst pressures between the apex extrados and the straight leg of the tubing. In general, these tests were performed using throughwall EDM slots or fatigue cracks. Two burst tests in Reference RAI-6-2 for Alloy 600MA, row 1 7/8 inch diameter tubing gave U-bend extrados to straight leg burst pressure ratios of 1.34. Tests were also performed in Reference RAI-6-3 for Alloy 690TT tubing of 0.740 inch diameter. These tests resulted in incomplete bursts (no tearing at edges of simulated cracks) and were believed (cannot be confirmed from reports) to have been performed for heat treated material following bending typical of Alloy 690 U-bend applications. The resulting burst pressure ratios from these tests for the U-bend apex extrados to straight leg ranged from 1.18 to 1.25. These data were used to support a lower bound effective flow stress for row 1 tubes of 90 ksi, which was lowered to 85 ksi for row 2 and 81 ksi for row 3.

The CMOA used a room temperature (RT) flow stress for row 3 of 81ksi, a value without uncertainties because it is intended as a lower bounding value compared to use of a distribution. This flow stress was developed as described in section 5.6 of the CMOA. In the Monte Carlo analysis for cycle length, every case among the 100,000 samples run uses this value, yielding conservative results since all cases are biased by the lower bound material value. The 81 ksi value corrected to 75.7 ksi for temperature was used to develop the cycle lengths reported in the CMOA and the supplement.

Analyses were performed using the IP-2 specific material properties distribution characterized by the row 3 strain hardened flow stress mean value and standard deviation shown in Table RAI-6-1. When large numbers of Monte Carlo samples are run with the flow stress mean and standard deviation, the complete distribution is sampled rather than using a fixed lower bound value. The probability and confidence levels are achieved by the Monte Carlo analysis, but the results are not biased by a fixed lower bound value for material properties. When the same level of combined conservatisms are evaluated as in the CMOA supplement, except that material properties are represented by a distribution with a mean and standard deviation, an increased margin above the required $3\Delta P_{NO}$ is obtained compared to the use of the lower bound 81 ksi RT flow stress.

The results of the analyses for burst pressures (BP) and burst probabilities are shown in Table RAI-6-2 and compared with the results given in the supplemental CMOA. POD uncertainties are included in all the analyses. The mean hot flow stress of 81.6 ksi obtained from the CMTR analyses for row 3 U-bends is significantly higher than the lower bound 75.7 ksi used for the CMOA analyses. The higher mean value more then compensates for the statistical treatment of uncertainties when applying the CMTR analysis results, and burst pressure margin ratios are increased by about 7% when applying the CMTR flow stress distribution. The results based on the CMTR flow stress do not include effects of wall thinning at the apex of the U-bend. In the manufacturing process, the larger wall thickness tubing is selected for the rows 1 to 3 U-bends in order to assure that the post bending wall thickness meets the minimum wall thickness requirements. For example, row 3 post bending wall thickness measurements for 21 tubes of 7/8 inch diameter were found to have an average wall thickness of 49.2 mils compared to the nominal 50 mil wall thickness. For three specimens, the wall thickness reduction at the extrados was about 2.5 mils. Even if the wall thickness is assumed to be 0.0475 inch at the row 3 U-bend apex, the burst pressure is increased from 4894 psi for the CMOA constant flow stress to 4828 psi for the CMTR distribution. As shown in Table RAI-6-2, similar trends are found if the ANL ligament tearing model is applied as a lower bound estimate of the burst pressure.

Overall, it is concluded that use of the lower bound row 3 flow stress of 81 ksi at room temperature as a constant flow stress leads to conservative burst pressure and cycle length predictions compared to use of CMTR material property distributions adjusted for strain hardening. The IP2 row 3 CMTR flow stress distributions corrected for strain hardening result in about 7% higher burst pressures.

References

RAI-6-1 Westinghouse R&D Memo No. 87-5D21-TBEND-M1, SG-87-02-039, "Mechanical Properties of U-bends Given Simulated Stress Relief Anneals,", R. J. Jacko, February 17, 1987.

RAI-6-2 Westinghouse Letter MI-SGMCE-144, "Burst Tests of Small Diameter U-Bends," A. W. Klein, June 16, 1982.

RAI-6-3 Westinghouse Report SG-87-12-007, "PWS 4.802 Leak and Burst Results from Tests on Inconel 690 Tubing," B. C. Gowda, December 1987.

Table RAI-6-1

IP2 Specific Material Properties Based on CMTRs for Rows 2 and 3

Parameter	Reference 7/8" Westinghouse CMTR Tubing Distribution[1]	IP2 CMTRs Row 2 data only	IP2 CMTRs Row 2 U-bend (12% strain)	IP2 CMTRs Row 3 data only	IP2 CMTRs Row 3 U-bend (9% strain)
U-Bend and Straight Leg Material Properties from CMTRs					
S_y (mean)-RT	50.98 ksi	48.5 ksi	79.6 ksi	49.3 ksi	75.6 ksi
S_u (mean)-RT	99.96 ksi	98.2 ksi	98.2 ksi	99.1 ksi	99.1 ksi
S_f (mean)-RT	75.47 ksi	73.3 ksi	88.9 ksi[3]	74.2 ksi	87.3 ksi[3]
σ_{Sf} – RT S_f standard dev.	3.50 ksi	4.84 ksi	4.53 ksi	4.68 ksi	4.42 ksi
Number of Heats		60		44	
Temp. Factor (Cold/Hot)			1.07		1.07
S_f (mean)- 590°F			83.1 ksi		81.6 ksi
σ_{Sf} – 590°F S_f standard dev.			4.23 ksi		4.13 ksi
S_f (mean), 590°F, PTW Test[4]			80.8		78.4
Lower Bound U-Bend Flow Stress Used in CMOA Analyses[2]					
S_f (lower bound)-RT		NA	85 ksi		81 ksi
S_f (lower bound)-590°F		NA	79.4 ksi		75.7 ksi

Notes:

1. Reference: WCAP-12522, developed for large number of Westinghouse 7/8" tubing heats.
2. Lower bound values for rows 2 and 3, no uncertainties apply; includes effects of strain hardening (Ref.: Section 5.6 of SG-00-05-008).
3. Derived strain hardening factor = 1.213 for Row 2 and =1.176 for row 3.
4. Part throughwall (PTW) burst test strain hardening factor = 1.18 for Row 2 and =1.13 for row 3.

Table RAI-6-2

Row 3 Burst Pressure Analysis Results for Alternate Flow Stress Distributions

EFPY	Flow Stress	Limiting BP (psi)	BP Margin Ratio	SLB Burst Probability	$3\Delta P_{NO}$ Burst Probability
Burst Correlation Applied					
0.85	Reference constant S_f = 75.7 ksi	4894	1.05	3.81×10^{-3}	3.82×10^{-2}
0.85	IP2 CMTRs, Mean S_f = 81.6 ksi, 0.050" Wall	5239	1.12	3.41×10^{-3}	2.67×10^{-2}
0.85	IP2 CMTRs, Mean S_f = 81.6 ksi, 0.0475" Wall	4928	1.06	3.78×10^{-3}	3.75×10^{-2}
ANL Ligament Tearing Eq. Applied					
0.45	Reference constant S_f = 75.7 ksi	4684	1.003	4.93×10^{-3}	4.83×10^{-2}
0.45	IP2 CMTRs, Mean S_f = 81.6 ksi, 0.050" Wall	5006	1.07	4.55×10^{-3}	3.37×10^{-2}
0.45	IP2 CMTRs, Mean S_f = 81.6 ksi, 0.0475" Wall	4714	1.01	4.91×10^{-3}	4.69×10^{-2}

Figure RAI-6-1