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May 30, 2000

2CAN050008

Mr. Samuel J. Collins
Director, Nuclear Reactor Regulation
U. S. Nuclear Regulatory Commission
NRR Mail Stop 05-E7
Washington, DC 20555

Subject: Arkansas Nuclear One - Unit 2
Docket No. 50-368
License No. NPF-6
Additional Information Regarding The ANO-2 Deterministic Operational Assessment Of Steam Generator Tubing For The Remainder Of Cycle 14

Dear Mr. Collins:

Arkansas Nuclear One – Unit 2 (ANO-2) has an excellent history with respect to managing the degradation of the ANO-2 steam generators (SG). Since 1992, we have conducted mid-cycle inspections to ensure continued safe operation of the facility. All tests performed to date have demonstrated that the tubes in the ANO-2 SGs would have retained structural integrity if exposed to pressures well in excess of worst case design basis accident conditions.

As discussed in a telephone conversation with you on May 15, 2000, Entergy is conducting testing on tubing with manufactured defects that mimic the most limiting flaw detected during the last mid-cycle outage (2P99). This testing is currently in its final stages. Information from the testing to date substantiates Entergy's previous position that the limiting flaw was capable of withstanding a differential pressure of greater than three times normal operating pressure (3ΔP) with margin. Given this fact, we believe our operational assessment remains valid, demonstrating that the unit can operate until the planned mid-September steam generator replacement outage in full compliance with our operating license and Entergy's commitment to NEI 97-06. Currently, Arkansas Nuclear One – Unit 2 (ANO-2) is operating with essentially no detectable primary-to-secondary leakage. To further assure the safe operation of the unit, should leakage from the steam generators (SG) be detected in excess of 25 GPD, the unit will be shutdown.

In correspondence dated February 11, 2000, Entergy provided the results of a detailed operational assessment of the ANO-2 steam generator tubes which justified operation to the end of Cycle 14. On February 17, 2000, representatives from ANO met with the NRC Staff to review this assessment. A significant focus of this review was the ultimate burst pressure of the limiting flaw (tube 72-72) identified during the last mid-cycle steam generator inspection outage (2P99). During in-situ pressure testing, tube 72-72 began leaking at 3737 psi, well above design basis accident pressure, and ultimately reached a pressure of 4147 psi

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before leakage exceeded the capacity of the test device. A bladder could not be installed in this tube to support additional testing. Post in-situ pressure test eddy current confirmed that the tube did not burst during the pressure test, but instead experienced tearing of radial ligaments resulting in increased leakage. Since the tube could not be pressurized to burst it was necessary to establish the burst pressure through analytical means. Evaluation of the in-situ pressure test data and eddy current data for tube 72-72, as well as test results from notched tube specimens, were utilized to gain insights into the ultimate burst pressure of tube 72-72. Calculations using the eddy current profile of tube 72-72 yielded a difference of about 500 psi between the point of ligament tearing and ultimate burst. When applying this additional pressure retaining capability to the ultimate pressure obtained from the in-situ pressure test, an ultimate burst pressure of approximately 4650 psi was obtained for tube 72-72, well in excess of the 3ΔP criterion of 4369 psi. Utilizing this information, an operational assessment was performed in accordance with NEI 97-06 "Steam Generator Program Guidelines," which indicated that ANO-2 could operate to the steam generator replacement outage in mid-September while maintaining an adequate margin of safety.

During the February 17 meeting and in subsequent correspondence dated May 2, 2000 (2CNA050001), the NRC Staff questioned conclusions Entergy had reached with respect to the ultimate burst pressure of tube 72-72. In summary, the Staff expressed a view that tube 72-72 could have been at the point of incipient burst when the test was terminated. The NRC further commented that the test most likely indicated a burst pressure of about 3900 to 4025 psi. The bases for NRC's views were provided in the May 2, 2000, letter.

Entergy disagrees with the Staff's view that tube 72-72 was in the incipient stage of failure at the conclusion of the in-situ pressure test. As previously stated, we believe ligament tearing was occurring, resulting in increased leakage, but that substantial structural integrity remained. To further substantiate this fact, additional extensive testing has been performed and is in progress. Specifically, flaws that mimic the pre-in-situ eddy current profile for tube 72-72 were manufactured into tubing similar to that utilized in the ANO-2 steam generators. Testing conclusively demonstrated that eddy current signals indicate a deeper flaw than was actually present in tube 72-72. Additionally, the testing has indicated that the actual flaw in tube 72-72 has minor variability in its shape that is not indicated by the eddy current profile. Results to date also support Entergy's previous assessment that a 500 psi margin exists between ligament tearing and burst for a flaw like that found in tube 72-72. This testing provides collaborative evidence confirming our original conclusion that the ultimate burst pressure of tube 72-72 exceeded the 3ΔP structural margin provision.

An ultimate burst pressure of tube 72-72 in excess of 3ΔP is also consistent with historic testing at ANO. Since eggcrate axial cracking was identified as having a significant impact on the operational assessment during the forced outage in 1996, Entergy has conducted four refueling/mid-cycle 100 percent examinations of the hot leg tubing. During each examination, bounding flaws exceeding a threshold criteria established in accordance with industry guidelines are in-situ pressure tested. This threshold criterion has been established to ensure that potentially structurally significant flaws are in-situ tested. During these examinations, 20 in-situ tests of eggcrate axial flaws have been conducted. With the exception of one tube in refueling outage 2R13 that burst at 3923 psi (well in excess of the design basis accident condition conservatively established at 2500 psi), all tubes have passed the 3ΔP structural margin provision. Additionally, none of these tubes showed signs of leakage when pressurized up to worst case peak accident pressure. The tube that failed in 2R13 was identified in the previous outage by one of the primary analysts, but dispositioned as acceptable during review by the resolution analysts. Corrective actions were taken following this condition by revising the inspection program to require confirmatory rotating pancake coil (RPC) examination of all potential flaws identified by either primary or secondary analysts in the lower three eggcrate supports. Thus, ANO has an excellent history of managing degradation at the hot leg eggcrates. With the exception of one flaw, which burst well in excess of expected accident conditions for which corrective actions have been taken, Entergy has consistently been able to demonstrate compliance with the $3\Delta P$ structural margin provision. We believe that tube 72-72 is no exception to this history.

As a result of degradation experienced in the ANO-2 SGs, Entergy has performed extensive testing and analysis to support operational assessment analyses for various operating intervals. Inputs into the operational assessment include flaw growth rate and the probability of detection of a given flaw size. Extensive growth rate analysis was performed to determine the amount of flaw growth occurring at ANO-2 between inspections. A site specific performance demonstration (SSPD) was performed to assess the probability of detection (POD) of the inspection program employed for ANO-2. Entergy believes these initiatives have resulted in appropriate growth rate and POD values for ANO-2, since they are directly applicable to the ANO-2 steam generators. These inputs were utilized in the current operational assessment.

In conclusion, based on this information and the guidance provided in NEI 97-06, a deterministic operational assessment was performed following refueling outage 2R13. That assessment concluded ANO-2 could operate safely until a planned mid-cycle outage in November 1999 (2P99), and that the largest flaw would meet a margin of $3\Delta P$. The test results of 2P99 were initially inconclusive as to whether or not the worst case flaw met $3\Delta P$. Further analysis and testing has shown the flaw did meet the $3\Delta P$ criterion. This provides a benchmark for the deterministic model performed for the run from 2R13 to 2P99. Based on the information provided and the subsequent testing performed on manufactured flaws simulating the worst case flaw in 2P99, the original conservative estimate of approximately 500 psig difference between ligament tearing and burst remains valid. This provides reasonable assurance that tube 72-72 met the $3\Delta P$ criterion with adequate margin to support operation until 2R14.

Not withstanding the above, Entergy is sensitive to the recent industry experience and, in light of the condition of the ANO-2 steam generators, pledges to take immediate action well in advance of technical specification leakage limits should indications of primary-to-secondary leakage be detected. As noted in previous correspondence, ANO has in place instrumentation to detect very small primary-to-secondary leaks and has in place an administrative limit of 0.1 GPM (144 GPD) beyond which the operators are instructed to shut down the unit. Other limits are established on rate of change to respond to rapidly propagating leaks. ANO has demonstrated its sensitivity to leakage when the unit was shutdown in 1996 due to a 50 GPD primary-to-secondary leak. The ANO-2 Operation's staff routinely trains on and is extremely sensitive to primary-to-secondary leakage/rupture scenarios and would promptly and effectively respond in the unlikely event of an actual condition. To further ensure a rapid response to primary-to secondary leakage, Entergy will revise operating procedures to reduce the shutdown limit from 144 GPD to 25 GPD confirmed leakage. This limit will remain in effect until the steam generators are replaced. In addition, Entergy will ensure Operation's personnel are briefed on the analysis, projections, and bases of the operational assessment in order to provide a further heightened awareness among the ANO-2 staff. Although the probability of a design basis accident occurring over the next 3 months is extremely remote, ANO-2 has shown that tube failures during such a scenario will not occur and that any leakage will be responded to effectively and promptly.

Entergy has evaluated, in cooperation with Westinghouse, the points raised by the specific comments in the NRC's May 2, 2000 letter. Entergy believes the information provided in the attachment to this letter is responsive to the Staff's comments. Additional information will be provided when the testing is complete. Entergy additionally believes that the data presented and testing performed to date, without exception or dispute, has demonstrated that the ANO-2 steam generator tubes would maintain structural and leakage integrity at peak accident pressure. Furthermore, we believe our operational assessment remains valid, demonstrating the unit can operate until the mid-September steam generator replacement outage in full compliance with our operating license and commitment to NEI 97-06. These evaluations and ANO's conservative operating philosophy provide reasonable assurance of the continued safe operation of the facility.

Should further information be required, or if the information formerly presented requires further discussion, please do not hesitate to contact me.

Very truly yours,

CGA/dbb
Attachment

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## ENTERGY OPERATIONS DISCUSSION OF NRC COMMENTS IN MAY 2, 2000 LETTER

### NRC Comment #1

At no time, when testing at pressures above 3900 psi, was Entergy able to hold pressure while maintaining a constant leak rate. When ramping beyond a reported test pressure of 4025 psi, the leak rate experienced a rapid increase from 1 gpm to 3.7 gpm at a reported test pressure of 4147 psi, whereupon the pressure dropped suddenly to 600 psi. The NRC believes this behavior to be consistent with a condition of incipient burst at the time the test was terminated. The rapid drop off in pressure precluded driving the crack to a fish-mouth rupture.

### Comment #1 Response

In-situ test data alone does not provide sufficient information to allow one to conclude the tube was at a point of incipient burst. Results of additional testing using samples fabricated to closely mimic tube 72-72 indicate a substantial difference in pressure between ligament tearing and burst. From these tests, two flaw types were developed which leaked prior to failure. One test sample was taken to the point of leakage. When attempting to increase pressure, a ligament tore and the pressure dropped significantly. This performance was similar to that of tube 72-72. A bladder was inserted and the pressure increased to a point where the bladder tore and no additional pressure could be achieved. The difference between the point of ligament tearing and the peak pressure was approximately 1000 psi. The flaw exhibited no tearing on the ends and did not burst. This result demonstrates that a flaw can still achieve higher pressures even after significant ligament tearing. Other samples tested achieved similar results.

The Staff commented that the in-situ test results most likely indicate a burst pressure of about 3900 to 4025 psi. When a burst test is performed, the maximum pressure obtained is considered the ultimate burst pressure of the tube. No consideration need be given for maintaining equilibrium conditions when addressing the margin above design basis accident pressure. Such consideration is not a requirement in the ASME Code, the EPRI In-situ Pressure Test Guidelines, NEI 97-06, or any NRC regulatory guidance documents. Thus the peak pressure of 4147 psig, which was adjusted for the pressure loss associated with flow through the crack opening, represents the peak pressure obtained during the test. Any additional strength to be credited between ligament tearing and burst should be added to the 4147 psig.

### NRC Comment #2

Entergy did not describe its procedure for accounting for the head loss between the water supply location and the crack, nor did you describe the leak rate that was considered when making this adjustment. However, it is the NRC's understanding that these adjustments assume equilibrium conditions exist rather than a rapidly changing crack geometry and leak rate. Thus, the NRC is concerned that at reported test pressure beyond 3900 psi, the actual pressure at the flaw may be somewhat smaller than the reported test pressure, particularly for reported test pressures above 4025 psi.

**Comment #2 Response**

Adjustments for leakage through the crack have been made to the reported pressure and any error resulting from dynamic effects would be insignificant. The accuracy of the reported test pressures is adequate for comparison to the 3ΔP acceptance criterion.

The pressure loss is based on testing performed up to a flow rate of 4.7 GPM on the entire in-situ system to establish the amount of pressure loss at a given flow rate. This effectively defines a system curve. As the system resistance changes, such as due to a crack opening, the system curve is used along with the pump flowrate to determine the appropriate adjustment. Thus at any given point during the test, if the flow rate is known, the pressure loss can be obtained. The flow rate is continually measured. While the accuracy of the measurement may somewhat improve under steady-state flow conditions, the value measured during the test is very reasonable and considered reliable. The slope of the curve of flow rate versus pressure loss is such that small variations in the flow rate will not result in a significant change in the pressure loss.

**NRC Comment #3**

The burst analyses of plus-point crack profiles B5534 and S5971 indicate a nominal burst pressure for the subject tube in the range of 3752 to 4311 psi, based on the Westinghouse burst model in WCAP-15128, Revision 1, "Depth-Based SG Tube Repair Criteria for Axial PWSCC [Primary Water Stress Corrosion Cracking] at Dented TSP [Tube Support Plate] Intersections," dated August 1999. This is consistent with the test results.

**Comment #3 Response**

The predicted burst pressure for profile S5971 was 4311 psi. The predicted tearing pressure for profile S5971 was 3752 psi, resulting in a difference of 559 psi. The predicted burst pressure for profile B5534 was 3644 psi. The predicted ligament tearing pressure for profile B5534 was 3125 psi, for a difference of 519 psi. Both of these calculations support the use of an additional 500 psi above the ligament tearing pressure of 4147 psi for tube 72-72 to calculate its ultimate burst pressure of 4650 psi.

In order to calculate a burst pressure, material properties must either be known or assumed. For ANO-2, material properties are not available on a tube-by-tube basis. The material properties are typically higher for pulled tubes than what would be assumed if one knew nothing of the properties. As such, there can be a considerable variation in the predicted burst strength of a given flaw. Testing of Electric Discharge Machine (EDM) notches has confirmed that the Eddy Current Test (ECT) profile of 72-72 was worse than actual flaw dimensions. This is also consistent with comparisons of ECT profiles of pulled tubes where the ECT data for the average depth is on average higher than the actual result. For these reasons Entergy is using the pressure difference between ligament tearing and burst to minimize the uncertainty of material property values.

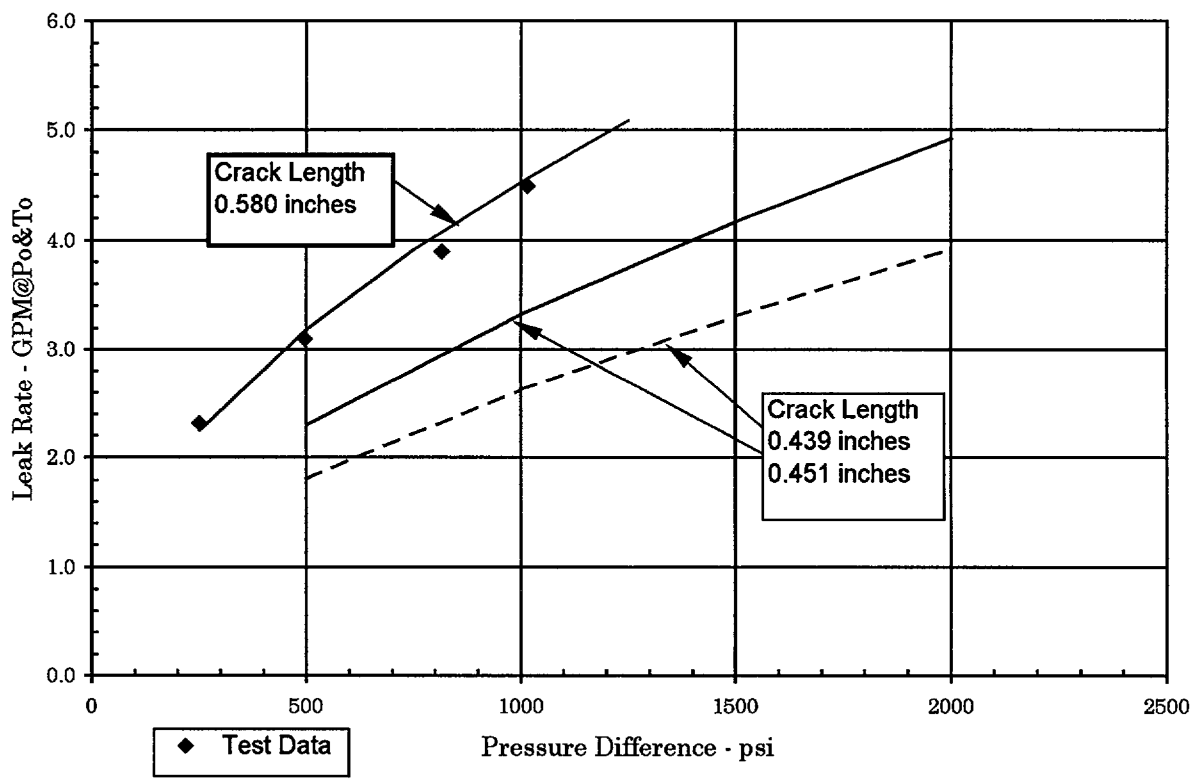
It is important to note that NRC Staff Comments 3 through 6 contend that the point of incipient burst may have been reached during the in-situ pressure testing. All of the comments rely on information provided, using a ligament tearing and burst prediction model documented in Westinghouse WCAP 15128, Revision 1, and an example flow stress of 160 ksi. Responses discussed herein are based on using the model parameters to be reported in Revision 3 of the WCAP. The tearing/burst routine calculates a ligament tearing and burst pressure for every possible incremental subcrack of the original crack profile. The minimum value from all of those calculations is reported as the solution. The methodology is based on an extensive database of burst pressures for the burst correlation portion of the model. For ligament tearing the algorithm relies on the model developed at Argonne National Laboratory (ANL). For each calculation, the subcrack is considered to be rectangular in shape with a depth equal to the average depth of that portion being considered. The average flow stress of the tubes in SG B, including row 72, is about 144 ksi. The predicted ligament tearing and burst pressures for the S5971 profile are 3752 and 4311 psi, respectively. The respective effective lengths for those calculations are 0.70" and 0.72". These are the lengths of the subcrack for which the pressure values were calculated. In addition, the Cochet ligament tearing model predicts a tearing pressure of 3264 psi. The WCAP algorithm reports the burst pressure as the greater of the Cochet ligament tearing model prediction or the equation used by the ASME Code for a lower bound prediction of the through-wall crack burst pressure. The WCAP model already accounts for the potential ligament tearing in the result provided. The burst pressure results from the model are qualified against data from pulled tubes from operating plants. The effective lengths represent values which are used in conjunction with the model to return the burst pressure value reported.

Actual leakage during the in-situ test did not occur until a pressure on the order of 3700 to 3800 psi was reached. This can be explained as model error, material property variation, or sizing error. As discussed later, PWSCC depth sizing has been demonstrated to overestimate average depths in one study on the order of 8 to 9%. Reducing the S5971 profile by 8% leads to a predicted tearing pressure of 4000 psi and burst pressure of 4900 psi. Because the model is based on an average prediction of the burst pressure beyond the ligament tearing pressure, it is possible for some crack configurations to actually exhibit burst pressures not significantly in excess of the ligament tearing pressure. This is inherent scatter associated with the model. However, testing of specimens made to simulate the 72-72 crack profile demonstrates that this is not the case and that significant margin between the burst pressure and ligament tearing pressure is to be expected.

Analyses were performed of the leak rate measurements performed following the peak pressure of the in-situ test. Leak rates were measured up to about 1015 psi (1700 psi corrected for flow) where the leak rate again reached the test equipment limit of about 4.5 GPM. The pressurization to 4147 psi results in a plastic opening of the crack that dominates the post peak pressure leak rates. For the analyses, plastic crack openings were calculated using the CRACKFLO model for various through-wall crack lengths for which the leak rate exceeded 4 GPM at 4147 psi. These plastic openings were then used to calculate the post peak pressure leak rates. Figure 1 shows the predicted leak rates versus pressure for through-wall lengths of 0.439, 0.451, and 0.580 inches, along with the measured values from tube 72-72 (noted as test data). It is evident that a through-wall length of 0.58 inch yields agreement with the measurements. Consequently, the ligament tearing of tube 72-72 at peak pressure was approximately 0.58 inches and not the total crack length. If the through-wall length was much longer, the post peak pressure measurements could not have reached approximately 1000 psi for a 4.5 gpm leak rate. This result demonstrates modest ligament tearing and that the indication would have a significantly higher burst pressure than the ligament tearing pressure in the test of 4147 psi.

**Figure 1**

Crack Leak Rate
Plastic Area for ΔP=4147 psi




## NRC Comment #4

The effective crack lengths (as defined in WCAP-15128) for profiles B5534 and S5971 were 0.905 inches and 0.72 inches, respectively. These lengths exceeded the critical crack lengths of 0.74 inches and 0.63 inches for differential pressure loadings of 3752 and 4311 psi, respectively. This means that failure of the remaining crack ligaments leads directly to burst without any further increase in pressure. It is possible for a partial ligament failure to occur prior to burst as was indicated by the fact that initial leakage was observed during the test at a pressure of 3890 psi. However, the test scenario was consistent with a state of incipient total ligament failure and incipient burst when the test was terminated.

**Comment #4 Response**

As previously stated, we believe ligament tearing was occurring, resulting in increased leakage, but that substantial structural integrity remained. To further substantiate this fact, additional extensive testing has been performed and is currently in progress. Specifically, flaws that mimic the pre-in-situ eddy current profile for tube 72-72 were manufactured into tubing similar to that utilized in the ANO-2 steam generators. Testing conclusively demonstrated the eddy current signal indicates a deeper flaw then was actually present in tube 72-72. Tubes with manufactured flaws of the size detected by eddy current for tube 72-72 failed at a corrected pressure of approximately 800 to 1600 psi below the peak pressure tube 72-72 obtained. Results of additional testing using samples fabricated to closely replicate tube 72-72 indicate a substantial difference in pressure between ligament tearing and burst.

If the flaw was through-wall at the total lengths suggested, then it could be at the point of incipient burst. However, the post-test leakage value indicates that the flaw was not uniformly distributed over the entire length. The post-test leak rate is consistent with a through-wall flaw of about 0.5-0.6 inches, which does not agree with the post-test profile. Entergy considers the post-test leak rate information much more reliable than the post-test NDE profile for reasons stated in the response to Comment #6.

**NRC Comment #5**

Entergy has estimated ligament tearing pressures of 3125 and 3752 psi for profiles B5534 and S5971, respectively, using the Argonne National Laboratory (ANL) model in NUREG/CR-6575. These estimates are based on ligament effective lengths of 1.065 and 0.86 inches, respectively. These lengths exceed the critical crack lengths (0.9 and 0.74 inches, respectively) associated with differential pressures of 3125 and 3752 psi, respectively. Therefore, at these lengths, failure of the ligaments should lead directly to burst without any additional increase in pressure. The NRC has not yet determined why the ANL model leads to a more conservative estimate of burst pressure than the burst model in WCAP-15128. However, results with the ANL model are consistent with those from the WCAP model, which indicate there is no pressure increase between the point of failure of the remaining ligament and tube burst.

**Comment #5 Response**

Results of additional testing using samples fabricated to closely replicate tube 72-72 indicate a substantial difference in pressure between ligament tearing and burst.

The ANL model predicts nominal ligament tearing of a rectangular shaped flaw and should provide a conservative answer related to the Westinghouse model, which estimates the burst pressure. It may also be considered to provide a lower bound estimate of the burst pressure. Once again, if the flaw were uniformly deep over the lengths suggested, then the flaw could be at the point of incipient burst. This assumption would be made without considering the post-test leakage results. Flaws are generally not uniform, especially over the lengths being discussed. The test data indicates that the crack did not break through at the lengths specified. Furthermore, additional testing presented in this submittal substantiates the assumption that the NDE profile overestimated the flaw depths.

**NRC Comment #6**

The NRC applied the same burst prediction model to the post-test plus-point profile. The calculated burst pressure is 1933 psi with the WCAP-15128 model. This is consistent with the hypothesis that the crack was at the point of incipient total ligament failure and incipient burst at the time the test was terminated, and that the crack had undergone significant ligament damage and degradation of its subsequent burst pressure capability.

**Comment #6 Response**

The purpose of the post-test profile was to evaluate the length and see if an extension of the crack tips occurred. Since no extension was evident, the flaw was assumed to have experienced tearing of radial ligaments, but did not burst.

The post-test eddy current signals were saturated at 400 kHz, so crack sizing had to be performed at 200 kHz for the depth profile analysis. Sizing experience has indicated that analyses of the 200 kHz data tend to result in over estimates of crack depth and increased voltages, but the data can indicate the post-test features of the indication. This means that any depth measurements would be highly uncertain, and should not be used as the basis for any calculation. The post-test results suggest that the crack opening did not extend significantly beyond the NDE identified depths near 65%. The post-test results following testing up to 4147 psi indicate tearing of some of the uncorroded wall thickness ligaments with no significant increase in crack length (i.e., no crack extension from the in-situ testing). This is a common test result in performing burst tests without a bladder. Based on the field results, it is inconclusive whether or not the tube was at the point of incipient burst. Based on recent testing described in response to #8, the original prediction that tube 72-72 met $3\Delta P$ remains valid.

**NRC Comment #7**

The NRC observes that the post-test crack profile appears fairly consistent over its entire 1.49-inch length, ranging from 90% through-wall (TW) to 100% TW. This contrasts with the two pre-test profiles which exhibit more irregularity over this length. Pre-test profile B5534 exhibits no detectable depth over the lower most 0.2 inches of this length, steps up to about 70% depth over the next 0.25 inches, and then steps up to about 85% for the next 0.75 inches, and then steps down to about 70% for the remainder of this length. Based on the post-test profile, it would appear that the actual pre-test crack profile was likely longer than indicated by the measured pre-test profile B5534 and of more consistent depth than indicated by either pre-test profile. This further calls into question estimated differences between ligament failure pressure and burst pressure based on the measure pre-test profiles.

**Comment #7 Response**

Results of additional testing using samples fabricated to replicate tube 72-72 indicate a flaw of the size of the pre-in-situ eddy current profile S5971 would not have been capable of being pressurized to over 4000 psi as was tube 72-72. In fact, tubes with manufactured flaws that mimic profile of S5971 failed at corrected pressures of approximately 2500 psi.

Inferring a pre-test depth from the post-test profile inherently leads to considerable uncertainty and yields no reasonable or consistent results. As stated in the response to Comment #6, the post-test signal is saturated, likely due to the separation of portions of the crack face, and the depth measurements are highly unreliable. Those NDE depths are also not consistent with the leak rate observed when the re-pressurization attempt was made following the initial in-situ test. Therefore, attempting to calculate a burst pressure using the post-test NDE will yield invalid results.

There is no basis for stating that the flaw was of more consistent depth than indicated by either profile. The sequence of leakage during the test indicates a non-uniform profile, when different ligaments tore increasing leakage in steps. The post-test leak rate indicates a through-wall flaw of about 0.58 inches, which is not consistent with the post-test eddy current examination profile. The profile of S5971 estimated the length at 1.42" and the post-test length at 1.49 inches. No significant difference is evident in these lengths. It is also of no value to compare this to the pre-test profile of B5534 since the ligament tearing and burst models are based on the profile of S5971. Results of additional testing using samples fabricated to closely replicate tube 72-72 indicate a substantial difference in pressure between ligament tearing and burst.

**NRC Comment #8**

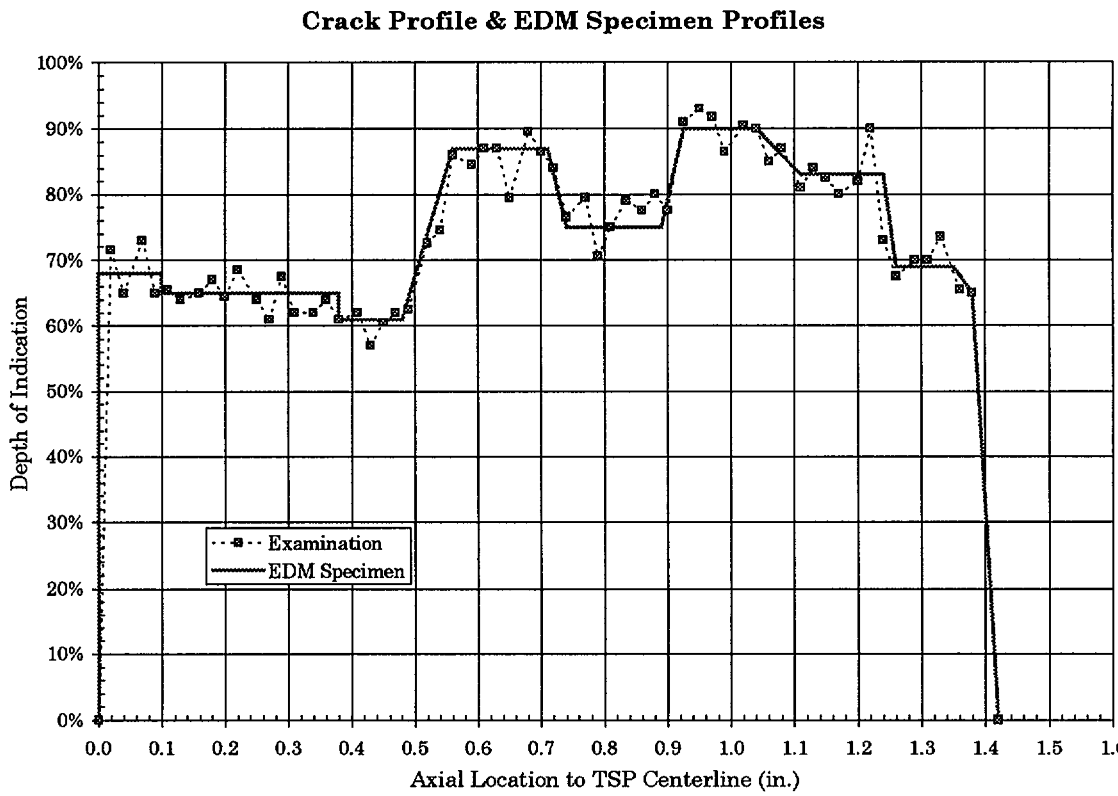
The electric discharge machine (EDM) notched samples contained 80% TW EDM notches with lengths of 0.5 inches and 0.7 inches. These samples appear non-representative of the likely pre-test crack profile, as discussed in item 7 above, and do not provide a credible basis for evaluating the pressure differences between ligament failure and burst.

**Comment #8 Response**

The reason 0.5-inch and 0.7-inch EDM samples were initially used is that they had been previously manufactured and thus available sooner. They provided reasonable samples for use to predict the difference between the ligament tearing and the burst pressures. The 0.7-inch sample was a conservative approximation of the estimated size of tube 72-72 at the point of maximum leakage based on follow-up calculations. The NRC has correctly stated that it does not match the entire profile of tube 72-72, and as a result, additional extensive testing has been performed and is currently in progress.

Batteries of leakage/pressure tests have been conducted to estimate the burst pressure of tube 72-72. These tests were performed by electrical mechanical discharge (EDM) cutting of flaws into representative samples of 3/4 inch Inconel 600 tubing. These flaws were then pressurized to determine their leakage characteristics and burst pressure. Initially, five samples were cut to replicate profile S5971 as shown in Figure 2. These samples were then pressurized. Each of the samples failed without indication of prior leakage. The adjusted failure pressure was, on average, recorded at approximately 2500 psi. These results clearly indicated the actual flaw in tube 72-72 was substantially smaller than that depicted by profile S5971. This was not totally unanticipated given the propensity for eddy current to oversize the average depth of axial flaws based on pulled tubes.

**FIGURE 2**




A subsequent battery of tests were performed varying the depth of the flaw while maintaining the overall flaw length and characteristics as indicated by pre-in-situ eddy current examination of tube 72-72. The test results did not simulate the leak rates and pressures seen during the in-situ pressure test of tube 72-72. Without advance leakage, these flaws opened significantly longer than that of the flaw in tube 72-72, as indicated by the inability to repressurize the tube. Leakage calculations show that the increased leakage from tube 72-72 during the final stages of the in-situ pressure test was most likely due to the tearing open of an approximate 0.58 inch long deep segment of the flaw.

Creating a flaw with leakage characteristics of tube 72-72 required minor variations in the flaw profile. Current testing is fine tuning the flaw dimensions to more closely replicate the results from the in-situ test of tube 72-72. Results to date support Entergy's previous assessment that a 500 psi margin exists between ligament tearing and burst for a flaw like that found in tube 72-72.