Commonwealth Edison Company
1400 Opus Place
Downers Grove, IL 60515

September 1, 1995

ComEd

Office of Nuclear Reactor Regulation
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555

Attn: Document Control Desk

Subject: Additional Information regarding Commonwealth Edison Company's Response to Questions Regarding the Increase in the Interim Plugging Criteria for Byron Unit 1 and Braidwood Unit 1
NRC Docket Numbers:50-454 and 50-456

Reference: D. Lynch letter to Commonwealth Edison Company dated August 11, 1995, transmitting Request for Additional Information

In the reference letter, the Nuclear Regulatory Commission transmitted to the Commonwealth Edison Company (ComEd) a request for additional information (RAI) regarding the technical bases supporting the pending license amendments, which involves an increase in the interim plugging criteria for steam generator tubes at Byron Unit 1 and Braidwood Unit 1. Attached is ComEd's response to this RAI (questions 49 to 54).

If you have any questions concerning this correspondence please contact this office.

Sincerely,

Denise M. Saccomando
Nuclear Licensing Administrator

Attachment

cc: D. Lynch, Senior Project Manager-NRR
R. Assa, Braidwood Project Manager-NRR
G. Dick, Byron Project Manager-NRR
S. Ray, Senior Resident Inspector-Braidwood
H. Peterson, Senior Resident Inspector-Byron
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REQUEST FOR ADDITIONAL INFORMATION
REGARDING THE PROPOSED REVISIONS TO THE TECHNICAL SPECIFICATIONS
RELATED TO THE STEAM GENERATOR TUBE VOLTAGE-BASED REPAIR CRITERIA
BYRON, UNIT 1, AND BRAIDWOOD, UNIT 1
DOCKET NOS. STN 50-454 AND STN 40-456

RAI 49 (Refer to Items 27 and 28 in the Staff's letter dated June 22, 1994, for Items 49 and 50.)

You state in response to Item 27, that the factors of safety in the original design of the steam generators (SGs) are your basis for not having to inspect the SG internal structural components which serve to limit the tube support plate (TSP) displacements during postulated accident conditions. Based on in-service experience with a variety of components of similar construction and exposed to environments similar to that in the Byron, Unit 1, and Braidwood, Unit 1, SGs, we find that the approach you proposed in your response is not adequate. During our telephone conference on August 3, 1995, we discussed the following areas of concern regarding your proposed basis for assuming that the SG structural internals which serve to limit the displacement of the TSPs during postulated accident conditions, will serve their newly intended function. In your response, discuss the following topics:

RAI 49a

How the factors of safety to which you refer in your response to Item 27 are intended to account for service induced degradation over the projected lifetime of the SGs in light of SG operating experiences to date. This discussion should include a consideration of: (1) the corrosion of the SG tubes: (2) the structural integrity of the TSPs; (3) the potential for corrosion of the TSPs; and (4) any other contributing factor to the potential for degradation of the SG structural internals.

Response 49a

The operating experiences of Westinghouse SGs relative to the integrity, i.e., lack of degradation, of the internals tube support structures, have been excellent at plants where significant denting has not resulted in large plastic deformation of various locations of the TSPs. As a result of the ongoing dialogue with the NRC relative to the integrity of the internals, an inspection plan has been developed by ComEd to verify the condition of TSP supporting components.

The subject of corrosion of the SG tubes has been dealt with extensively as part of the development of the voltage based plugging criteria. The axial strength of the tubes in the presence of significant voltage amplitude Outside Diameter Stress Corrosion Cracking (ODSCC) indications is considerable. Discussion of the axial strength of the tubes is provided in the response to question 54, e.g., the axial rupture force for a 10 volt indication in a tube with Lower Tolerance Limit (LTL) material properties is almost 5000 lbs, or more than an order of magnitude greater than the load that would be imparted by the TSPs during a Steam Line Break (SLB) event (assuming the tube to be locked to the TSP).

As noted, degradation of the TSPs, e.g., cracking of the ligaments between tube holes or between a tube hole and a flow hole, has not been observed in plants without significant denting of the tubes. The potential exceptions and implications were discussed at length at the ComEd meetings with the NRC on July 20, 1995, and August 17, 1995, relative to experiences at foreign plants. The ComEd inspection plan includes provisions to determine if similar degradation has occurred in the SGs at Braidwood Unit 1 and Byron Unit 1.

Contributing factors to potential degradation assessed include fatigue, stress and water chemistry. The result of having these contributing factors present is corrosion fatigue and/or carbon steel stress corrosion cracking (SCC). Fatigue requires high, cyclic loadings. As indicated in 49c and earlier responses, the operational and shutdown loads on a load path components are low . In addition, there has been no evidence of loose load path components due to the results of fatigue failure in any SGs after long service times. It is important to note that the time frame examined is much longer than the service time for Byron or Braidwood. Therefore, there is no evidence to support an operational fatigue related degradation mechanism.

Corrosion related degradation of carbon steal is also addressed in 49c. Again, significant corrosion related degradation of load path components would result in loose parts after long SG service. This has not been observed as part of secondary side tube removal operations post cleanliness verification. Visual inspection of the top TSP and vertical bars in the Braidwood 1C SG conducted in 1994 showed no evidence of loose, missing or degraded load path components. Therefore, there is no evidence to support a corrosion related degradation mechanism at Byron and Braidwood.

Overall, the potential contributing factors to degradation of the structural components were assessed and found to be negligible. It is concluded that TSP degradation without significant SG tube denting would be extremely unlikely. This is further discussed in the response to question 49f of this RAI.

RAI 49b

Evidence from the SG fabrication records of Byron, Unit 1, and Braidwood, Unit 1, which would demonstrate that the welds attaching the SG internals are as sound as assumed in WCAP-14273.

Response 49b

The original equipment manufacturer (OEM, Westinghouse) Design Report includes the as-built non-conformance reports for components comprising the tube support system in the SGs. A review of the Design Report was undertaken for the Braidwood Unit 1 and Byron Unit 1 SGs. The following non-conformance topics were reported:

1. Mechanical trimming of some TSP local and rim segments for clearance to align the holes in the TSP with those in the tube sheet (also referred to as the tube plate). This operation would have no effect on the structural integrity of the TSPs with regard to the drawing dimensions since a minimum ligament between the rim and the outer tube holes is required. This could mean that at those location(s), shims could have been installed instead of wedges, or that no shims or wedges were installed. This is not of consequence since the restraining effect of the wedges is not modelled in the dynamic response analysis.

2. One tube sheet stayrod (also referred to as a tierod) hole with oversize threads was restored using a Helicoil® screw thread insert. The shear strength of the connection of the stayrod to the tube sheet would not be expected to be degraded since the internal shear area of the insert would be the same as the internal shear area of the original threaded hole in the tube sheet.

3. One tube sheet stayrod with damaged end threads was restored with weld *build-up* and the threads were recut. This would not have a degrading effect on the stayrod relative to its load carrying capability or to increase its potential for in-service corrosion.

4. Wrapper configuration and location anomalies consisting of:

   4.1 Roundness,

   4.2 Elevation of the bottom of the wrapper with respect to the top of the tube sheet,

   4.3 The overall length of the wrapper.

   None of these conditions would be expected to have a deleterious effect on the structural integrity of the wrapper. The non-conformance with respect to roundness could lead to the same conditions as discussed above with regard to the TSP rim trimming, i.e., shims instead of wedges or the absence of either wedges or shims at a local location.

All conditions were corrected or deemed to be acceptable for structural integrity and operation of the SGs. There were no reported instances of internals welds being unacceptable or of welds being accepted with non-conforming dimensions, e.g., less than required by the fabrication drawings. ComEd has prepared a SG internal inspection plan. Included in this plan is a visual inspection of welds attaching the SG internals. This inspection plan is discussed in the response to question 64 of the RAI issued from the Staff on August 24, 1995.

RAI 49c

Relevant experience with respect to the corrosion resistance of the base and weld materials of the relevant SG internal structures in the SG operating environment.

Response 49c

With regard to active degradation of the welds in the carbon steel load path components, two mechanisms are plausible, corrosion fatigue and stress corrosion cracking (SCC). Since active stresses and variations in stress are low in these components, corrosion fatigue is unlikely. This includes either initiation or propagation. Environmental effects have been observed in corrosion fatigue tests of carbon and low alloy steels in high temperature water. However, high cycle stresses and /or oxygen levels are needed for these effects to be substantial. The operating conditions for the Byron and Braidwood units are low oxygen and high pH. Carbon steel does not corrode under these conditions. Therefore, corrosion fatigue is highly unlikely.

High welding residual stresses make SCC a more likely active degradation mode. However, under constant loading, highly oxidizing conditions are needed for the onset of SCC. At high temperatures, oxidizing conditions equivalent to about 100 ppb of dissolved oxygen are needed for SCC to occur. The Byron and Braidwood SGs have operated with low oxygen levels, (typically less than 2 ppb). This low dissolved oxygen level is further supported by the elevated hydrazine program. Therefore, SCC of carbon steel welds is highly unlikely. Even if high residual stresses would cause cracking of the weld, the cracking would be across the weld (perpendicular to the weld) which would not significantly effect the load carrying capability of the weld. Additional information to support this response is provided in RAI 49f.

RAI 49d

Differences between the design and as-built configurations in light of such differences which you cited as one of the reasons for not retrieving loose parts from inside a SG.

Response 49d

During the recent Byron Unit 2 steam generator inspection, during March of 1995, a loose part was found on a tube support plate in one of the Model D-5 steam generators. Due to the location of the part, visual observation and retrieval was not possible due to the lack of access through the existing penetrations. An evaluation was performed to determine the feasibility of installing a handhole in an appropriate location to retrieve the part. This evaluation included locating all internal components in the area of the proposed penetration by means of reviewing drawings and confirmation by ultrasonic testing. A composite sketch was made that indicated the internal components with their associated dimensions and locations. This sketch was used for evaluating the placement of the proposed handhole and for comparison with ultrasonic testing results. The ultrasonic test indicated that a wrapper position plate that was welded to the inner surface of the shell deviated from the sketch position by 3 inches and would impede the installation of the proposed handhole. Consequently, the handhole was not installed at this time and an evaluation was performed to leave the part in-place for one cycle while proper handhole placement is determined.

While developing this response, it was discovered that the composite sketch showing the internal components had an error in a dimension which mispositioned the wrapper position plate by 3 inches with respect to the actual design drawings. The ultrasonic test had in fact verified that the wrapper position block was located per design and that the composite sketch was in error. Therefore, no differences between design and as-built configurations are noted in reference to this loose part.

Differences between design and as-built configurations are further addressed in question 49.b.

RAI 49e

The applicability of the information discussed above to any SG internal component which serves a significant role in limiting the displacement of the TSPs during postulated accident conditions.

Response 49e

The information provided in the response to questions 49a through 49f apply to the SG load path components as follows:

1. In the absence of denting, there has been no evidence of service related degradation of any load path component in any Westinghouse fabricated unit (Question 49a and 49f).

2. The foreign experience in question 49a is related to fabrication by a fabricator other than Westinghouse.

3. A review of Byron and Braidwood fabrication records identified no evidence that the load path components are different from the design (Question 49b).

4. Corrosion behavior of carbon steel components in a low oxygen, high pH environment is well understood. Therefore, there is no reason to expect corrosion of the load path components in a non-heat transfer application.

As a defense-in-depth measure, to assure the preceding assessments are correct, ComEd has developed an inspection program for each of the load path components. This program is fully described in the answer to question 64 of the RAI issued from the Staff on August 24, 1994. This review and the internals inspection provide assurance that the public health and safety is not impacted by the implementation of the 3.0 volt IPC.

RAI 49f

Relevant operating experience from other nuclear power plants which could be used to assess the material condition of the SG internal structures, including any information gained from SG replacement projects.

Response 49f

ComEd has contacted utility personnel representing 69 out of 75 domestic PWR units, including 10 units that have replaced SGs. No SG internal structural concerns have been reported at 58 units. TSP cracking has been observed at 11 units as confirmed by visual inspection. The TSP cracking occurred in units with severe corrosion induced denting of SG tubes. TSP corrosion induced denting of SG tubes is associated with tube to TSP crevices filled with strong, acidic solutions i.e., high sulfate and chloride. SG tube ODSCC is associated with crevices filled with strong, caustic solutions i.e., high sodium and potassium. If excessive ODSCC is present in a SG, as has been seen at Byron Unit 1 and Braidwood Unit 1, then acidic crevices are not present. Therefore, corrosion induced TSP cracking in the Byron Unit 1 and Braidwood Unit 1 SGs will not occur.

Byron Unit 1 and Braidwood Unit 1 have not observed denting in either unit. It is ComEd's conclusion that the TSP's in the SG's at Byron Unit 1 and Braidwood Unit 1 are structurally sound. An inspection plan has been developed to verify TSP structural integrity. Provisions to assess the level of TSP denting and restriction on the use of a 3.0 volt IPC if such denting is present are contained within WCAP-14273.

RAI 50

If it is not possible to establish a conclusive basis for the integrity of all internal SG support structures based on the considerations in Item 49, provide your proposed SG internals inspection plan. Alternatively, provide an analysis of the TSP displacements which does not take credit for internal support structures for which inspection data is not available. (The staff notes that you previously provided an analysis excluding the support of the wedges.)

Response 50

The proposed SG internal inspection plan has been presented in the response to question 64 of the RAI issued on August 24, 1995. No additional TSP analysis is anticipated.

RAI 51 (Refer to Item 31.b in the staff's letter dated June 22, 1995.)

You propose that large mixed residuals for the hot leg of the SG tubes be defined as those masking a 3.0 volt indication (i.e., at the proposed voltage-based repair limit). This criterion is acceptable for eddy current indications which may lead to SG tube axial bursting, provided that these indications are contained within the TSPs. (Your analysis of this consideration is still under staff review.) For eddy current indications which may lead to circumferential SG tube burst, this condition may also be acceptable in light of your proposed 35 volt inspection criterion. (This consideration is also still under staff review.) Discuss how the potential leakage contribution will be considered from SG tubes containing mixed residuals which would mask indications less than 3.0 volts. The staff has previously found it acceptable to define a large mixed residual as one that would result in a 1.0 volt signal being either missed or misread.

Response 51

In the Byron/Braidwood Technical Specification revision submittal for a 3 volt IPC dated September 1, 1995, ComEd changed the criteria for large mixed residual inspection which had been presented in its July 7, 1995 submittal. The revised criteria now agrees with the requirements of Generic Letter (GL) 95-05. In the September 1, 1995 submittal, all intersections, hot-leg and cold-leg, that contain large mixed residuals that could cause a 1.0 volt bobbin coil signal to be missed or misread will be inspected with the rotating pancake coil (RPC). Any crack-like indications confirmed by RPC shall cause the tube to be repaired, and therefore, the voltage-based repair criteria will not be implemented at this intersection.

The main steam line break (MSLB) leakage contributions due to a missed or misread 1.0 volt indication due to a large mixed residual would not significantly contribute to the overall MSLB leakage evaluation. No indications below 1.0 volt in the EPRI probability of leak database have leaked. The end-of-cycle structural integrity of a 1.0 volt indication left in service is expected to meet the structural criteria of Regulatory Guide 1.121. This position is consistent with GL 95-05 for large mixed residuals.

Therefore, the Byron/Braidwood Technical Specifications submittal dated September 1, 1995 is consistent with the approach previously acceptable to the Staff.

RAI 52 (Refer to Items 32 and 35 in the staff's letter dated June 22, 1995.)

If dents greater than 5 volts, as measured by the bobbin coil, are identified in SG tubes adjacent to expanded tubes during the forthcoming and future outages, state whether the staff will be informed. State whether the staff will be informed if a 0.590 inch probe does not pass through a tube adjacent to an expanded tube in the forthcoming and future inspections.

State whether a SG tube with a 5.0 volt dent can have more than 65 mils of denting.

Response 52

The criteria for selecting tubes for expansion requires that the tube to be expanded and adjacent tubes do not contain corrosion induced dents greater than 5.0 volts. This is specified in Section 12.4 of WCAP 14273. Therefore, no intersections adjacent to the expanded intersections will contain corrosion induced dents during the forthcoming Byron Unit 1 and Braidwood Unit 1 inspections. The staff will be informed during future inspections should corrosion induced denting greater than 5.0 volts be found in intersections adjacent to expanded intersections. In addition, a safety assessment of the significance of this condition will be provided to the Staff should corrosion induced dents form in intersections adjacent to the tube expansions. As discussed in the response to question 32, the safety assessment will assess the structural integrity of the expanded tube TSP ligaments and its impact on limiting TSP displacements. If it is determined that additional tubes need to be expanded to maintain the necessary limited TSP displacements, then additional tubes will be expanded.

The use of the 0.590 inch diameter bobbin coil probe was to gauge if a 65 mil dent was present in a SG tube. ComEd has revised its position on how to gauge if a 65 mil dent is present in a SG tube. In the September 1, 1995 submittal for a 3 Volt IPC, ComEd specified that an appropriately size probe will be used as a go/no-go gauge for detection of a 65 mil dent. The appropriately sized probe will be the nominal 0.610 inch diameter bobbin coil probe. The Staff will be informed if the 0.610 inch diameter go/no-go probe fails to pass through a tube intersection adjacent to an expanded tube if this intersection has passed a 0.610 inch diameter probe in the past. Also, as is required by the September 1, 1995 3 volt submittal, if a 0.610 inch diameter probe will not pass through a portion of a tube, IPC will not be applied to this portion of the tube that is inspected by a smaller probe and IPC will not be applied to the adjacent intersections.

The typical correlation between bobbin voltage and dent sizes is 20-25 volts per uniform mil of radial dent. For non-uniform denting or for tube ovalization, the bobbin voltage is not easily predicted, however, a 65 mil dent or ovalization would result in a voltage significantly more than 5.0 volts. From field measurements of dents that have been sized by profilometry and measurements of laboratory induced dents, a 5.0 volt response is associated with much smaller than a 65 mil dent. Consequently, a 5.0 volt dent cannot have more than 65 mils of denting.

RAI 53

Item 33 of the staff's letter dated June 22, 1995 , was intended to address circumferential cracking at the expansion transition in the SG tube at the top of the tube sheet and not the SG tube expansion transition at the expanded TSP location. Accordingly, state what inspections will be performed at the SG tube expansion transition at the top of the tube sheet and whether indications of circumferential cracking at this location will be reported to the NRC as well as any circumferential cracking at the TSP intersections.

Response 53

The scheduled inspection scope for the 1995 outages at Braidwood Unit 1 and Byron Unit 1 include a 100% RPC inspection of the hot-leg, top of tube sheet expansion transitions. The focus of these inspection is to identify circumferential cracking at the tube sheet roll transition regions. The results of these inspections will be reported to the Staff in the normal eddy current inspection report required by Technical Specification 4.4.5.5.d. Tubes selected for expansion at the TSPs are required to be Non-detectable Degradation (NDD) for circumferential cracking at the top of the tube sheet.

At subsequent periodic inspections of the expanded tubes, the staff wiii be notified prior to restart if circumferential cracks are found at the top of tube sheet expansions or at the TSP intersections as discussed in the response to Question 33 of the RAI issued by the Staff on June 22, 1995. A circumferential crack at the top of the tube sheet in the expanded tubes would be evaluated and reported the same as a circumferential crack found at the TSPs. In the September 1, 1995 submittal for a 3.0 volt IPC, ComEd is proposing that Technical Specification 4.4.5.5.d.2 require the notification of the NRC prior to plant operation (Mode 4) should circumferential cracking be detected at TSP intersections. This reporting requirement is consistent with GL 95-05.

RAI 54 (Refer to Item 41 in the staff's letter dated June 22, 1995.)

Provide a plot of the axial force required to fail a SG tube versus the bobbin voltage for those SG tube specimens which were tensile tested. Provide a discussion of the material properties adjustments made to the data, if any. Discuss how the lower tolerance limit material properties curve was developed in Figure 41-1 given that both 3/4-inch and 7/8-inch data are used. The staff notes that the residual SG tube cross-sectional area may vary with the axial elevation of the degradation. For the correlation in Figure 41-1, discuss how the appropriate residual cross-sectional area was determined (i.e., the location where the circumferential severance is postulated to occur).

Response 54

1. Introduction

Section 9.0 of WCAP-14273, Reference 1, presents axial strength information for cellular corrosion in the form of a correlation of the remaining cross-section area (CSA) of the tube as a function of the bobbin amplitude of the TSP ODSCC. Previous RAIs from the NRC requested an assessment of the probability of burst associated with the potential for a circumferential separation of the tube during a postulated SLB event. In response to that request, the correlations of the WCAP were repeated and an estimate of the probability of burst as a function of bobbin amplitude was calculated.

The evaluation of Reference 1 was based on developing a correlation between the bobbin amplitude and the fraction of the remaining CSA of the tube, A_f. Based on information from examinations performed in Belgium, the correlation appeared to be independent of tube size. A relationship of form,

$$A_f = a_0 + a_1 V , \qquad (1)$$

was fitted to the available data using least squares regression. The database consisted of the results of destructive examinations and the results from tensile testing of removed tube sections, from which the remaining CSA was estimated from the structural properties of the tube material. The residual strength of a tube with cellular ODSCC at the elevations of the TSPs could then be estimated as a function of the tube size and the structural properties of the tube material.

This question requests the results that would be obtained using only the data from specimens which were tensile tested, i.e., establishing a correlation of axial rupture force to bobbin amplitude. The following sections describe the database for such an evaluation, the results of performing regression analyses using that database, and conclusions regarding the probability of circumferential rupture.

2. Regression Analysis Database

The data used in the regression analysis are listed in Table 54-1. These represent the specimens which were tensile tested as part of their destructive examination. As for the correlation of the burst pressure of TSP ODSCC indications to the bobbin amplitude, the results of tests of some NDD specimens were included in the database to *anchor* the left end of the curve. These were assigned a bobbin amplitude of 0.1 volt.

Regression analyses were performed independently for the 3/4" and the 7/8" data and for a combined database obtained by modifying the 7/8" axial force results to be representative of 3/4" diameter tubing.

Adjustment for Flow Stress

In addition to presenting the bobbin amplitude and axial rupture force, Table 54-1 lists the structural properties of the tubes tested and a *normalized* rupture force based on standardizing the results to a reference value of the flow stress, e.g., 75 ksi. This is identical to the data adjustments made to correlate the burst pressure of tubes with indications to the bobbin amplitude. The normalization in this case could be made to either the ultimate tensile stress or the flow stress without significantly affecting the results. The analysis presented here is based on normalizing the flow stress since the axial strength of tubes with circumferential cracks has been successfully predicted as a function of flow strength rather than as a function of ultimate tensile strength (although for an uncracked tube the ultimate tensile strength would be used).

Adjustment for Tube Size

As noted previously, the correlation of the remaining CSA *fraction* to the bobbin amplitude was found to be approximately independent of tube size. Hence, a correlation of the remaining CSA (i.e., area rather than fraction of undegraded area) to the bobbin amplitude would be dependent on tube size. This is also expected to be the case for a correlation of the axial rupture force to the bobbin amplitude. Thus, in order to consider a merged database, an adjustment of the data based on the tube CSA is needed. Intuitively, one would expect that a simple adjustment based on the non-degraded CSA could be valid since this is the type of adjustment to be made to correlate results for non-degraded tubes. Thus, the correlation of the axial rupture force divided by the undegraded area to the bobbin amplitude was investigated. This was done for this analysis by simply reducing the axial force data for 7/8" tubes by the ratio of the non-degraded area of a 3/4" tube to that of a 7/8" tube, i.e., the force results for 7/8" tubes were reduced by a factor of 0.737 to be representative of 3/4" tubes, and then correlating the axial rupture force to the bobbin amplitude for 3/4" diameter tubes. The basic assumption being made here is that the slope of the correlation of the rupture force to the bobbin amplitude is independent of volts. A visual examination of the resulting database, see Figure 54-1, confirmed the assumption as being reasonable.

3. Selection of a Regression Coordinate System

The selection of the regression coordinate system was based on examining the index of determination for various coordinate systems as described in Appendix A of Reference 2. This was done independently for the 3/4" and 7/8" data and for the combined database. For each case considered, the correlation of the rupture force, F_r, to the common logarithm of the bobbin amplitude resulted is the largest index of determination, r^2. The results of the comparisons are listed in Table 54-2. Taken as a percentage, the index of determination is a measure of how much of the variance of the data is explained by the regression, thus, the larger the value, the better the implied correlation.

For the combined database, a second order polynomial fit was also performed. The index of determination for the second order fit was found to be 66.4%, thus not offering a significant advantage relative to the linear regression which had an index of determination of 65.7%. Thus, the final form of the regression equation relating the axial rupture force to the bobbin amplitude, V, is,

$$F_r = b_0 + b_1 \log(V), \qquad (2)$$

where the maximum likelihood estimates of the values of the coefficients b_0 and b_1 are obtained from the regression analysis.

4. Results of the Regression Analysis

The results of the regression analysis are provided in Table 54-3 and illustrated on Figure 54-1. In summary, the axial rupture force in thousands of pounds, klbs, can be reliably predicted from the bobbin amplitude as,

$$F_r = 7.905 - 1.173\log(V). \tag{3}$$

The standard error of the rupture force predicted by the regression equation is 0.788 klbs. The standard error of the slope coefficient is 0.219 and the *p*-value for the slope coefficient is 8.0×10^{-5}. Since this is less than the criterion value of 0.05, i.e., 5%, the use of the regression equation is considered to be justified.

Using the above equation, a 95% one-sided prediction bound for the rupture force as a function of bobbin amplitude was calculated. The resulting curve was also adjusted to represent 95/95 lower tolerance limit (LTL) material properties. Both of these curves are also depicted on Figure 54-1. It is apparent that the structural limit obtained from this analysis approach is in excess of 100 volts.

5. Discussion of the Regressions for 3/4" and 7/8" Tubes

Separate regression analyses were performed for the 3/4" and 7/8" databases (See Figures 54-4 and 54-5). The intercepts from these regression analyses were 7.824 and 10.776, respectively. Adjusting the 7/8" result by a factor of 0.737 results in an intercept of 7.942; which is very close to the result obtained for the 3/4" data. The slope for the 3/4" data was found to be -1.102; while that for the 7/8" data was -1.726. Since the database for the 7/8" tubes is rather small, four degraded tube results, the value of the slope obtained relative to that from the 3/4" data is not judged to be unreasonable. To verify this judgement, the pooled estimate of the variance of the residuals from the two regressions and the *t* statistic for the difference in the slopes were calculated. These were found to be 0.936 and 0.578, respectively. The probability of obtaining an absolute value of *t* greater than or equal to 0.578 for 13 DoFs is about 57%. Thus, the data do not contradict the assumption that the slope of the correlation could be considered to be independent of the tube size, i.e., there is no indication that merging the data based only on an adjustment of the rupture force, which is independent of voltage, is not justified. Although the upper prediction bound is not shown on Figure 54-1, all of the data fall within the a two-sided 90% prediction band.

6. Analysis of the Regression Residuals

The residuals of the regression analysis were analyzed as described in Appendix A of Reference 2. A plot of the residuals as a function of the predicted rupture values is shown on Figure 54-2. It is apparent from this figure that the residuals are independent of the predicted rupture force and that the variance of the residuals is approximately uniform. A normal plot of the ordered residuals is shown on Figure 54-3. When compared to Figure 3A.4 of Reference 3, it is apparent that the residuals are approximately normally distributed. Thus, the assumptions inherent in performing the regression analysis are verified and the use of the results of the regression analysis may be considered to be justified.

7. Probability of Burst

Using the results of the regression analyses, the probability of rupture (PoR) of an individual indication was estimated using the methodology described in Section 5 of Reference 2, which includes the effect of the uncertainties in determining the regression coefficients. The results are illustrated on Figure 54-6. For a single 10 volt indication, the PoR is on the order of $3 \cdot 10^{-6}$. The rupture force is taken as the product of two normal distributions, i.e., the regression prediction times a factor accounting for the distribution of material properties, so the distribution of the rupture force is skewed right. Therefore, estimating the PoR based on inference statistics for a symmetric distribution yields conservative results.

8. Summary/Conclusions

The database relating the axial rupture force to the bobbin amplitude for tube ODSCC indications at TSP elevations was analyzed to yield an equation for predicting the rupture force as a linear function of the common logarithm of the bobbin amplitude. The following are a summary of the results of the evaluation:

1) It was found that a single equation could be used to predict rupture force for 3/4" and 7/8" tubes if the force is adjusted to account for the undegraded cross-section area of the tube.

2) The data indicate that the structural limit for axial separation during a SLB event is greater than 100 volts.

3) For a single indication with a bobbin amplitude of 10 volts, the probability of axial separation during a SLB event is on the order of $3 \cdot 10^{-6}$.

References:

1. WCAP-14273 (Proprietary), "Technical Support for Alternate Plugging Criteria with Tube Expansion at Tube Support Plate Intersections for Braidwood 1 and Byron 1 Model D4 Steam Generators," Westinghouse Electric Corporation, February, 1995.

2. WCAP-14277, "SLB Leak Rate and Tube Burst Probability Analysis Methods for ODSCC at TSP Intersections," Westinghouse Electric Corporation, January, 1995.

3. Draper, N., and Smith, H., Applied Regression Analysis, Second Edition, John Wiley & Sons, New York (1981).

Table 54-1: Database for Correlating Axial Rupture Strength of Cellular ODSCC Specimens with the Bobbin Amplitude of the Indication								
Plant[1]	Tube/TSP	Bobbin Amplitude (Volts)	Yield S_y (ksi)	Ultimate S_u (ksi)	Flow S_f (ksi)	Rupture Force (lbs)	Strength Normalized (lbs)	Size Normalized (lbs)
E-4	R47C66/4	0.3	51.0	97.0	74.0	7.014	7.109	7.109
E-4	R45C54/3	1.4	54.0	97.0	75.5	7.644	7.593	7.593
E-4	R33C96/2	6.0	54.0	97.0	75.5	7.194	7.146	7.146
E-4	R26C34/3	8.6	53.0	100.0	76.5	7.756	7.604	7.604
E-4	R26C47/2	11.7	52.0	96.0	74.0	6.632	6.722	6.722
E-4	R16C31/3	15.7	60.0	112.0	86.0	6.745	5.882	5.882
E-4	R47C66/2	16.0	51.0	97.0	74.0	5.171	5.241	5.241
E-4	R45C54/2	16.2	54.0	97.0	75.5	7.419	7.370	7.370
E-4	R43C87/2	20.0	54.0	97.0	75.5	6.812	6.767	6.767
AA-1	R16C42/FS	0.1[2]	49.7	98.0	73.8	9.356	9.504	9.504
AA-1	R27C43/FS	0.1[2]	62.3	113.6	88.0	10.853	9.254	9.254
P-1	R22C38/FS	0.1[2]	63.3	111.6	87.5	14.783	12.678	9.344
P-1	R28C42/FS	0.1[2]	58.5	106.1	82.3	14.320	13.058	9.623
P-1	R22C38/2	0.3	63.3	111.6	87.5	11.420	9.794	7.218
P-1	R28C42/1	0.6	58.5	106.1	82.3	13.750	12.538	9.240
P-1	R22C38/3	0.6	63.3	111.6	87.5	12.000	10.292	7.585
P-1	R28C42/2	1.0	58.5	106.1	82.3	12.500	11.398	8.400

Notes:
1. Specimens for plants E-4 and AA-1 are of nominal 3/4" OD by 0.043" thick. Specimens from plant P-1 are of nominal 7/8" OD by 0.050" thick.
2. NDD specimens assigned a value of 0.1 volt similar to the assignment for NDD specimens used in the development of the burst strength versus bobbin amplitude correlation.

Table 54-2: Indices of Determination for the Linear Correlations Investigated			
Database Considered	Ordinate Coordinate	Abscissa Coordinate	
		Volts	Log(Volts)
3/4" Tubes	Force	51.1 %	**64.2 %**
	Log(Force)	50.5 %	59.4 %
7/8" Tubes	Force	14.0 %	**28.9 %**
	Log(Force)	12.0 %	26.5 %
Combined 3/4" & 7/8"	Force	52.9 %	**65.7 %**
	Log(Force)	54.3 %	63.5 %

Table 54-3: Regression Analysis of Axial Rupture Force on Bobbin Amplitude Results $F_r = b_0 + b_1 \log(V)$	
Parameter	Value
Intercept (b_0)	7.905
Slope (b_1)	-1.173
Force Standard Error	0.788
Index of Determination (r^2)	65.7 %
Degrees of Freedom (DoF)	15
Slope *p*-Value	$8.0 \cdot 10^{-5}$

Note: The data used for this regression analysis were normalized to an ultimate tensile strength of 100 ksi.

Figure 54-1: Axial Rupture Force vs. Bobbin Amplitude
Data Adjusted to 3/4" x 0.043" SG Alloy 600 MA Tubes, S_f = 75 ksi

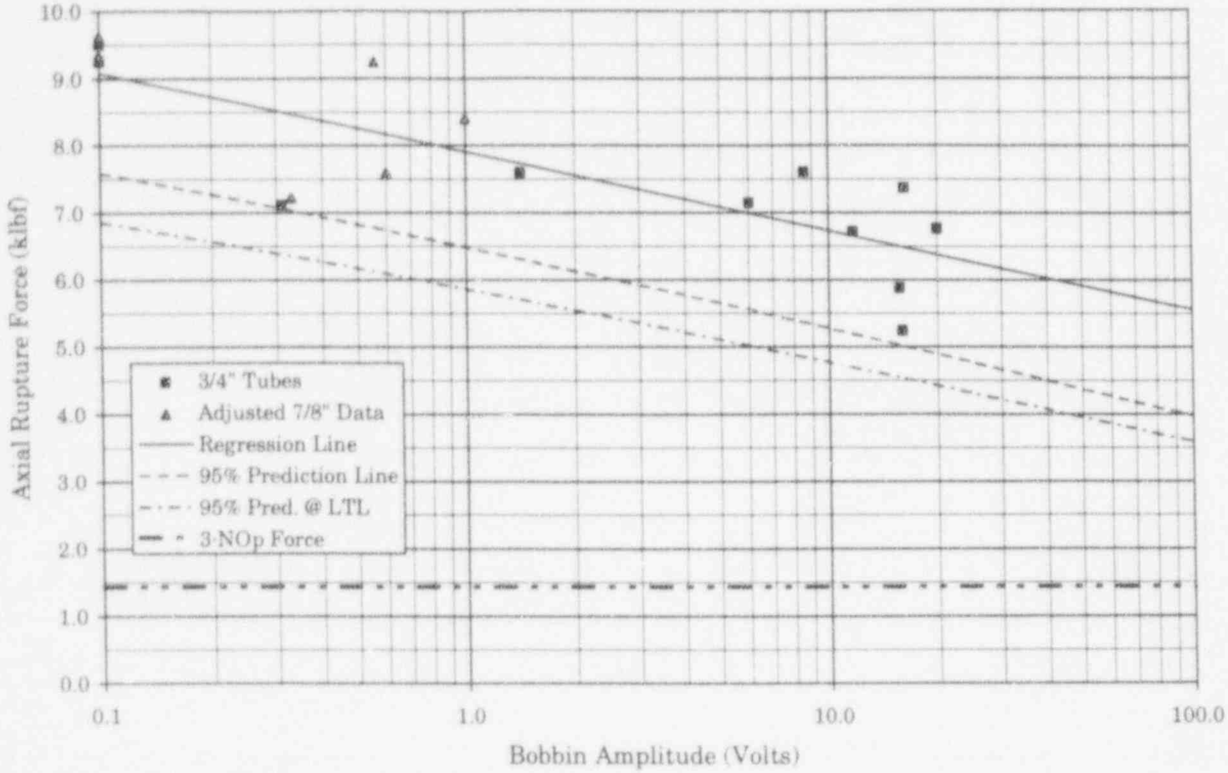

Figure 54-2: Residual vs. Predicted Rupture Force
Correlation of Axial Rupture Force to Bobbin Amplitude

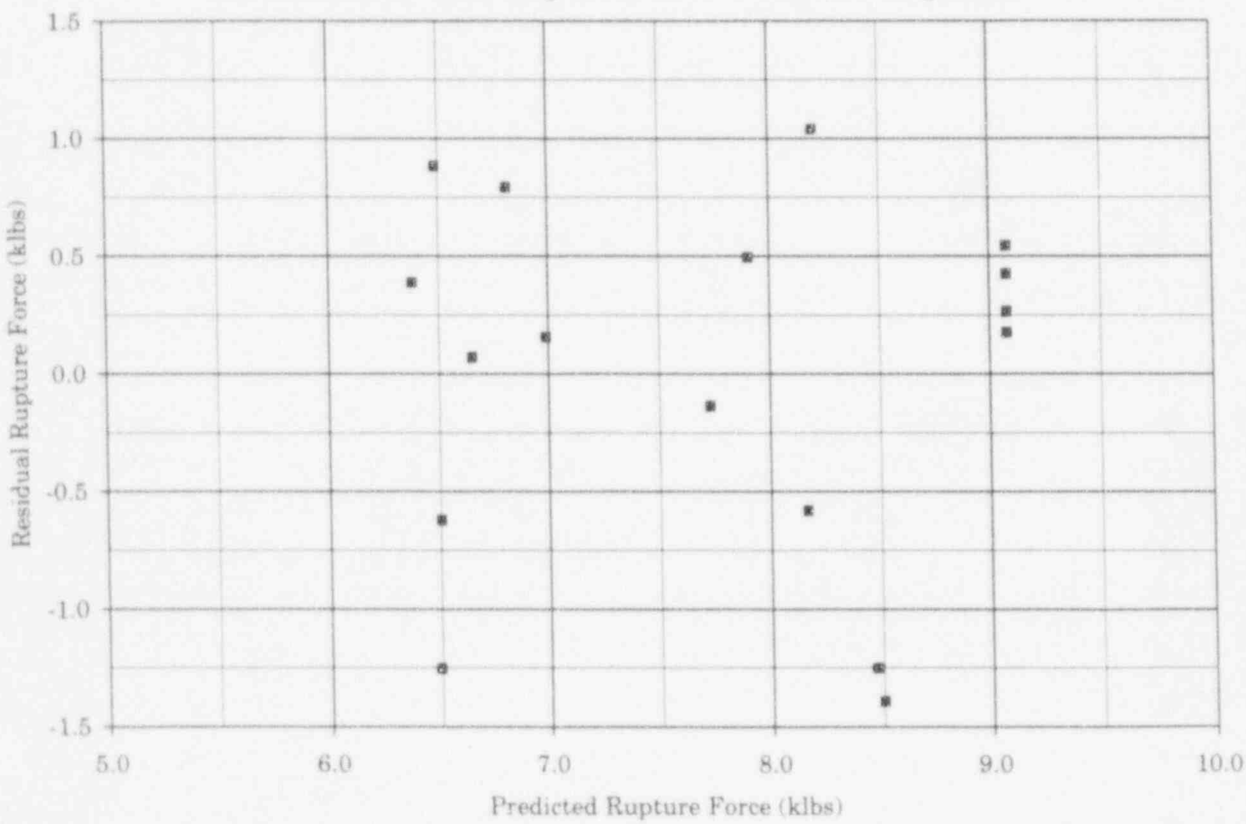

Figure 54-3: Cumulative Probability vs. Ordered Residual Value
Correlation of Axial Rupture Force to Bobbin Amplitude

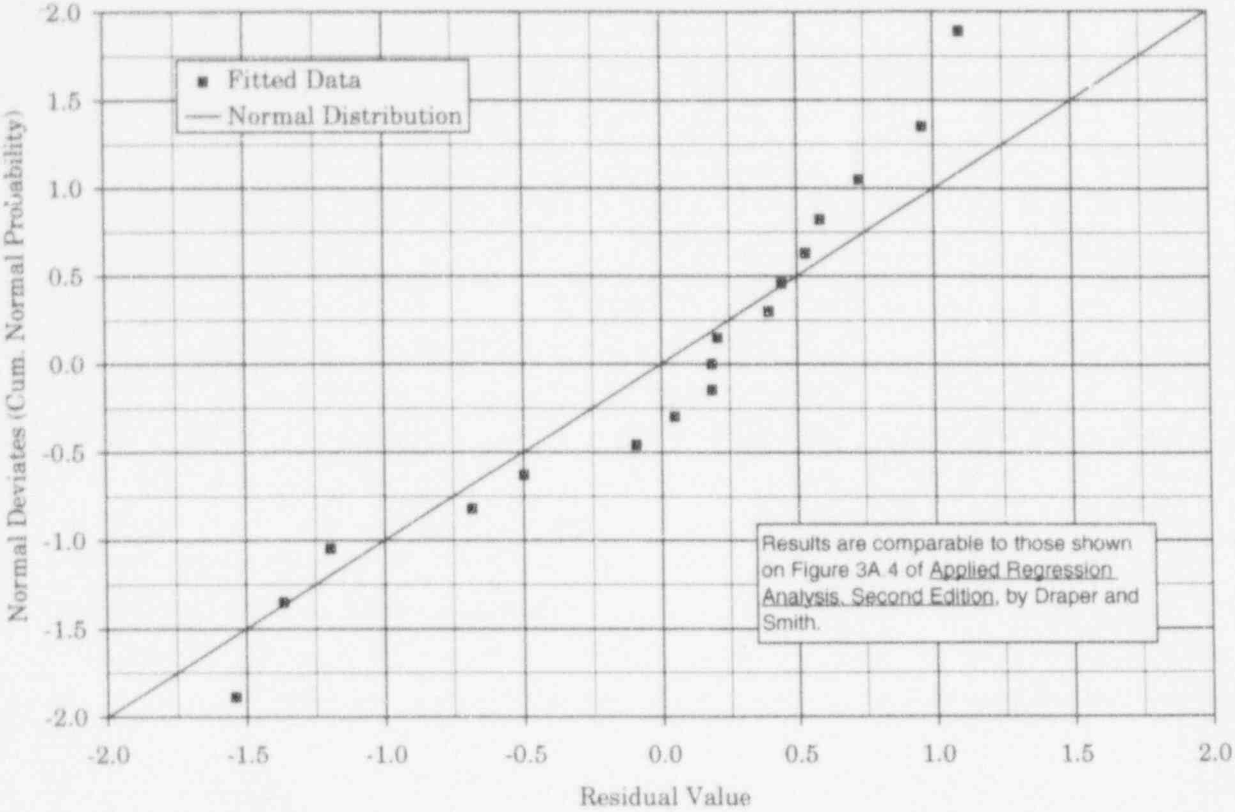

Figure 54-4: Axial Rupture Force vs. Bobbin Amplitude
3/4" OD x 0.043" Thick, Alloy 600 MA SG Tubes, S_f = 75 ksi

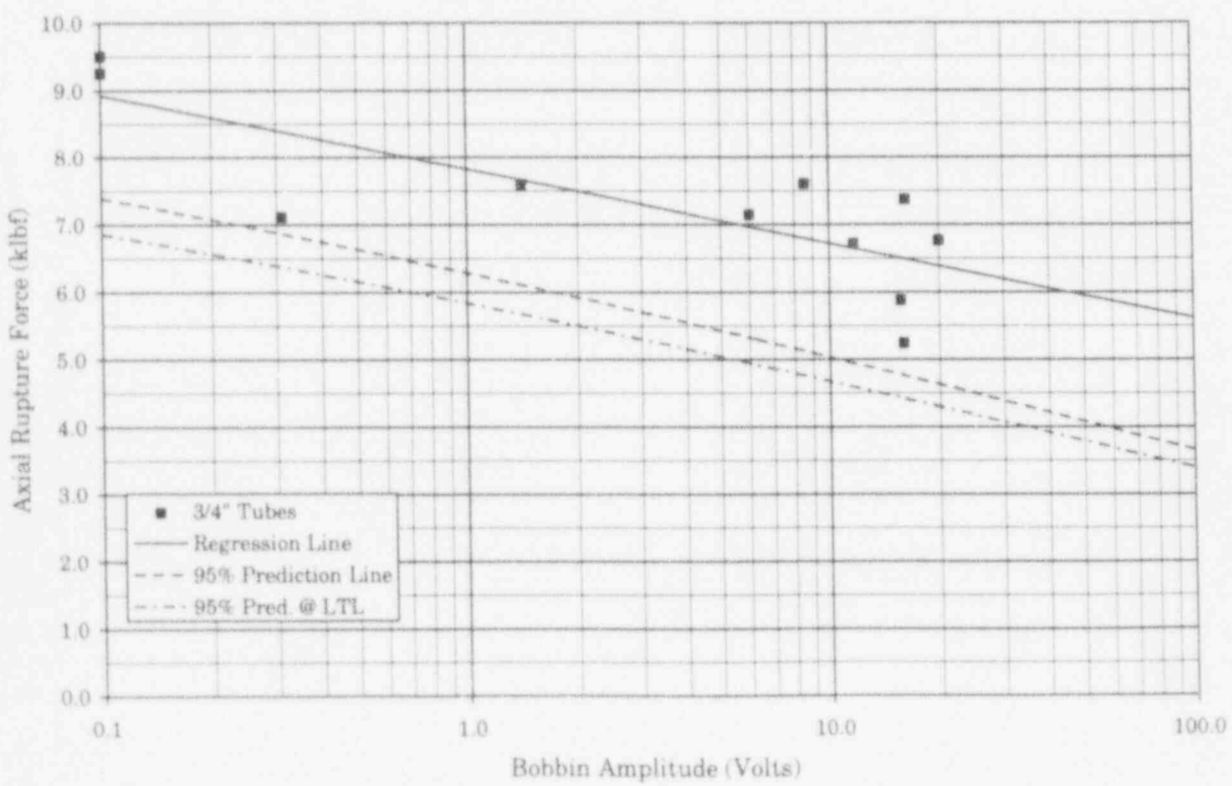

Figure 54-5: Axial Rupture Force vs. Bobbin Amplitude
7/8" OD x 0.050" Thick Alloy 600 MA SG Tubes, S_f = 75 ksi

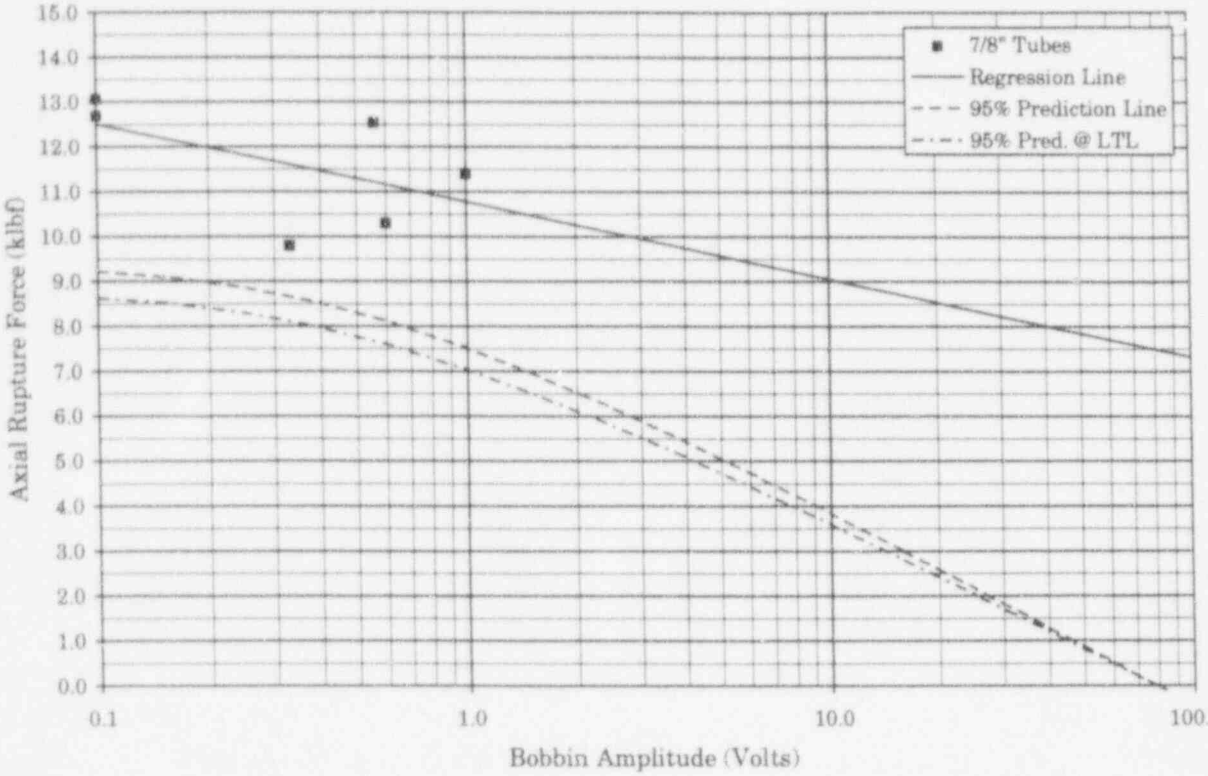

Figure 54-6: Probability of Rupture vs. Bobbin Amplitude
TSP ODSCC for 3/4" x 0.043" Alloy 600 MA SG Tubes