BEAVER VALLEY UNIT 1

INTERIM PLUGGING CRITERIA 90 DAY REPORT

MAY 1995

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1.0 INTRODUCTION

This report provides the Beaver Valley-1 steam generator steam line break (SLB) leak rate and tube burst probability analysis results in support of the implementation of a 1.0 volt Interim Plugging Criteria (IPC) at end of cycle 10 (EOC-10). Information required by the NRC Safety Evaluation Report (SER) is included in this report. The analysis results are provided for Steam Generator (SG) A, which is the limiting SG for the actual EOC-10 and projected EOC-11 bobbin voltage distributions.

The results of the EOC-10 inspection are provided in Section 4. At EOC-10, plugs were removed from previously plugged tubes, the tubes were reinspected, and tubes with indications satisfying the IPC repair limits were returned to service. The indications returned to service are included in the Cycle 11 analyses. Comparisons of the EOC-10 voltage distributions as well as leak rates and tube burst probabilities calculated for the actual distributions are compared with the projections to EOC-10 previously reported in the Beaver Valley-1 IPC report, WCAP-14123, Reference 9.1. Leak rates and burst probabilities for the projected EOC-11 voltage distributions are reported in Section 8 and compared with allowable limits. Analysis methods are consistent with the NRC SER and WCAP-14123. The methods are described in more detail in the Westinghouse methods report, WCAP-14277, Reference 9.2.

Three tubes were pulled from Beaver Valley Unit 1 steam generators during the cycle 10 outage to provide additional data supporting the Alternate Plugging Criteria (APC) database. Pulled tube examination results for the tube support plate (TSP) indications on the pulled tubes are given in Section 3.

2.0 SUMMARY AND CONCLUSIONS

SLB leak rate and tube burst probability analyses were performed for the actual EOC-10 and projected EOC-11 voltage distributions. SG A was found to be the limiting SG for both the EOC-10 inspection and the projected EOC-11 distributions. For the actual EOC-10 distribution, the SLB leak rate is estimated to be 0.15 gpm and the burst probability is 3.84×10^{-5}. These values are lower than projected for EOC-10 in WCAP-14123 even for an assumed probability of detection (POD) of 1.0 at EOC-9. The projected EOC-11 distributions with the NRC SER required POD = 0.6 result in a SLB leak rate of 0.31 gpm and a burst probability of 9.7×10^{-5}. All results are much lower than the allowable SLB leakage limit of 6.6 gpm and the NRC reporting guideline of 10^{-2} for the tube burst probability.

Comparisons of the EOC-10 projections with the actual distribution for SG A show that a POD = 1.0 results in an over prediction of the indications > 0.8 volt and an under prediction below 0.8 volt, while the POD = 0.6 substantially overestimates the actual distribution above 0.5 volt. These results show the importance of applying a voltage dependent POD and adjusting rotating pancake coil (RPC) NDF (no degradation found) indications left in service by the fraction of indications that may become confirmed at the end of the next operating cycle. These comparisons of projections with the actual distribution imply a POD approaching unity above about 1.0 volt and about 0.6 at about 0.5 volt.

A total of 1089 indications were found in the EOC-10 inspection of which 152 were RPC inspected (including all indications above 1.0 volt) and 88 were confirmed as flaws by the RPC inspection. The RPC confirmed indications included 66 above 1.0 volt. SG A had 484 bobbin indications of which 73 were above 1.0 volt and 41 of the 73 were confirmed by RPC inspection. During the inspection, 242 previously plugged tubes were deplugged and inspected for possible return to service based on the 1.0 volt IPC. A total of 164 tubes (80 in SG A) with 223 indications (113 in SG A) were found to satisfy the IPC repair limits and were returned to service. This resulted in a total of 1201 indications returned to service including 535 in SG A. No unexpected inspection results were found at the TSP intersections such as circumferential indications, indications extending outside the TSP or primary water stress corrosion cracking (PWSCC) at dented TSP intersections.

Three tubes with eight TSP intersections were pulled during the outage to provide data to support the Electric Power Research Institute (EPRI) IPC/APC correlations. Five of the eight intersections had field reported flaw indications and a sixth TSP intersection had a small 0.29 volt indication found by reevaluation of the field data and also found by the ultrasonic test (UT) inspection. The bobbin flaw voltages for these indications ranged up to 1.08 volts. One intersection had a mixed residual signal of 1.73 volts with a flaw indication of 0.62 volt. Post-pull eddy current data show modest and acceptable changes in voltage compared to field inspection. The post-pull RPC data show crack indication features typical of that found previously for indications

with cellular patches. The field RPC and UT data also include volumetric features typical of cellular corrosion.

Two of the pulled tube indications were leak tested with no resulting leakage even at SLB pressure differentials. All eight intersections were burst tested with resulting burst pressures near or above the mean EPRI burst correlation. Inclusion of the Beaver Valley-1 pulled tubes in the probability of leakage and burst pressure correlation results in negligible changes to the correlations without the Beaver Valley-1 data. Four indications were axially tensile tested to the axial load capability for the cellular indications in support of the database for a tube expansion APC. These tensile test results were also found to be consistent with the existing database. The crack morphology for the Beaver Valley-1 pulled tubes is dominantly axial ODSCC with cellular patches and is consistent with that found in the EPRI database supporting IPC applications.

The probability of prior cycle detection (POPCD) was evaluated for the EOC-9 inspection based on indications RPC confirmed plus not RPC inspected in 1995. The inclusion of indications not RPC inspected leads to a lower bound POD assessment, since it can be expected that many of these low voltage (< 1.0 volt) indications would not be confirmed by RPC. A POD assessment based on RPC confirmed indications is appropriate for IPC applications since only indications detected by both bobbin and RPC probes can be expected to contribute significantly to leakage and burst at EOC-10. This is based on the database for POD versus maximum depth from pulled tube examinations that show that both bobbin and RPC PODs approach unity at > 90% depth. The Beaver Valley-1 EOC-9 POPCD strongly supports a voltage dependent POD substantially higher than the NRC POD = 0.6 above about 0.5 volt and approaching unity above 2 to 3 volts. The Beaver Valley-1 POPCD is in general agreement with the EPRI proposed POD even though the EOC-9 inspection was not an IPC inspection. It is concluded that the POD applied for IPC leak and burst projections needs to be upgraded from the POD = 0.6 to a voltage dependent POD. This conclusion is further supported by the comparisons in Section 7 between projected and actual EOC-10 voltage distributions. The comparisons in Section 8 of SLB leak rates and tube burst probabilities calculated from the EOC-10 projected distributions by applying a POD = 1.0 exceed those calculated from the actual EOC-10 distributions.

3.0 BEAVER VALLEY UNIT 1 1995 PULLED TUBES

3.1 PULLED TUBE EXAMINATION RESULTS

3.1.1 Introduction

Three hot leg steam generator tube segments removed from Steam Generator A of Beaver Valley Unit 1 (Tube R10C48, Tube R22C38 and Tube R28C42) were examined at the Westinghouse Science and Technology Center in support of alternative repair criteria (ARC) applications. The examination was conducted to characterize corrosion at steam generator hot leg support plate crevice locations. The tubes were selected to obtain a sampling of the indications observed in the January 1995 field eddy current inspection. The first, second and third support plate crevice regions (TSP1, TSP2 and TSP3) from Tubes R22C38 and R28C42 and the TSP1 and TSP2 region from Tube R10C48 were removed for examination. Five of these eight TSP locations had original field eddy current calls of OD origin indications.

After nondestructive laboratory examination by eddy current, ultrasonic testing, radiography, dimensional characterization and visual examination, two selected support plate regions were leak tested at elevated temperature. Subsequently, room temperature burst testing was conducted on these two TSP regions, as well as the remaining six non-leak tested TSP regions and a free span section from each of the three tubes pulled for ARC applications. Four of the burst tested TSP specimens were destructively examined using scanning electron microscopy (SEM) fractography techniques to characterize the corrosion and two of these four TSP burst tested specimens were further examined using metallography. The remaining four burst tested TSP regions were pulled apart by tensile testing to characterize the effect of intergranular cellular corrosion (ICC) that had been observed within the crevice region adjacent to the burst openings. Both the axial burst openings and the circumferentially torn ICC regions were characterized by SEM fractography techniques. Three of these four TSP regions were then characterized using metallographic techniques. Overall, all eight TSP intersections had their burst fracture faces characterized by SEM fractography and five of the intersections were further examined using metallography.

3.1.2 Non Destructive Examination (NDE) Results

Table 3-1 presents a summary of the more important field and laboratory NDE results. The eddy current data were reviewed, including reevaluation of the field data, to finalize the voltages assigned to the indications and to assess the field no detectable degradation (NDD) calls for detectability under laboratory analysis conditions. A single analyst performed this work to minimize data variability. NDE data were taken in the field by bobbin, RPC and UT probes. The results for the different probes are generally consistent except for the first TSP of R10C48 which was NDD for the field bobbin and RPC probes but reported by UT probe as axial indications. Laboratory review of the field data and the post-pull bobbin data indicate a small 0.29 volt bobbin indication (see Figure 3-1) for R10C48, TSP1. In

addition, laboratory review of the field RPC data indicated a possible small indication at R28C42, TSP3, which is seen in the post-pull bobbin but not identified in the field calls for either of the four probes. The laboratory review and field bobbin voltages are in reasonable agreement and, except for R22C38, TSP3, show modest differences due to analyst interpretation of the distorted bobbin responses. The field call for R22C38, TSP3 was intentionally called to include the residual bobbin signal to assure that the indication was included in the RPC program for residual signals that could mask a bobbin signal near one volt. The flaw component of this indication as obtained from the reevaluation of the field data is 0.62 volt (see Figure 3-2). The laboratory reevaluation of the field voltages is recommended for the ARC voltage, consistent with prior tube pull evaluations, to minimize analyst variability in the database voltages since analyst variability is a component of the NDE uncertainty used for ARC analyses.

The RPC and UT responses indicate a high likelihood of cellular corrosion patches which can lead to some distortion in the bobbin responses. Figure 3-3 shows the pre-pull RPC inspection data for R28C42, TSP2. The broad angular involvement shown in Figure 3-3 is typical of that found for cellular patches. Similarly, the UT results indicated the presence of many small indications in addition to the larger macrocrack associated with the peak RPC response.

As a result of the tube pulling operations, the post-pull bobbin data show dent signals at most of the TSP intersections. These dent signals were not present in the pre-pull bobbin data. As a consequence, the post pull bobbin data have somewhat reduced reliability for assessing the differences between pre-pull and post-pull bobbin voltages although the dents are less than 5 volts, and bobbin voltages can be adequately identified. Some increase in signal strength (voltage) was generally observed in the laboratory eddy current data due to the tube pulling operation. Field bobbin probe signal strengths ranged from 0.44 to 1.73 volts (0.33 to 1.0 volts after data reevaluation) while corresponding post-pull bobbin strengths ranged from 0.45 to 2.1 volts. The largest increase was for Tube R22C38, TSP3 where the bobbin probe signal strength increased from 0.6 volts to 2.1 volts (with a secondary indication of 0.5 volts). This is considered a moderate increase suggesting that there was some tearing of ligaments between microcracks. In addition, R28C42, TSP3 shows a post-pull bobbin indication which was not identifiable in the pre-pull bobbin data although indicated by laboratory reevaluation of the field RPC data.

3.1.3 Leak Testing

Two TSP crevice regions (TSP3 of Tube R22C38 and TSP2 of Tube R28C42), those which had the largest voltage (original) field eddy current indications were leak tested at elevated temperature and pressure at conditions ranging from a simulated normal operating condition to a simulated steam line break condition. None developed leaks. Table 3-2 presents test condition data for the specimens.

3.1.4 Burst and Tensile Testing

All eight pulled TSP crevice regions and three free span regions were burst tested at room temperature at a pressurization rate of 2000 psi per second. The burst tests were performed simulating free span conditions with no TSP enveloping the indications. In addition, the five field indication specimens were tested using a bladder and foil for the burst tests with a "semi-constraint" condition which simulated the lateral constraint provided by the TSPs located below and above the crack indication at prototypical spacing between TSPs. Results of the burst tests are presented in Table 3-3. All burst specimens developed axial burst openings. The openings for the TSP crevice region specimens were centered within the crevice regions. The circumferential positions of the burst openings in the support plate crevice region specimens were close to the location of the deepest laboratory UT indications for the specimens that had corrosion indications. The eddy current RPC data does not provide an absolute circumferential position. All TSP specimens burst at high pressures. The lowest burst pressure for the TSP crevice regions (Tube R22C38, TSP1, a 0.7 volt field bobbin indication) was 9,712 psi, 80% of the burst pressure of its free span equivalent.

Following burst testing, a visual inspection showed the presence of wide-spread ICC that was confined to the crevice region. As a consequence, four of the burst specimens (Tube R22C38, TSPs 2 and 3 and Tube R28C42, TSPs 1 and 2) were tensile tested at room temperature to obtain tensile strength data and to pull apart the ICC networks for subsequent destructive examination. These four specimens had high tensile loads, with the lowest being 11,420 psi (R22C38, TSP2). Table 3-3 provides the tensile properties obtained on these four specimens, as well as from a nonburst tested, free span section from each of the pulled tubes.

The tensile and burst strengths for the free span sections are typical for Westinghouse tubing of this vintage, although the strengths of Tubes R10C48 and R22C38 are somewhat on the high side.

3.1.5 Destructive Examination Results

A summary of post-burst test visual inspection data and of burst property data related to the presence of corrosion is presented in Table 3-4 for each of the burst TSP region specimens. The data in Table 3-4 were used to plan destructive examination work efforts. Corrosion cracks were observed on all eight of the TSP specimens. These eight specimens were candidates for destructive examination. The free span sections of Tubes R10C48, R22C38 and R28C42, selected for a reference burst pressure and tensile property test, had no degradation, as would be expected. Two of the four specimens, shown in Table 3-4, that were burst tested, but not tensile tested, were selected for complete destructive examination of their crevice region corrosion. These examinations included SEM fractography of the burst openings and metallography of secondary corrosion within the crevice regions. The other two were characterized by SEM fractography of their burst openings. In addition, three of the four specimens, shown in Table 3-4, that were burst and then tensile tested, were

selected for complete destructive examination, that included SEM fractography of both their axial burst openings and their circumferentially tensile torn fracture faces, as well as metallography of secondary crevice region corrosion. The fourth burst and tensile tested specimen was characterized by SEM fractography of both its axial burst opening and its circumferentially tensile torn fracture face.

The burst fracture faces of these eight TSP crevice region specimens were opened for SEM fractographic examinations. Table 3-5 presents the results of the fractographic data in the form of macrocrack length versus depth, macrocrack length/average and maximum depth, and the number/location/width of ductile or uncorroded ligaments found on the fracture face. The burst openings occurred in axial macrocracks that were composed of numerous axially oriented intergranular microcracks of OD origin. Ductile ligaments separating the microcracks were present in six of the eight examined TSP specimens. The data of Table 3-5 indicate that most of the TSP regions from Beaver Valley Unit 1 pulled tubes had a typical number of remaining uncorroded ligaments between microcracks comprising the burst macrocracks. Only R22C38, TSP1 had no remaining ligaments and had a maximum depth of 52% with an average depth of only 26%. All intergranular corrosion was confined to and centered within the crevice regions. The burst opening corrosion macrocracks for the TSP crevice regions had maximum depths ranging from 22% to 61% throughwall, with average depths ranging from 11% to 38% throughwall and with macrocrack lengths ranging from 0.068 to 0.750 inch.

Three TSP regions were initially called bobbin NDD in the field and one (TSP1 of Tube R10C48) was subsequently found by reevaluation of the field data to have a small (0.28 volt) indication prior to the tube exam. (A second TSP region, TSP3 of Tube R28C42, was found by data reevaluation to have a small, 0.2 volt, field RPC volumetric indication.) The maximum crack depths for these three locations were 47%, 22%, and 34% for the TSP1 and TSP2 region of Tube R10C48 and the TSP3 region of Tube R28C42, respectively. The corresponding average macrocrack depths were 36%, 11% and 17%, respectively.

The circumferential tensile fracture faces of the four TSP crevice region specimens that were opened by tensile testing were examined by SEM fractography to characterize their ICC networks. Table 3-6 presents the results of the fractographic data in the form of ICC depth versus circumferential position, ICC network length, ICC network average depth (averaged over the entire tube circumference and normalized to pre-burst and pre-tensile test dimensions), and the number of ductile or uncorroded ligaments found within the ICC networks on the fracture faces. The ICC networks had similar ICC average depths that ranged from 8% to 16% deep and ICC network lengths that ranged from a total length of 111^0 to a total of 270^0. The individual ICC depth data were obtained from the local ICC front which was relatively uniform in depth. These individual ICC depth data ignored any deeper axial cracks which occasionally penetrated the ICC front.

Figures 3-4 to 3-11 present sketches of the crack distributions found by visual (30X stereoscope) examinations. The sketches show the locations where cracks were found

and their overall appearance, not the exact number of cracks or their detailed morphology. All TSP regions had their corrosion centered within and confined to the crevice regions.

Due to the complexities of the crack networks observed in the TSP regions, radial metallography was utilized, in addition to transverse metallography, to provide an overall understanding of the intergranular corrosion morphology for the five TSP regions that were selected for metallographic characterization. In radial metallography, small sections of the tube (typically 0.5 by 0.5 inch) are flattened, mounted with the OD surface facing upwards and then progressively ground, polished, etched and viewed from the OD surface towards the inside diameter (ID) surface. Table 3-7 provides a summary of the metallographic data. It can be noted that the maximum depth for Tube R22C38, TSP1 from the transverse metallographic section was 65% compared to the maximum depth of 52% for the burst crack face (SEM fractography). In this case, the maximum crack depth did not contribute to the weakest macrocrack which burst. For the other TSP regions, the maximum depth was found on the burst crack face.

From the metallographic examinations conducted on the five selected TSP regions, it was concluded that the dominant OD origin corrosion morphology was axial intergranular stress corrosion cracking (IGSCC). In addition, in all five cases for the TSP regions, there were areas or patches with ICC found in association with the axial IGSCC. The most significant ICC (in area) occurred in the cases of TSP2 and TSP1 of Tube R28C42. With an ICC morphology, a complex mixture of short axial and oblique angled cracks interact to form cell-like structures. Figure 3-12a provides an example of the ICC morphology found in the case of TSP2 of Tube R28C42 at a depth of 14% below the OD surface. With progressive radial grinding, it was shown that the axial IGSCC became more dominant with depth while the ICC tended to disappear more quickly. Figure 3-12b shows the same location shown in Figure 3-12a, but at a depth of 34%. Only axial IGSCC remains at this depth. The maximum depth of ICC was always less than that of the axial IGSCC present at the same location. However, the depth of ICC frequently was close to that of the more dominant axial IGSCC. Finally, in some areas, especially where the cracking occurred at very high densities, shallow IGA also was present. The IGA always was significantly less deep than the surrounding ICC.

IGSCC morphology can be characterized by depth/width (D/W) ratios where the extent of IGA associated with a given crack is measured by the ratio of crack depth to the width of the crack at its mid-depth. D/W ratios greater than 20 are defined as minor and ratios less than 3 are defined as significant. Crack density is also considered an important parameter in characterizing corrosion. Crack densities greater than 100 cracks in 360 degrees are defined as high while values less than 25 are defined as low. The OD origin axial intergranular corrosion observed in TSP crevice regions of the Beaver Valley Unit 1 tubes had little variation in crack densities or in crack morphologies. The crack density ranged from the high side of moderate to high and the crack morphology was typically moderate with values ranging from minor to high, as measured by D/W ratios. Note, that all individual

D/W ratios that were low (D/W <3) were associated with very shallow cracks. As many shallow cracks were present, the reported average D/W ratios were somewhat low compared to those typically reported for other plants where the corrosion is deeper. Table 3-7 presents the metallographic data. Specimen R28C42, TSP2 had the largest number of cracks (an estimated 186 cracks over the tube circumference for the center of the crevice region) with most associated with a large 250^0 long ICC zone. The largest average D/W ratio (22) occurred in Specimen R22C38, TSP1 and the lowest average D/W ratio (3) occurred in Specimen R10C48, TSP3, where most cracks were very shallow.

3.1.6 Conclusions

All eight of the TSP crevice regions of Tubes R10C48, R22C38 and R28C42 had OD origin corrosion present. Metallographic data showed that the corroded TSP crevice regions had combinations of axially oriented IGSCC and ICC with the axial IGSCC predominating. All corrosion was confined to the crevice regions. The corrosion morphology was typical of pulled tubes within the EPRI database.

Eddy current bobbin and RPC probe data correlated well with the corrosion distribution for the deeper cracks. Three TSP crevice regions were initially called bobbin NDD in the field and two were subsequently found by reevaluation of the field data to have small (0.28 volt by bobbin for one and 0.2 volt by RPC for the other) indications prior to the tube exam. These two regions had corrosion ranging from 34% to 47% throughwall, maximum depth, while the third NDD region had corrosion up to 22% deep. Consequently, this location had corrosion just below the eddy current detection threshold and the other two had corrosion near the eddy current detection threshold. These three locations also serve in determining the UT detection threshold. TSP1 of Tube R10C48 (the deepest of the three) was called by field UT inspections as having corrosion while all three were called by lab UT inspections as having corrosion. Consequently, these locations also had corrosion near the UT detection threshold.

The TSP crevice region burst pressures ranged from 9,712 to 12,891 psi. All burst pressures were well above safety limitations required by R.G. 1.121 and close to free span burst values, i.e., those without corrosion. The burst pressure data were consistent with expectations and near or above mean predictions for the ARC burst pressure versus bobbin voltage correlation. Tensile tests performed on four of the TSP regions with extensive ICC also showed high strength for the specimens.

3.2 BEAVER VALLEY-1 PULLED TUBE EVALUATION FOR ARC APPLICATIONS

The pulled tube examination results were evaluated for application to the EPRI database for ARC applications. The eddy current data were reviewed, including reevaluation of the field data, to finalize the voltages assigned to the indications and to assess the field NDD calls for detectability under laboratory analysis conditions. The data for incorporation into the EPRI database were then defined and reviewed against the EPRI outlier criteria to provide acceptability for the database.

3.2.1 Eddy Current Data Review

Table 3-8 provides a summary of the eddy current data evaluations for the Beaver Valley-1 pulled tubes. These NDE data results have been discussed above in Section 3.1.2. As noted above, the field and laboratory reevaluations of the field bobbin data are in good agreement except for R22C38 TSP3 and R10C48 TSP1 which had a bobbin indication by reevaluation that was not reported as a flaw in the field inspection. The difference between the field and reevaluation calls for R22C38 TSP3 is due to the field call including the mixed residual in the reported voltage to ensure that the indication was RPC inspected. The reevaluated bobbin voltages including the adjustment for the American Society of Mechanical Engineers (ASME) calibration standard are used for the EPRI ARC database. The reevaluation was performed by the same analyst that performed a large part of the EPRI database and the use of these voltages minimizes analyst variability in the database, which is separately accounted for in ARC applications as an NDE uncertainty.

3.2.2 Beaver Valley-1 Data for ARC Applications

The pulled tube leak test, burst test, axial tensile test and destructive examination results are summarized in Table 3-9. Two of the largest indications were leak tested and no leakage was found even at SLB conditions. It can be inferred from the maximum 61% depth of any indication that none of the indications would leak at accident conditions as noted in Table 3-9. The measured burst pressures are adjusted to the reference 150 ksi for the sum of the yield plus ultimate tensile strengths. The data of Table 3-9 should be used in EPRI ARC burst pressure and SLB probability of leakage correlations. Since none of the indications are leakers, the data do not add to the SLB leak rate versus voltage correlation. Section 3.3 assesses the impact of these data on the EPRI correlations.

The Beaver Valley-1 pulled tube results were evaluated against the EPRI data exclusion criteria for potential exclusions from the database. Criteria 1a to 1e apply primarily to unacceptable voltage, burst or leak rate measurements and indications without leak test measurements. None of these criteria are applicable to the Beaver Valley-1 indications. Criterion 2b applies only to indications greater than 20 volts which is not applicable to these indications. Criterion 3 applies to potential errors in the leakage measurements and is also not applicable to the Beaver Valley-1 indications with no leakage.

EPRI Criterion 2a applies to atypical ligament morphology for indications having high burst pressures relative to the burst/voltage correlation and states that high burst pressure indications with ≤ 2 uncorroded ligaments in shallow cracks < 60% deep shall be excluded from the database. Table 3-9 identifies the number of remaining ligaments and the maximum depths for the indications. The indications at R22C38 TSP1, R28C42 TSP3 and R10C48 TSP2 satisfy the data exclusion criterion for ligaments and depth but the latter two indications are bobbin NDD and thus would not be included in the database. The indication at R22C38 TSP1 does not satisfy the part of Criterion 2a requiring that the indication be high on the

burst/voltage correlation. As shown in Section 3.3, this indication lies just below the mean fit of the correlation and, therefore, does not satisfy the requirements for exclusion from the database. Normally, Criterion 2a leads to exclusion from the database due to higher than expected voltages resulting from the lack of ligaments in a shallow crack. For R22C38 TSP1, the bobbin voltage may be high but the burst pressure is less than expected. This can be seen from Table 3-9 in that the burst pressure is lower for TSP1 than the other indications on this tube at TSP2 and TSP3 even though the crack length and average depth are smaller than found at TSP2 and TSP3. The burst test opening and burst test recordings for the TSP1 indication were reviewed and it was found that it is a clear burst with significant crack extension (burst length of Table 3-3) and there was no identifiable problem with the burst test pressure measurements. Therefore, there is no identifiable basis for excluding this data point and it is retained in the EPRI database.

3.3 COMPARISON OF BEAVER VALLEY-1 DATA WITH EXISTING IPC CORRELATIONS

The purpose of this section is to report on evaluations performed which utilized the results of leak rate and burst testing of tube sections which were removed from Beaver Valley Unit 1 in the Spring of 1995. The Beaver Valley 1 pulled tube data for ARC applications is given in Tables 3-1 through 3-9. A total of six (6) tube sections which exhibited bobbin amplitudes greater than zero volts, based on the field inspection data, were tested to determine their burst pressure. Two (2) of the specimen were tested to evaluate their probability of leak and their leak rate at SLB conditions. Neither of these indications were found to leak. Four (4) of the specimens were judged to have a zero probability of leak based on a post-burst inspection of the crack morphology. Destructive examination of the cracks after the testing revealed that all of the specimens were consistent with the EPRI acceptance criteria for inclusion of the results into the reference database. Accordingly, all of the specimens' test results were retained for further consideration. The test results from the remaining specimens, see Table 3-10, were compared to the EPRI database of similar test results for 7/8" outside diameter steam generator tubes. In addition, the effect of including the new test data in the reference database was evaluated. In summary, the test data are consistent with the database relative to the burst pressures, the probability of leak, and the leak rate as a function of the bobbin amplitude. The results of these comparisons and evaluations are discussed in what follows.

3.3.1 Burst Pressure vs. Bobbin Amplitude

Results from six (6) burst tests, performed on tube specimens which exhibited non-zero bobbin amplitudes at locations corresponding to the in-plant elevations of the tube support plates, were considered for evaluation. A plot of the burst pressures of the Beaver Valley 1 specimens is depicted on Figure 3-13 relative to the correlation developed for the reference database. A visual examination of the graph indicates that all of the burst pressures measured fall within the scatterband of the reference data about the reference regression line, thus, no significant departures from the reference database are indicated. Although not shown, all of the data fall within a 90% non-simultaneous prediction band about the regression line. Since a two-sided

simultaneous prediction band for the six data points would be wider than the non-simultaneous band, no statistically significant anomalies are indicated.

Since the Beaver Valley 1 burst pressure data were not indicated to be from a separate population from the reference data, the regression analysis of the burst pressure on the common logarithm of the bobbin amplitude was repeated with the additional data included. A comparison of the regression results obtained by including those data in the regression analysis is provided in Table 3-11. The intercept of the burst pressure, P_B, as a linear function of the common logarithm of the bobbin amplitude regression line is increased by 0.7%, and the slope is decreased by 1.6%, i.e., the slope with the Beaver Valley 1 data is a larger negative number. Regression predictions obtained by including these data in the regression analysis are also shown on Figure 3-13. Since the intercept is increased and the slope reduced by the inclusion of the Beaver Valley 1 data, predicted burst pressures for indications up to about 50 volts would be slightly more than the value obtained using the reference regression line. There is also a decrease of 0.4% in the standard error of the residuals. The effect of this change would be reflected in a slightly smaller deviation of the 95% prediction line from the regression line. The net effect of all of the changes on the SLB structural limit, using 95%/95% lower tolerance limit material properties, is an increase by 0.22 volts, i.e., from 8.82 volts to 9.04 volts. The 3·ΔP limit increases from 4.05 to 4.20 volts, and the SLB ΔP limit increases from 28.5 volts to 28.7 volts. The decrease in the standard error of the residuals will also slightly decrease the probability of burst for bobbin indications over all of the structural range of interest. Based on the small change in the structural limit, the decrease in the probability of burst would also likely be small. For very high voltages, e.g., about twice the SLB structural limit, the effect of the higher intercept and smaller standard error would be expected to be offset by the smaller slope and the probability of burst would slightly increase.

3.3.2 Probability of Leak (PoL)

The same six data points examined relative to the burst pressure correlation were also examined relative to the reference correlation for the PoL as a function of the common logarithm of the bobbin amplitude. Figure 3-14 illustrates the Beaver Valley 1 data relative to the reference correlation. All of the specimens exhibited PoL behavior commensurate with expectations indicated by the reference regression curve. Based on the visual examination, there appears to be no significant evidence of irregular results, i.e., outlying behavior is not indicated.

In order to assess the effect of the new data on the correlation curve, the database was expanded to include the Beaver Valley 1 data and a *Generalized Linear Model* regression of the PoL on the common logarithm of the bobbin amplitude was repeated. A comparison of the correlation parameters with those for the reference database is shown in Table 3-12. These results indicate a 0.1% reduction in the *logistic* intercept parameter and a 0.1% increase in the *logistic* slope parameter. The values of the parameter variance-covariance matrix were similarly affected, each being slightly reduced. The Pearson standard error decreased by 2.8% from 0.64 to 0.62.

This would normally be considered to be a negative indicator since the ideal value is 1.0, however, the magnitude of the change is not considered to be significant, and the cause of the change is due to the fact that none of the indications leaked. In order to assess whether or not these changes are significant the reference correlation and the new correlation were also plotted on Figure 3-14. An examination of Figure 3-14 reveals essentially no change in the correlation, thus, the Beaver Valley 1 data are consistent with the reference database. It is noted that when the total leak rate is determined using the leak rate to bobbin volts correlation, the resulting value can be quite insensitive to the form of the PoL function. Hence, the effect of the changes in the parameter values and variances is judged to be insignificant relative to the calculation of the expected total leak rate.

3.3.3 Leak Rate vs. Bobbin Amplitude

Since none of the indications exhibited any leakage, the reference correlation of leak rate to voltage is unaffected. However, the reference correlation of leak rate to voltage exhibits a *p*-value of 6.5% for the slope parameter, hence, the use of the correlation in performing Monte Carlo simulations to estimate the total leak rate is not justified based on the requirements stipulated in the draft Generic Letter for voltage based plugging criteria.

3.3.4 General Conclusions

The review of the effect of the Beaver Valley 1 data indicates that the burst pressure, the probability of leak, and the leak rate correlations to the common logarithm of the bobbin amplitude would not be significantly changed by the inclusion of the data. Therefore, it is unlikely that the conclusions relative to EOC probability of burst and EOC total leak rate based on correlations obtained using the reference database would be significantly affected by repeating those analyses using an expanded database which includes the Beaver Valley 1 test data. Although expected to be not significant, it is noted that inclusion of the Beaver Valley 1 test data will result in a decrease in the probability of leak and a decrease in the probability of burst. This is because of a decrease in the uncertainty of the estimate of the population standard errors due to the increase in the number of degrees of freedom of the data, the decreases in the standard errors of the regressions, and the changes in the parameters of the regressions. Thus, the 95% confidence bound on the total leak rate would likewise be reduced, as would the probability of burst of one or more indications.

Table 3-1 (Page 1 of 3)

Comparison of NDE Indications Observed at Beaver Valley Unit 1 on S/G Tubes at Hot Leg Locations

Tube/ Location	Field E/C	Lab E/C	Field UT	Lab UT	Lab X-Ray
R10C48, TSP1	Bobbin: NDD (0.28V DI)* RPC: NDD	Bobbin: 0.45V DI, 50% deep; 1.9V dent RPC: NDD	Small patch OD axial Inds	Small patch OD axial Inds + separate patch Circ Inds at crevice bottom	Short Circ Ind at TSP bottom, possible ICC
R10C48, TSP2	Bobbin: NDD RPC: NDD	Bobbin: 2V dent RPC: NDD	NDD	Short Circ Ind at crevice bottom	NDD

NOTES: 1. CECCO 5 probes were utilized to interrogate the pulled tube specimens both prior and subsequent to tube pulling operations. The results of the CECCO examinations are generally consistent with the other NDE results. Field CECCO results were previously submitted in the Return to Power Report submitted on March 2, 1995.

2. The laboratory UT and/or X-ray results that indicate Circ. Inds are associated with ICC or breaks in deposits at TSP edges. No circumferential cracking was identified by destructive examination.

Legend of Abbreviations:

()* = field reevaluation value (corrected for cross calibration)
NDD = No Detectable Degradation
RPC = Rotating Pancake Coil
ICC = intergranular cellular corrosion
TSP = Tube Support Plate
Ind = Indication
SAI = Single Axial Ind
E/C = Eddy Current
UT = Ultrasonic Test
V = Voltage
MAI = Multiple Axial Inds
#C = number of cracks
Circ = circumferential
Max = maximum
DI = Distorted Indication
OD = Outside Diameter

Table 3-1 (Page 2 of 3)

Comparison of NDE Indications Observed at Beaver Valley Unit 1
on S/G Tubes at Hot Leg Locations

Tube/ Location	Field E/C	Lab E/C	Field UT	Lab UT	Lab X-Ray
R22C38, TSP1	Bobbin: 0.64V DI (0.7V Ind, 37% deep)* RPC: NDD (2 patches, 0.2 & 0.3V, 88 & 52% deep)*	Bobbin: 0.9V DI (36% deep) plus two distorted dents (1.2V & 3.9V) RPC: many patches, 0.25 & 0.55V, up to 93% deep	Two patches OD axial Inds, plus one short Circ Ind	Three patches of OD axial and Circ Inds, 40% max depth	Faint spider-like Inds within crevice region
R22C38, TSP2	Bobbin: 0.44V DI (0.33V DI, 76% deep)* RPC: SAI (0.14V Ind with many patches, 58% deep)	Bobbin: 0.7 & 0.7V Inds, up to 84% deep; 3V dent RPC: many patches, 0.38V, up to 84% deep	Three patches OD axial Inds	Three groups of OD axial and Circ Inds, 40% max depth	NDD
R22C38, TSP3	Bobbin: 1.73V DI (0.6V DI)* RPC: 0.41" SAI (0.5V, 120° patch, 62% deep & 0.27V small patch, 65% deep)	Bobbin: 2.1 & 0.5V Inds, up to 76% deep & 2.3V dent RPC: 0.7V, 120° patch	Possible shallow OD axial Inds within crevice deposit signals	Patch of OD axial and Circ Inds, with 0.29" SAI in patch, 35% deep	Possible MAI (2), 0.25" max, within crevice region

Table 3-1 (Page 3 of 3)

Comparison of NDE Indications Observed at Beaver Valley Unit 1
on S/G Tubes at Hot Leg Locations

Tube/ Location	Field E/C	Lab E/C	Field UT	Lab UT	Lab X-Ray
R28C42, TSP1	Bobbin: 0.72V DI (0.56V Ind, 66% deep)* RPC: SAI (0.29 & 0.15V patches, up to 62% deep)*	Bobbin: DI in 2V dent RPC: two patches, 60% deep	One patch OD axial Inds	Large patch (180^0) OD axial and Circ Inds, 30% max depth	NDD
R28C42, TSP2	Bobbin: 1.12V DI (1.0V Ind, 53% deep)* RPC: 0.44" SAI (0.3V 180^0 patch, 53% deep)*	Bobbin: 1.0V DI, 75% deep; 2.9V dent RPC: 0.66V 180^0 volumetric Ind, 83% deep	Shallow OD SAI within crevice deposit signals	120^0 patch OD axial and Circ Inds at mid-crevice to TSP bottom, 30% max depth	Possible faint SAI, 0.1" long
R28C42, TSP3	Bobbin: NDD RPC: NDD (0.2V volumetric Ind, 59% deep)*	Bobbin: 0.6V DI in 4V dent RPC: noisy data	NDD	Small spot with OD axial and Circ response, 20% max depth	NDD

Table 3-2

Beaver Valley Unit 1 Leak Test Results for Steam Generator Tubing

Tube No., Location	Test Type: Differential Pressure (psi)	Leak Rate (liters/hour)	Test Conditions
R22C38, TSP3	NOC: 1332 ITC1: 1919 SLB: 2588	zero zero zero	P_p= 2294, P_S= 962, T_P= 615, T_S= 612 P_p= 2434, P_S= 515, T_P= 622, T_S= 618 P_p= 2783, P_S= 195, T_P= 622, T_S= 613
R28C42, TSP2	NOC: 1257 ITC1: 1894 SLB: 2560	zero zero zero	P_p= 2216, P_S= 959, T_P= 612, T_S= 606 P_p= 2416, P_S= 522, T_P= 620, T_S= 605 P_p= 2770, P_S= 210, T_P= 622, T_S= 593

Legend: All data within a table block is presented in the order of testing, NOC= normal operating conditions, ITC= intermediate test conditions, SLB= steam line break conditions, P_p= primary side pressure (psi), P_S= secondary side pressure (psi), T_P= primary side temperature (^{0}F), T_S= secondary side temperature (^{0}F)

Table 3-3

Room Temperature Burst and Tensile Test Results
for Beaver Valley Unit 1 Hot Leg S/G Tubing

Location	Burst Pressure (psig)	Ductility (% Dia.)	Burst Length (inches)	Burst Width (inches)	Tensile Fracture Load (lbs)	0.2% Offset Tensile YS (psi)	Tensile UTS (psi)	Tensile Elongation (%)
R10C48, FS	12,964	31.3	2.078	0.406	15,270	65,700	115,700	29.3
R10C48, TSP1	11,968	19.0	1.507	0.366				
R10C48, TSP2	12,891	26.3	1.869	0.449				
R22C38, FS	12,056	28.8	1.780	0.356	14,730	63,000	111,600	29.8
R22C38, TSP1	9,712+	14.4	1.301	0.305				
R22C38, TSP2	10,254+	13.8	1.357	0.348	11,420*	NM	NM	NM
R22C38, TSP3	10,576+	15.8	1.295	0.296	12,000*	NM	NM	NM
R28C42, FS	12,100	32.3	1.924	0.408	14,320	58,450	106,050	32.0
R28C42, TSP1	11,353+	22.7	1.527	0.380	13,750*	NM	NM	NM
R28C42, TSP2	10,503+	19.4	1.401	0.350	12,500*	NM	NM	NM
R28C42, TSP3	11,792	23.5	1.598	0.423				
Control (NX8161)	11,440 11,455	no data 32.7	no data 1.965	no data 0.365		51,450	105,700	30.2

Legend: TSP = support plate crevice region location; FS = free span location; NM - not meaningful, as data was obtained from a tensile test of a burst specimen
+ = Burst specimen used a bladder and foil over largest defect area and was burst in a semi-restraint condition. All other burst specimens were burst without bladders and foils and without a restraint conditions.
* = These four tensile specimens were tensile tested following burst testing.
YS = Yield strength.
UTS = Ultimate tensile strength.

Table 3-4

Beaver Valley Unit 1 Destructive Examination Planning Data for TSP Specimens

Specimen	E/C Data (field bobbin probe)	Burst & Ductility Ratios (specimen/ FS value)	FF Corrosion* (visually observed)	Crevice Region* Corrosion (visually observed)	DE Plan
R10-C48, FS	NDD	1.00/ 1.00	No	No	No
R10-C48, TSP1	NDD (0.28V DI)	0.92/0.61	Yes	Yes, 70° ICC patch + axial cracks at TSP bottom edge	Yes, both metallography and SEM FF
R10-C48, TSP2	NDD	0.99/ 0.84	Yes	Yes, 30° ICC patch + random axial cracks	Yes, SEM FF only
R22-C38, FS	NDD	1.00/ 1.00	No	No	No
R22-C38, TSP1	0.64V DI (0.7V Ind)	0.80/0.50	Yes	Yes, mostly axial cracks over 360°	Yes, both metallography and SEM FF
R22-C38, TSP2	0.44V DI (0.33V DI)	0.85/0.48	Yes	Yes, 80° ICC patch + other minor cracks	Yes, both metallography and SEM FF (after tensile testing of burst specimen)
R22-C38, TSP3	1.73V DI (0.6V DI)	0.88/ 0.55	Yes	Yes, 80° ICC patch + 2 long SAI	Yes, both metallography and SEM FF (after tensile testing of burst specimen)
R28-C42, FS	NDD	1.00/ 1.00	No	No	No
R28-C42, TSP1	0.72V DI (0.56V Ind)	0.94/0.70	Yes	Yes, 120° ICC patch + 2 long SAI	Yes, SEM FF only (after tensile testing of burst specimen)
R28-C42, TSP2	1.12V DI (1.0V Ind)	0.87/ 0.60	Yes	Yes, 360° ICC at TSP bottom edge + 140° ICC patch	Yes, both metallography and SEM FF (after tensile testing of burst specimen)
R28-C42, TSP3	NDD	0.97/0.73	Yes	Yes, 60° ICC patch	Yes, SEM FF only

* = All bursts occurred centered within the crevice regions.
FS = free span; TSP = tube support plate; FF = fracture face
SEM = Scanning Electron Microscopy
DE = Destructive Examination

Table 3-5 (Page 1 of 4)

Beaver Valley Unit 1 S/G Tube Burst Opening Macrocrack Profiles

Tube, Specimen	Length vs. Depth & Ductile Ligament Data (inches/% throughwall)	Positional Information	Comments
R10C48, TSP1	0.00/00<---Ligament 1/0.007" wide 0.04/36 0.08/40 0.12/44 0.16/40 0.20/38<---Ligament 2/0.003" wide 0.24/44<---Ligament 3/0.020" wide 0.28/32 0.32/47 <--(Max. depth = 47%) (0.346/00) (Ave. depth = 36%, Macrocrack Length = 0.346")	Crack Bottom (located 0.016" above TSP bottom) Crack Top	The axially oriented burst macrocrack had three ductile ligaments with dimple rupture features occurring over more than 50% of their length.
R10C48, TSP2	0.00/00 0.01/08 0.02/14 0.03/22 <--(Max. depth = 22%) 0.04/12 0.05/00<---Ligament 1/0.020" wide 0.06/18 (0.068/00) (Ave. depth = 11%, Macrocrack Length = 0.068 inch)	Crack Bottom Crack Top (located 0.20" below TSP top)	The axially oriented burst macrocrack had one ductile ligament with dimple rupture features occurring over more than 50% of its length.

Table 3-5 (Page 2 of 4)
Beaver Valley Unit 1 S/G Tube Burst Opening Macrocrack Profiles

Tube, Specimen	Length vs. Depth & Ductile Ligament Data (inches/% throughwall)	Positional Information	Comments
R22C38, TSP1	0.00/00 0.05/18 0.10/25 0.15/29 0.20/42 0.25/30 0.30/28 0.35/52 <-(Max. depth = 52%) 0.40/42 0.45/18 0.50/25 0.55/25 0.60/18 0.65/20 (0.675/00) (Ave. depth = 26%, Macrocrack Length = 0.675 inch)	Crack Bottom (located 0.052" above TSP bottom) Crack Top	The axially oriented burst macrocrack had no ductile ligaments with dimple rupture features occurring over more than 50% of their length.
R22C38, TSP2	0.00/00 <---Ligament 1/0.004" wide 0.05/32 0.10/24 0.15/18 <---Ligament 2/0.008" wide 0.20/46 <---Ligaments 3 & 4/0.003 & 0.007" wide 0.25/52 <---Ligament 5/0.002" wide 0.30/45 0.35/48 0.40/54 <---Ligament 6/0.001" wide 0.45/54 <---Ligament 7/0.001" wide 0.50/42 <---Ligament 8/0.0014" wide (0.53/61) <-(Max. depth = 61%) 0.55/57 <---Ligament 9/0.004" wide 0.60/50 <---Ligament 10/0.007" wide 0.65/46 <---Ligament 11/0.002" wide 0.70/41 <---Ligament 12/0.002" wide 0.75/00 (Ave. depth = 38%, Macrocrack Length = 0.750")	Crack Top & Location of TSP Top <---Tensile Fracture Location Crack Bottom & Location of TSP Bottom	The axially oriented burst macrocrack had twelve ductile ligaments with dimple rupture features occurring over more than 50% of their length.

Table 3-5 (Page 3 of 4)
Beaver Valley Unit 1 S/G Tube Burst Opening Macrocrack Profiles

Tube, Specimen	Length vs. Depth & Ductile Ligament Data (inches/% throughwall)	Positional Information	Comments
R22C38, TSP3	0.00/00 <---Ligaments 1 & 2/both 0.001" wide 0.05/48 0.10/50 (0.13/54) <--(Max. depth = 54%) 0.15/48 0.20/42 <---Ligament 3/0.005" wide 0.25/32 <---Ligament 4/0.003" wide 0.30/36 0.35/38 0.40/36 <---Ligament 5/0.001" wide 0.45/42 0.50/46 0.55/34 <---Ligament 6/0.001" wide 0.60/32 <---Ligament 7/0.006" wide 0.65/24 <---Ligaments 8 & 9/0.006 & 0.008" wide 0.70/12 (0.706/00) (Ave. depth = 35%, Macrocrack Length = 0.706 inch)	Crack Top & TSP Top Location <---Tensile Fracture Location Crack Bottom	The axially oriented burst macrocrack had nine ductile ligaments with dimple rupture features occurring over more than 50% of their length.
R28C42, TSP1	0.00/00 <---Ligaments 1, 2, 3/0.001, .005, .002" wide 0.05/17 <---Ligaments 4, 5, 6/0.009, .026, .003" wide 0.10/28 0.15/30 <---Ligament 7/0.004" wide 0.20/26 0.25/40 0.30/48 (0.33/52) <--(Max. depth = 52%) 0.35/38 0.40/48 0.45/41 <---Ligament 8/0.003" wide 0.50/43 <---Ligament 9/0.003" wide 0.55/40 <---Ligaments 10 & 11/both 0.001" wide 0.60/34 <---Ligament 12/0.004" wide 0.65/40 <---Ligament 13/0.002" wide 0.70/08 (0.716/00) (Ave. depth = 32%, Macrocrack Length = 0.716 inch)	Crack Top & TSP Top Location <---Tensile Fracture Location Crack Bottom	The axially oriented burst macrocrack had thirteen ductile ligaments with dimple rupture features occurring over more than 50% of their length.

Table 3-5 (Page 4 of 4)
Beaver Valley Unit 1 S/G Tube Burst Opening Macrocrack Profiles

Tube, Specimen	Length vs. Depth & Ductile Ligament Data (inches/% throughwall)	Positional Information	Comments
R28C42, TSP2	0.00/00 0.05/12 0.10/10 0.15/08 0.20/36 0.25/33 <---Ligament 1/0.001" wide 0.30/32 <-- Ligaments 2 & 3/0.013 & 0.005" wide 0.35/41 <---Ligament 4/0.027" wide (0.34/44) <--(Max. depth = 44%) 0.40/42 <---Ligaments 5 & 6/0.002 & 0.004" wide 0.45/40 <---Ligament 7/0.001" wide 0.50/40 <---Ligament 8/0.0043" wide 0.55/38 <---Ligament 9/0.006" wide 0.60/30 <---Ligaments 10, 11, 12/.004, .002, .013"wide 0.65/16 0.70/04 (0.732/00) (Ave. depth = 25%, Macrocrack Length = 0.732 inch)	Crack Top & TSP Top Location <---Tensile Fracture Location Crack Bottom	The axially oriented burst macrocrack had twelve ductile ligaments with dimple rupture features occurring over more than 50% of their length.
R28C42, TSP3	0.00/00 0.05/16 0.10/14 0.15/10 0.20/14 0.25/14 0.30/18 0.35/27 0.40/34 <--(Max. depth = 34%) 0.45/24 0.50/28 0.55/20 0.60/16 0.65/14 0.70/10 (0.718/00) (Ave. depth = 17%, Macrocrack Length = 0.718 inch)	Crack Bottom (located 0.022" above TSP bottom) Crack Top	The axially oriented burst macrocrack had no ductile ligaments with dimple rupture features occurring over more than 50% of their length.

Table 3-6 (Page 1 of 4)

Beaver Valley Unit 1 S/G Tube ICC Network Profiles on Te[illegible]acture Faces

Tube, Location	Circ Position vs. ICC Depth (degrees/% throughwall)	Comments
R22C38, TSP2	8/20 (15/0) <-- ICC Network #1 Tip 30/0 52/0 75/0 (77/0) <-- ICC Network #2 Tip 98/16 120/44 <-- Axial Burst Location 142/40 165/8 (168/0) <-- ICC Network #2 Tip 188/8 210/0 232/0 255/0 (265/16) <-- ICC patch, 8° long, 10% ave. depth 278/0 300/0 322/0 345/0 (355/0) <-- ICC Network #1 Tip (Ave. depth = 8% around original tube)	There were two main ICC networks. Networks #1 & 2 were 20° and 91° long, respectively. There were 3 ductile ligaments present within these ICC networks.

Table 3-6 (Page 2 of 4)

Beaver Valley Unit 1 S/G Tube ICC Network Profiles on Tensile Fracture Faces

Tube, Location	Circ Position vs. ICC Depth (degrees/% throughwall)	Comments
R22C38, TSP3	0/0 (5/0) <-- ICC Network #1 Tip 22/7 45/1 (47/0) <-- ICC Network #1 Tip 68/0 (75/10) <-- ICC patch, 4^0 long, 10% ave. depth 90/0 (95/0) <-- ICC Network #2 Tip 112/34 135/42 158/40 180/44 <-- Axial burst location 202/40 (220/0) <-- ICC Network #2 Tip 225/0 (240/0) <-- ICC Network #3 Tip 248/16 (255/0) <-- ICC Network #3 Tip 270/0 (285/0) <-- ICC Network #4 Tip 292/10 (300/0) <-- ICC Network #4 Tip 315/2 <-- ICC patch, 5^0 long, 2% ave. depth 338/0 (Ave. depth = 15% around original tube)	There were four main ICC networks. Networks #1, 2, 3 & 4 were 42^0, 125^0, 15^0, and 15^0 long, respectively. There were 18 ductile ligaments present within these ICC networks.

Table 3-6 (Page 3 of 4)

Beaver Valley Unit 1 S/G Tube ICC Network Profiles on Tensile Fracture Faces

Tube, Location	Circ Position vs. ICC Depth (degrees/% throughwall)	Comments
R28C42,TSP1	0/0 (15/0) <-- ICC Network #1 Tip 22/4 (32/0) <-- ICC Network #1 Tip 45/0 (60/0) <-- ICC Network #2 Tip 68/3 (80/0) <-- ICC Network #2 Tip 90/0 (92/0) <-- ICC Network #3 Tip 112/24 135/12 158/35 180/28 <-- Axial burst location 202/32 225/16 248/16 270/10 292/8 315/2 (325/0) <-- ICC Network #3 Tip 338/0 (Ave. depth = 12% around original tube)	There were three main ICC networks. Networks #1, 2, & 3 were 17^0, 20^0 and 233^0 long, respectively. There were 29 ductile ligaments present within these ICC networks.

Table 3-6 (Page 4 of 4)

Beaver Valley Unit 1 S/G Tube ICC Network Profiles on Tensile Fracture Faces

Tube, Location	Circ Position vs. ICC Depth (degrees/% throughwall)	Comments
R28C42,TSP2	8/35 30/36 52/28 75/12 98/10 120/11 142/6 (160/0) <-- ICC Network Tip 165/0 (170/18) <-- ICC patch, 5^0 long, 18% ave depth 188/0 210/0 232/0 255/0 (270/0) <-- ICC Network Tip 278/22 300/26 <-- Axial Burst Location 322/30 345/34 (Ave. depth = 16% around original tube)	The 250^0 long ICC network had 11 ductile ligaments present within the main ICC network.

TABLE 3-7 Page 1 of 2
METALLOGRAPHIC DATA OF BEAVER VALLEY UNIT 1 STEAM GENERATOR TUBES

Specimen	Section Type	Number of Cracks	Section Length (Inch)	Cracks per Inch	Estimated Maximum Number of Cracks at Mid-Crevice Location	Max./Avg. Depth (% Throughwall)	Max. Depth of ICC Transverse and Axial Components (% Throughwall in Radial Section)	Avg. D/W Ratio From Transverse Section
R10C48, TSP1	Transverse	39	2.18	18	90	20/4	10% < Oblique < 32%	3*
	Radial	16	0.37	43		depth = 4%	32% < Axial < 60%	
	Radial	19	0.39	48		depth = 10%		
	Radial	[illegible]	0.40	18		depth = 32%		
	Radial	0	0.40	0		depth = 60%		
R22C38, TSP1	Transverse	44	2.16	20	77	65/33	28% < Oblique < 48%	22
	Radial	12	0.40	30		depth = 4%	Axial > 48%	
	Radial	11	0.42	26		depth = 10%		
	Radial	9	0.42	21		depth = 28%		
	Radial	1	0.42	2		depth = 48%		

* The small value of the D/W ratio is biased by the counting of many shallow cracks. The average D/W ratio for the larger cracks having an average depth of 13% throughwall was 9. These values are consistent with the trend of observing larger D/W ratios for deeper cracks.

TABLE 3-7 Page 2 of 2
METALLOGRAPHIC DATA OF BEAVER VALLEY UNIT 1 STEAM GENERATOR TUBES

Specimen	Section Type	Number of Cracks	Section Length (Inch)	Cracks per Inch	Estimated Maximum Number of Cracks at Mid-Crevice Location	Max./Avg. Depth (% Throughwall)	Max. Depth of ICC Transverse and Axial Components (% Throughwall in Radial Section)	Avg. D/W Ratio From Transverse Section
R22C38, TSP2	Transverse	33	2.51	13	70	43/24	16 < Oblique < 38	9
	Radial	17	0.42	40		depth = 2%	38 < Axial < 60	
	Radial	12	0.44	27		depth = 16%		
	Radial	4	0.44	9		depth = 38%		
	Radial	0	0.44	0		depth = 60%		
R22C38, TSP3	Transverse	40	2.52	16	126	40/23	38 < Oblique < 60	10
	Radial	26	0.30	87		depth = 2%	38 < Axial < 60	
	Radial	29	0.38	76		depth = 16%		
	Radial	10	0.43	23		depth = 38%		
	Radial	0	0.43	0		depth = 60%		
R28C42, TSP2	Transverse	149	2.65	56	186	21/13		6
	Radial 1	18	0.38	48		depth = 2%	16 < Oblique < 34	
	Radial 1	23	0.47	49		depth = 16%	34 < Axial < 56	
	Radial 1	5	0.49	10		depth = 34%		
	Radial 1	0	0.49	0		depth = 56%		
	Radial 2	30	0.49	61		depth = 2%	14 < Oblique < 34	
	Radial 2	30	0.49	61		depth = 14%	34 < Axial < 52	
	Radial 2	10	0.49	20		depth = 34%		
	Radial 2	0	0.49	0		depth = 52%		

Table 3-8. Summary of Beaver Valley-1 Pulled Tube Eddy Current Results												
Tube	TSP	Field Call			Lab. Reevaluation of Field Data					Post Pull Data		
		Bobbin Volts(1)	RPC Volts	UT	Bobbin Volts	ASME Cal.(2)	Bobbin Volts(2)	Depth	RPC Volts	Bobbin Volts	RPC Volts	UT
Steam Generator A												
R22C38	1	0.64	0.60	MAI	0.70	1.029	0.72	37%	0.3	0.9	0.55	MAI
	2	0.44	0.26	MAI	0.52	1.029	0.54	76%	0.14	0.7	0.38	MAI
	3	1.73(3)	0.35	MAI	0.60	1.029	0.62	DI	0.5	2.1	0.7	MAI
R28C42	1	0.72	0.39	MAI	0.56	1.029	0.58	66%	0.29	DI	0.5	MAI
	2	1.12	0.19	SAI	1.05	1.029	1.08	53%	0.32	1.0	0.66	MAI
	3	NDD	NDD	NDD	NDD	-	-	-	0.2	[illegible]	Noisy	MAI
R10C48	1	NDD	NDD	MAI	0.28	1.029	0.29	24%	NDD	0.45	NDD	MAI
	2	NDD	NDD	NDD	NDD	-	-	-	NDD	Dent	NDD	NDD

Notes: 1. Field data include cross calibration of ASME standard to the reference laboratory standard
2. ASME calibration represents the cross calibration factor for the field ASME standard to the reference laboratory standard and is applied to the laboratory reevaluation to obtain the corrected APC volts
3. Bobbin voltage included mixed residual to assure that indication was RPC inspected (i.e., > 1.0 volt). Flaw component of 0.6 volt from reevaluation is recommended for ARC database

Table 3-9. Beaver Valley-1 Pulled Tube Data for ARC Applications															
Tube	TSP [1]	Bobbin Data		RPC Volts	Destructive Exam Results				Leak Rate-l/hr		Axial Tensile Fracture (lbs)	Burst Pressure Data - ksi			
		Volts	Depth		Max. Depth	Avg. Depth	Crack Length	No. Lig. [2]	N. O. 1300 psid	SLB 2560 psid		Meas. Burst Press.	σ_y	σ_u	Adj. Burst Press.
Steam Generator A															
R22C38	1	0.72	37%	0.3	52%	26%	0.675	0	0.0[3]	0.0[3]	-	9.712			8.344
	2	0.54	76%	0.14	61%	38%	0.750"	12	0.0[3]	0.0[3]	11,420	10.254			8.809
	3	0.62	DI	0.5	54%	35%	0.706"	9	0.0	0.0	12,000	10.576			9.086
	FS										14,730	12.056	63.0	111.6	10.357
R28C42	1	0.58	66%	0.29	52%	32%	0.716"	13	0.0[3]	0.0[3]	13,750	11.353			10.352
	2	1.08	53%	0.2	44%	25%	0.732"	12	0.0	0.0	12,500	10.503		2.45	9.577
	3	NDD	NDD	0.2	34%	17%	0.718"	0	0.0[3]	0.0[3]	-	11.792			10.753
	FS										14,320	12.100	58.5	106.1	11.033
R10C48	1	0.29	24%	NDD	47%	36%	0.346"	3	0.0[3]	0.0[3]	-	11.968			9.896
	2	NDD	NDD	NDD	22%	11%	0.068"	1	0.0[3]	0.0[3]		12.891			10.660
	FS										15,270	12.964	65.7	115.7	10.720

Notes:
1. FS is freespan section of tubing with no tube degradation to obtain tensile properties and undegraded tubing burst pressure.
2. Number of uncorroded ligaments with > 50% of ligament length remaining in burst crack face.
3. Inferred from destructive exam depth, leak test not performed. Corrosion depth too shallow for leakage at SLB conditions.

Table 3-10 Results of Leak Rate and Burst Testing of Tube Sections Removed from Beaver Valley Unit 1				
Specimen ID	Bobbin Amplitude (Volts)	Burst Pressure for σ_f = 75 ksi (ksi)	Probability of Leak During SLB	Leak Rate During SLB (lph)
R22C038-1	0.72	8.344	0	
R22C038-2	0.54	8.809	0	
R22C038-3	0.62	9.086	0	
R28C042-1	0.58	10.352	0	
R28C042-2	1.08	9.577	0	
R10C048-1	0.29	9.896	0	

Table 3-11 Effects of the Beaver Valley Unit 1 Data on the Burst Pressure vs. Bobbin Volts Correlation $P_B = \alpha_1 + \alpha_2 \log(Volts)$		
Parameter	Reference Database Value	Database with Beaver Valley 1
α_1	7.556	7.607
α_2	-2.319	-2.355
σ_{Error}	0.817	0.814
N (data pairs)	70	76
p Value for α_2	$1.4 \cdot 10^{-27}$	$4.9 \cdot 10^{-30}$
r^2	82.7%	82.8%

Table 3-12 Effect of Beaver Valley Unit 1 Data on the Probability of Leak Correlation

$$Pr(Leak) = \left\{1 + e^{-[\beta_1 + \beta_2 \log(Volts)]}\right\}^{-1}$$

Parameter	Reference Database Value	Database with Beaver Valley 1
β_1	-6.897	-6.905
β_2	8.351	8.359
V_{11}	3.500	3.484
V_{12}	-3.846	-3.828
V_{22}	4.582	4.563
DoF	97	103
Deviance	25.1	25.1
Pearson σ_{Error}	0.64	0.62

Note: Parameters V_{ij} are elements of the covariance matrix of the coefficients, β_k, of the above regression equation.

DoF = Degrees of freedom.

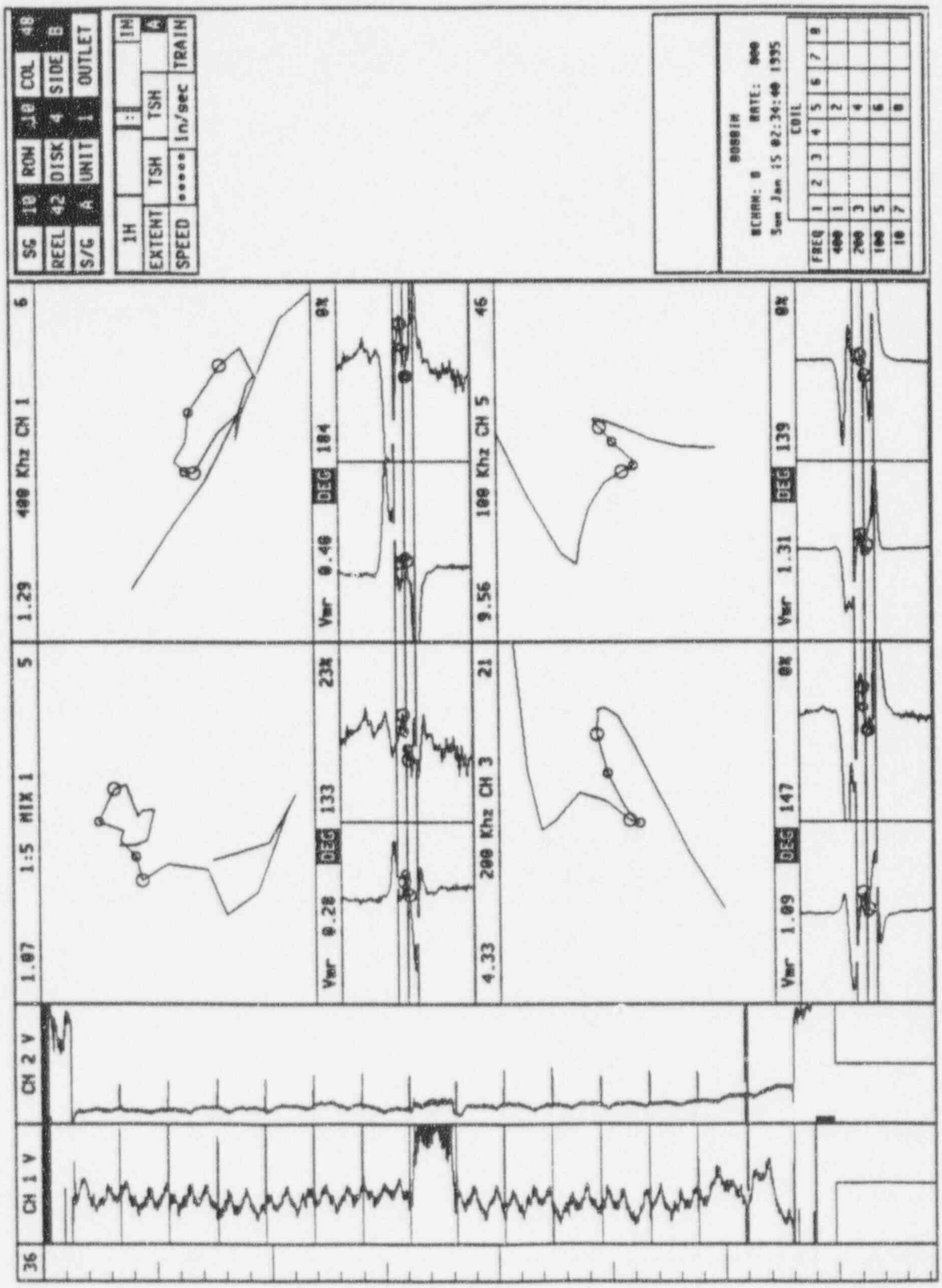


Figure 3-1 Reevaluation of Field Bobbin Data for R10 C48 TSP1

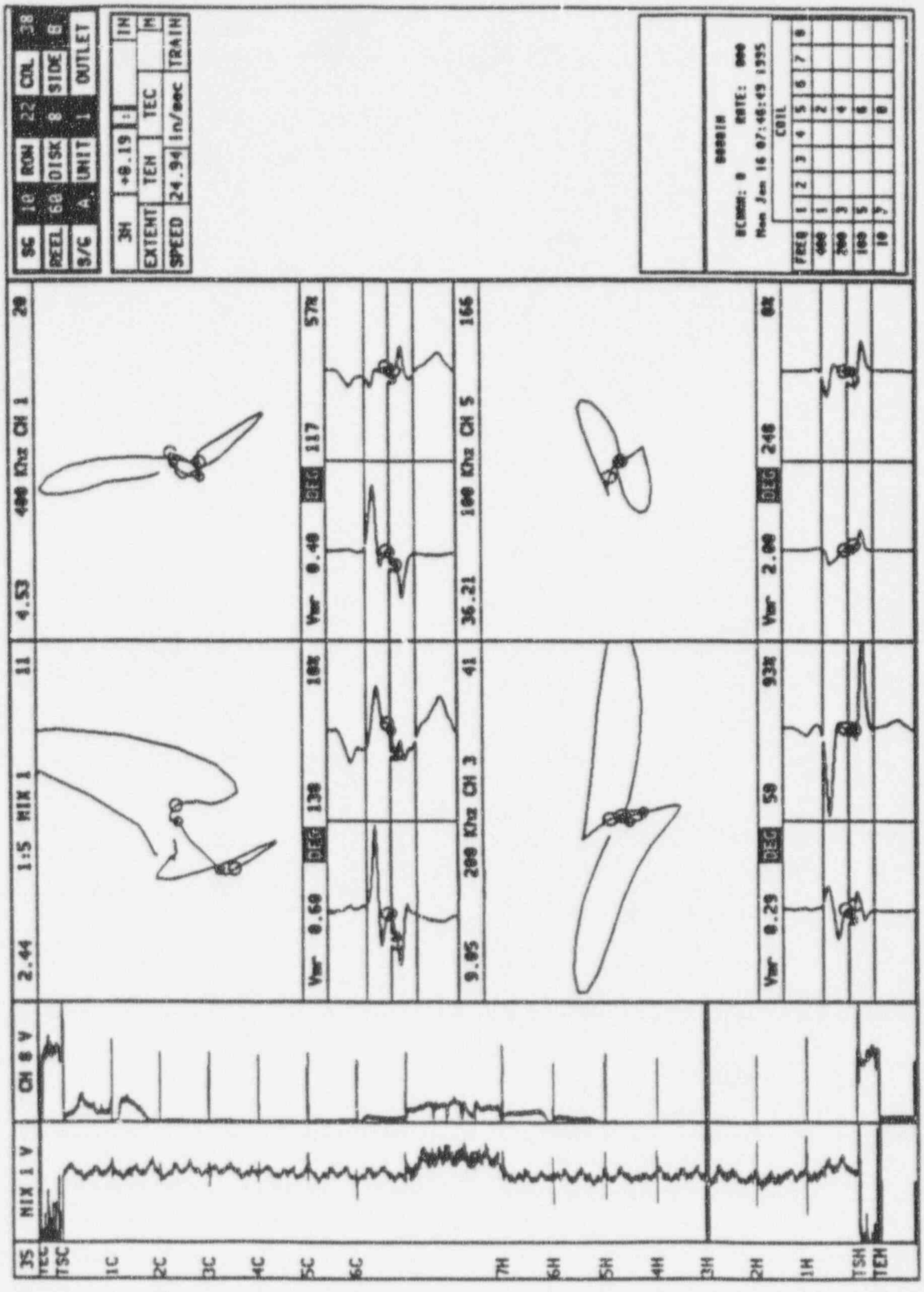


Figure 3-2 Reevaluation of Field Bobbin Data for R22 C38 TSP 3

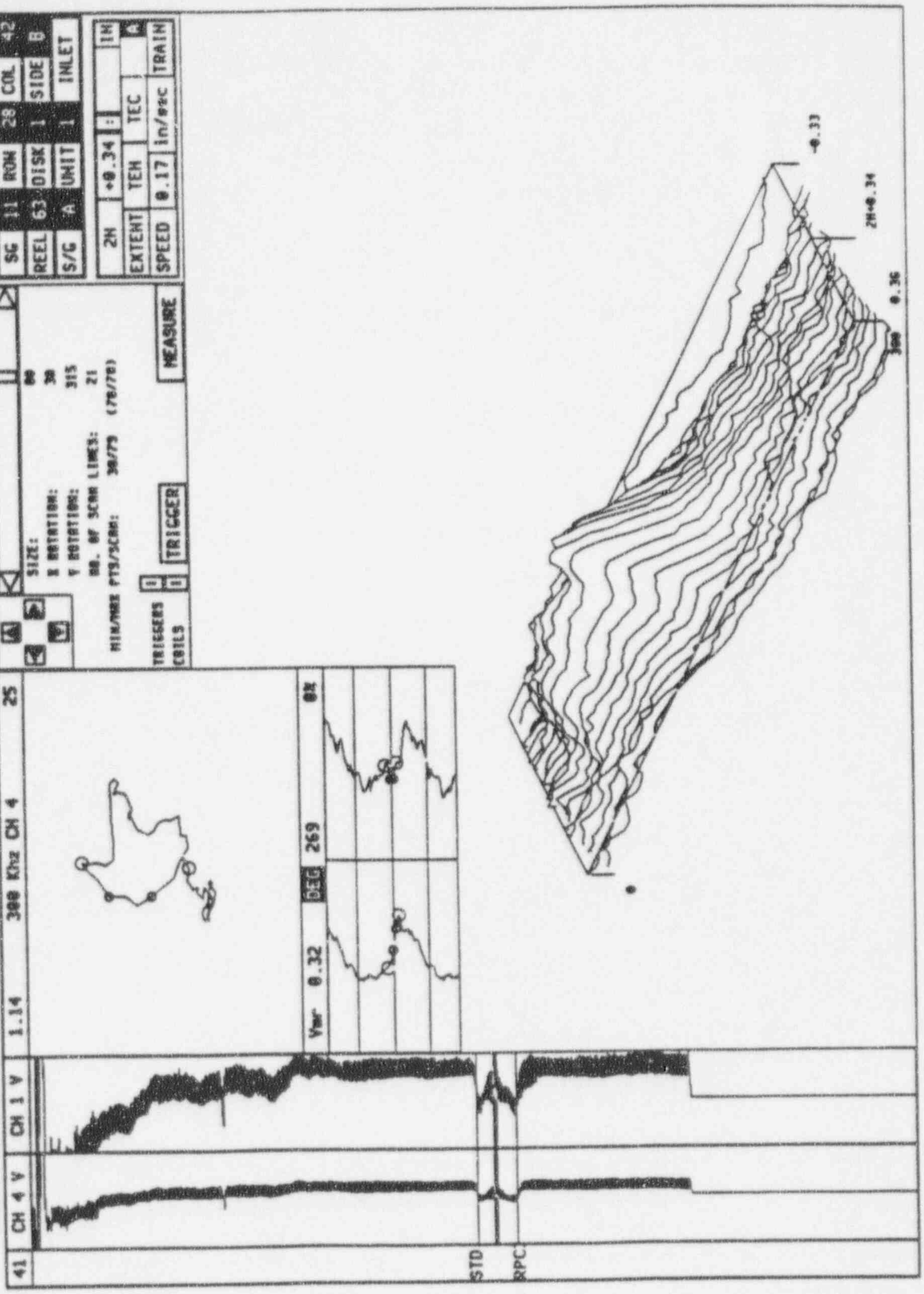


Figure 3-3 Field RPC Trace for R28 C42 TSP2

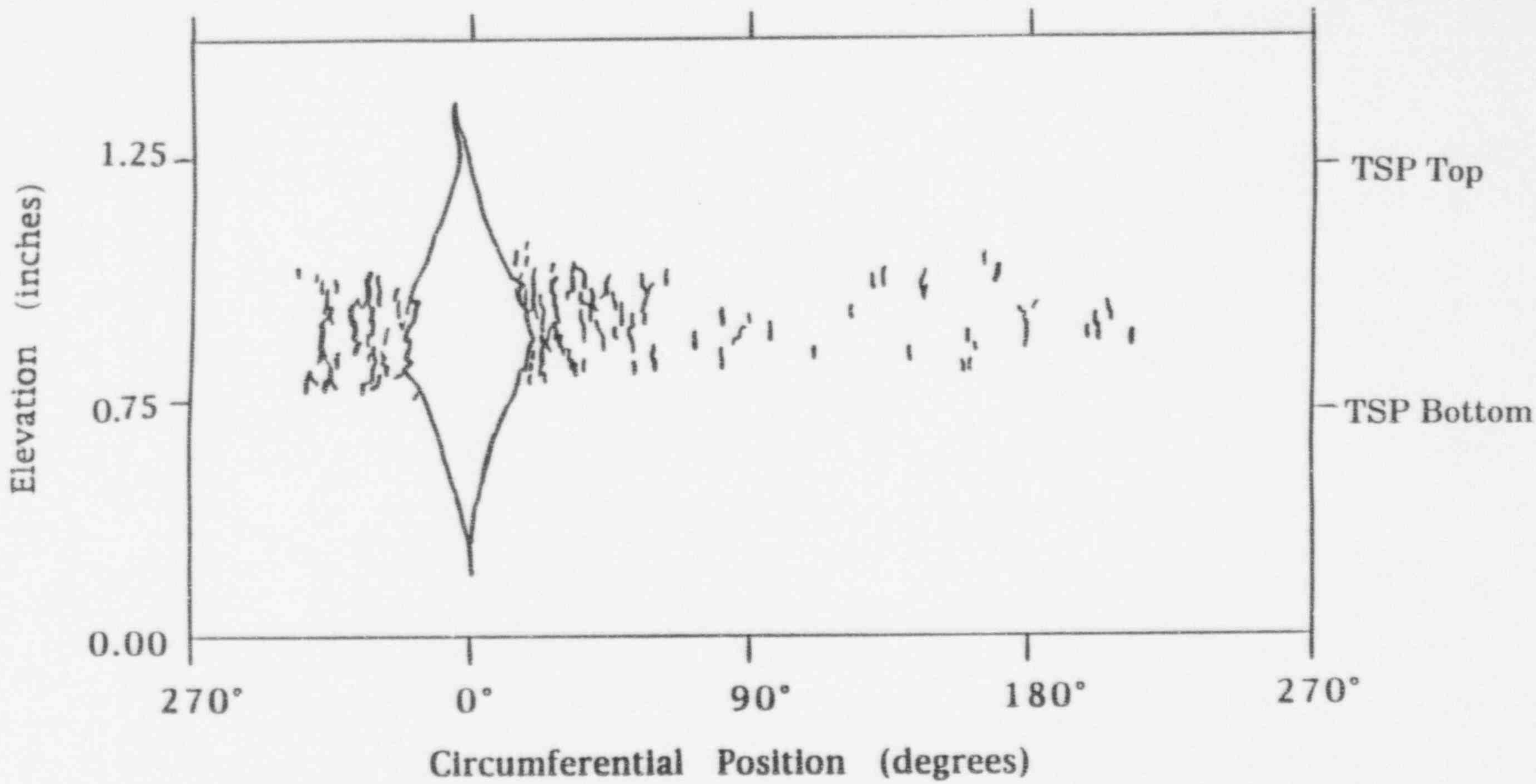


Figure 3-4 Sketch of the OD surface crack distribution found at the first tube support plate (TSP1) region of Tube R10C48 following burst testing. Also shown is the location of the axial burst opening. (The burst opening extended beyond the TSP crevice region, but the corrosion cracking on the burst fracture was confined to the crevice region.)

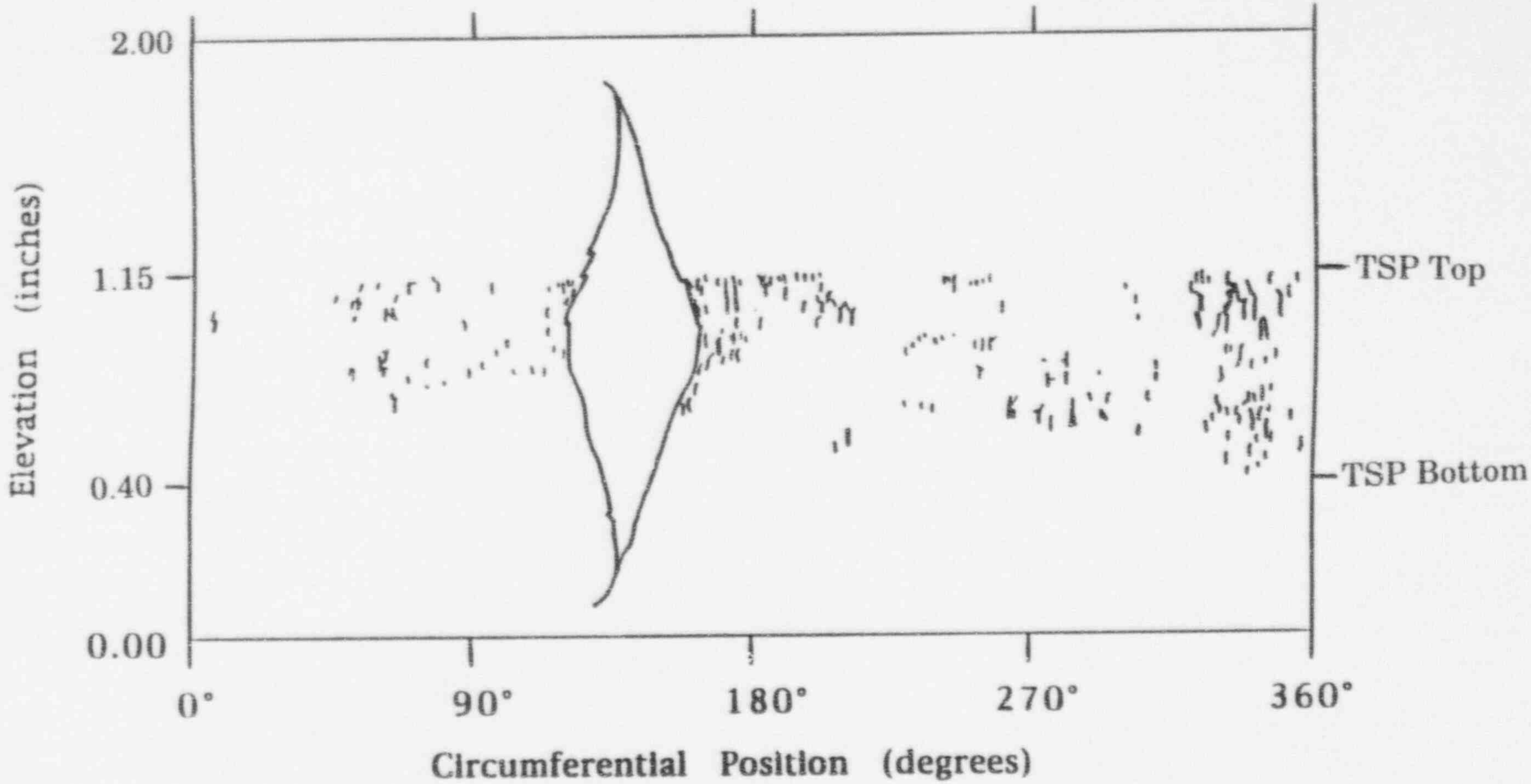


Figure 3-5 Sketch of the OD surface crack distribution found at the second tube support plate (TSP2) region of Tube R10C48 following burst testing. Also shown is the location of the axial burst opening. (The burst opening extended beyond the TSP crevice region, but the corrosion cracking on the burst fracture was confined to the crevice region.)

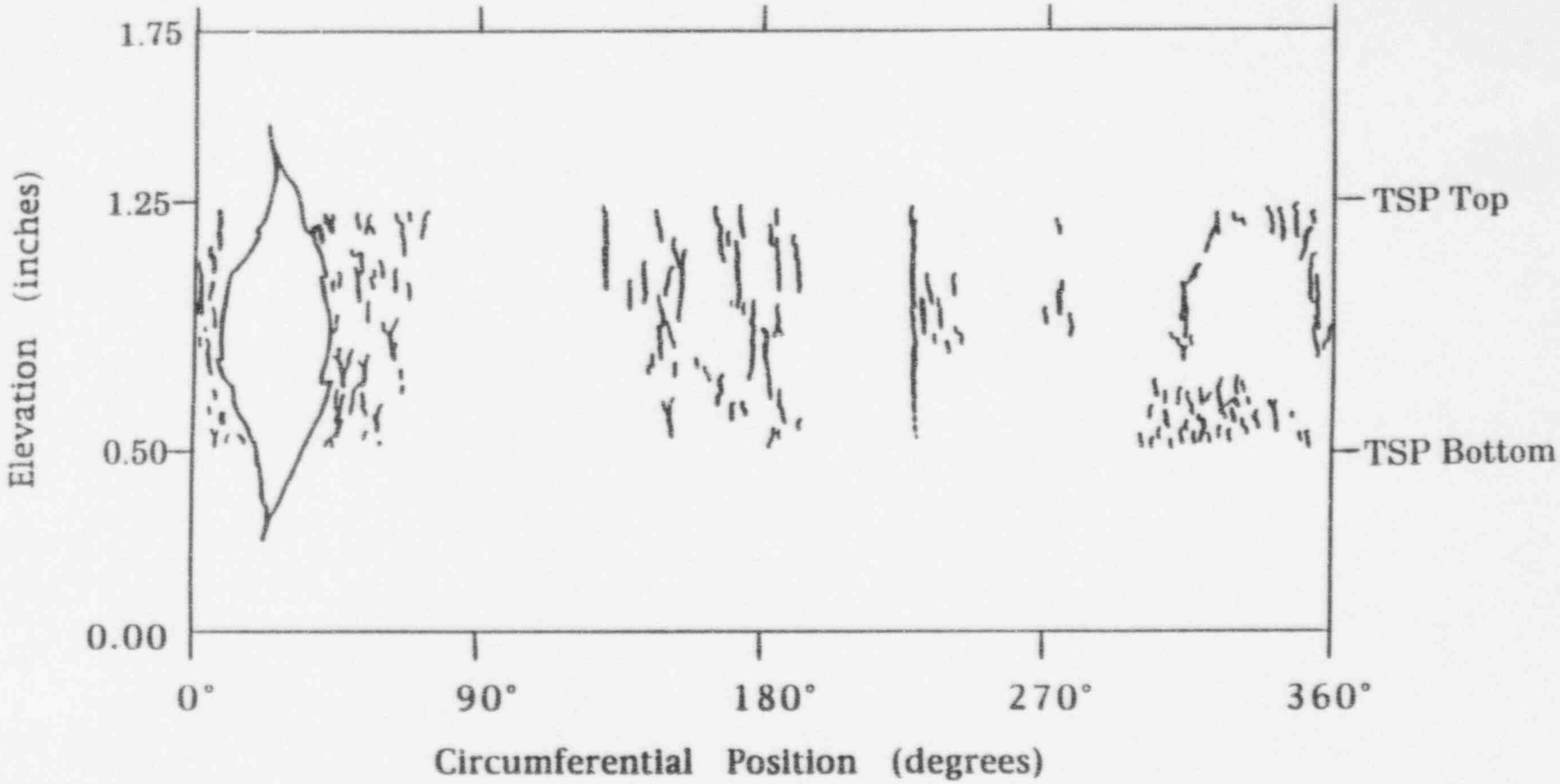


Figure 3-6 Sketch of the OD surface crack distribution found at the first tube support plate (TSP1) region of Tube R22C38 following burst testing. Also shown is the location of the axial burst opening. (The burst opening extended beyond the TSP crevice region, but the corrosion cracking on the burst fracture was confined to the crevice region.)

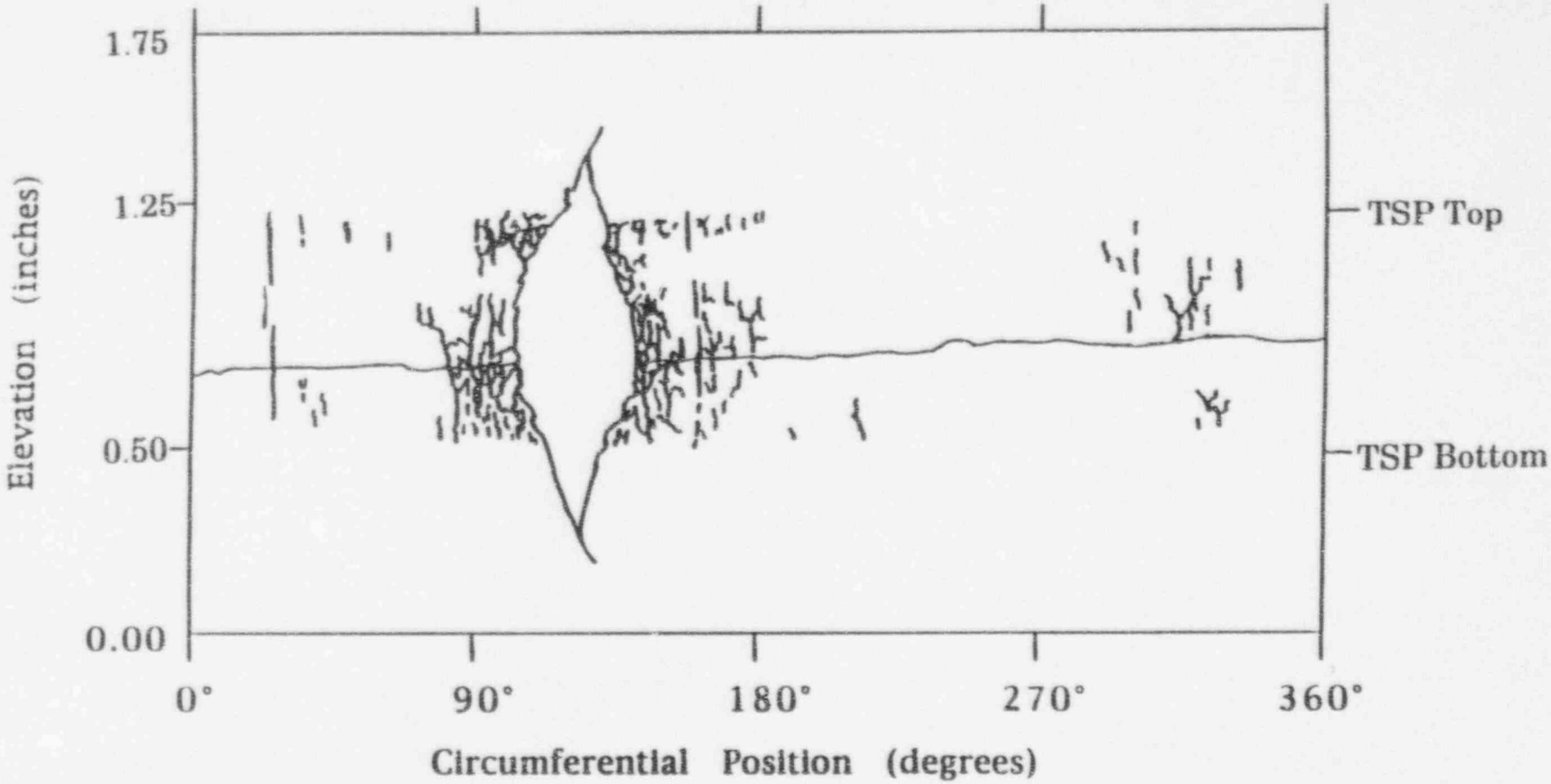


Figure 3-7 Sketch of the OD surface crack distribution found at the second tube support plate (TSP2) region of Tube R22C38 following burst testing and following subsequent tensile testing. Also shown are the locations of the axial burst opening and the circumferential tensile fracture. (The burst opening extended beyond the TSP crevice region, but the corrosion cracking on the burst fracture was confined to the crevice region.)

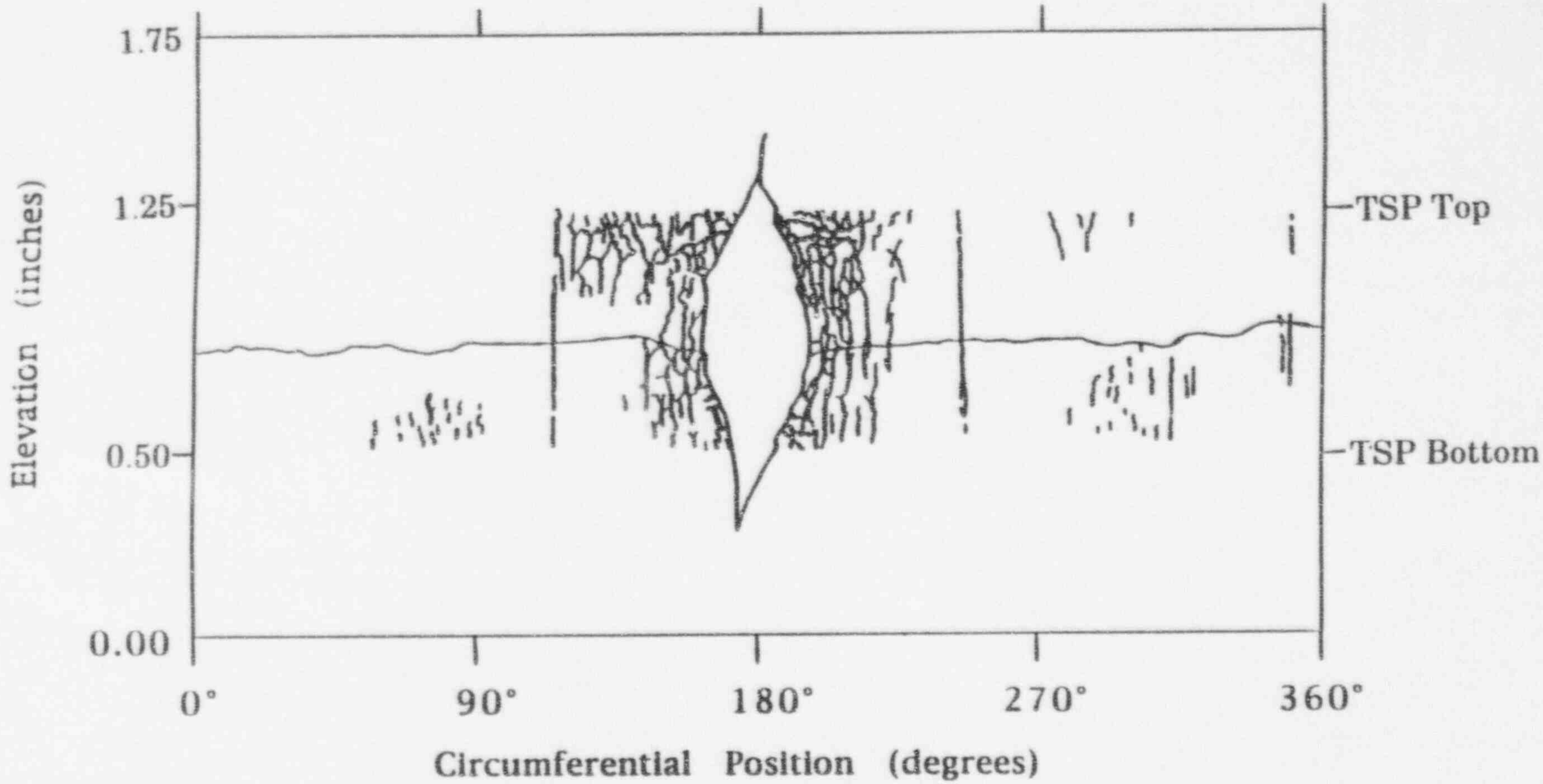


Figure 3-8 Sketch of the OD surface crack distribution found at the third tube support plate (TSP3) region of Tube R22C38 following burst testing and following subsequent tensile testing. Also shown are the locations of the axial burst opening and the circumferential tensile fracture. (The burst opening extended beyond the TSP crevice region, but the corrosion cracking on the burst fracture was confined to the crevice region.)

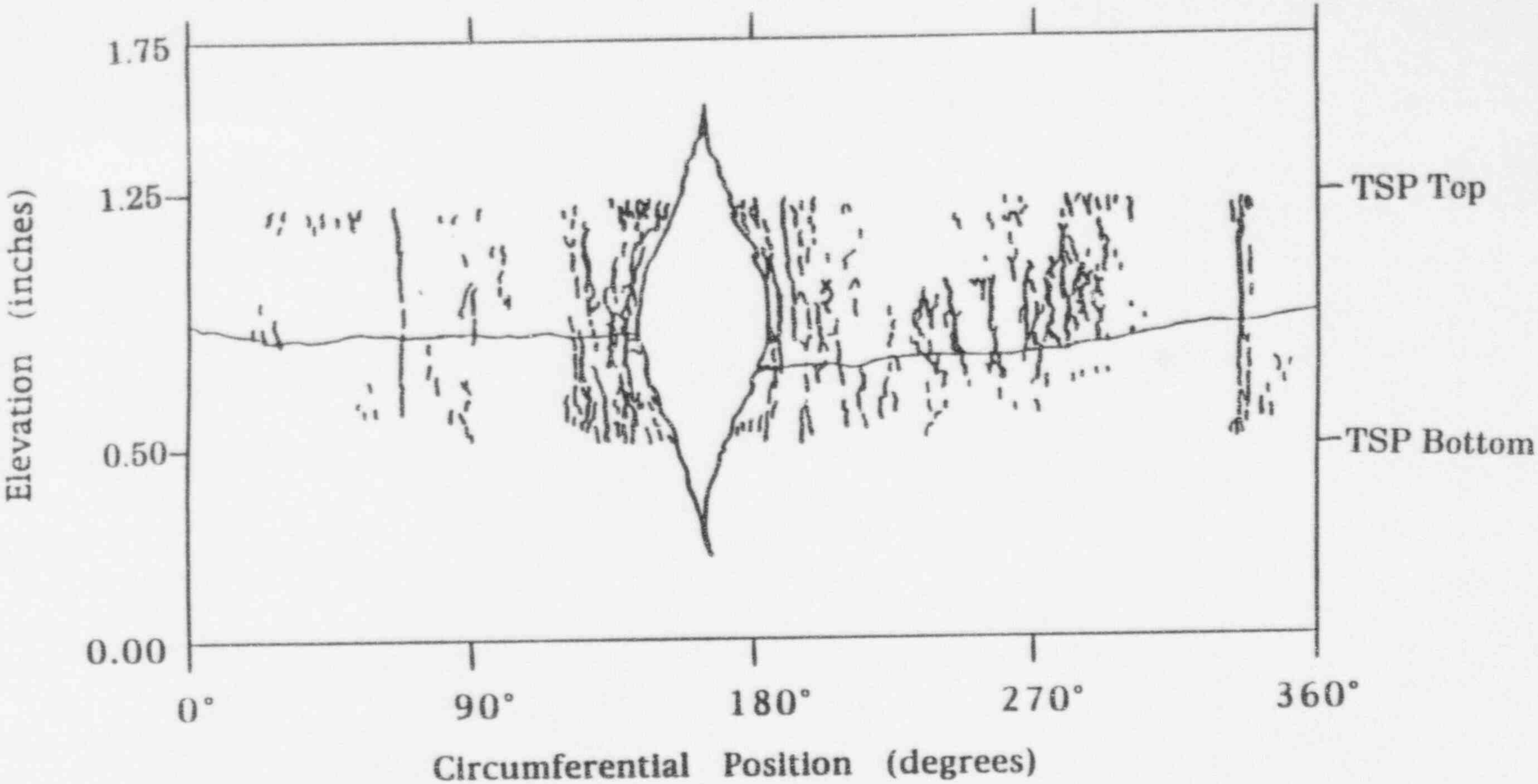


Figure 3-9 Sketch of the OD surface crack distribution found at the first tube support plate (TSP1) region of Tube R28C42 following burst testing and following subsequent tensile testing. Also shown are the locations of the axial burst opening and the circumferential tensile fracture. (The burst opening extended beyond the TSP crevice region, but the corrosion cracking on the burst fracture was confined to the crevice region.)

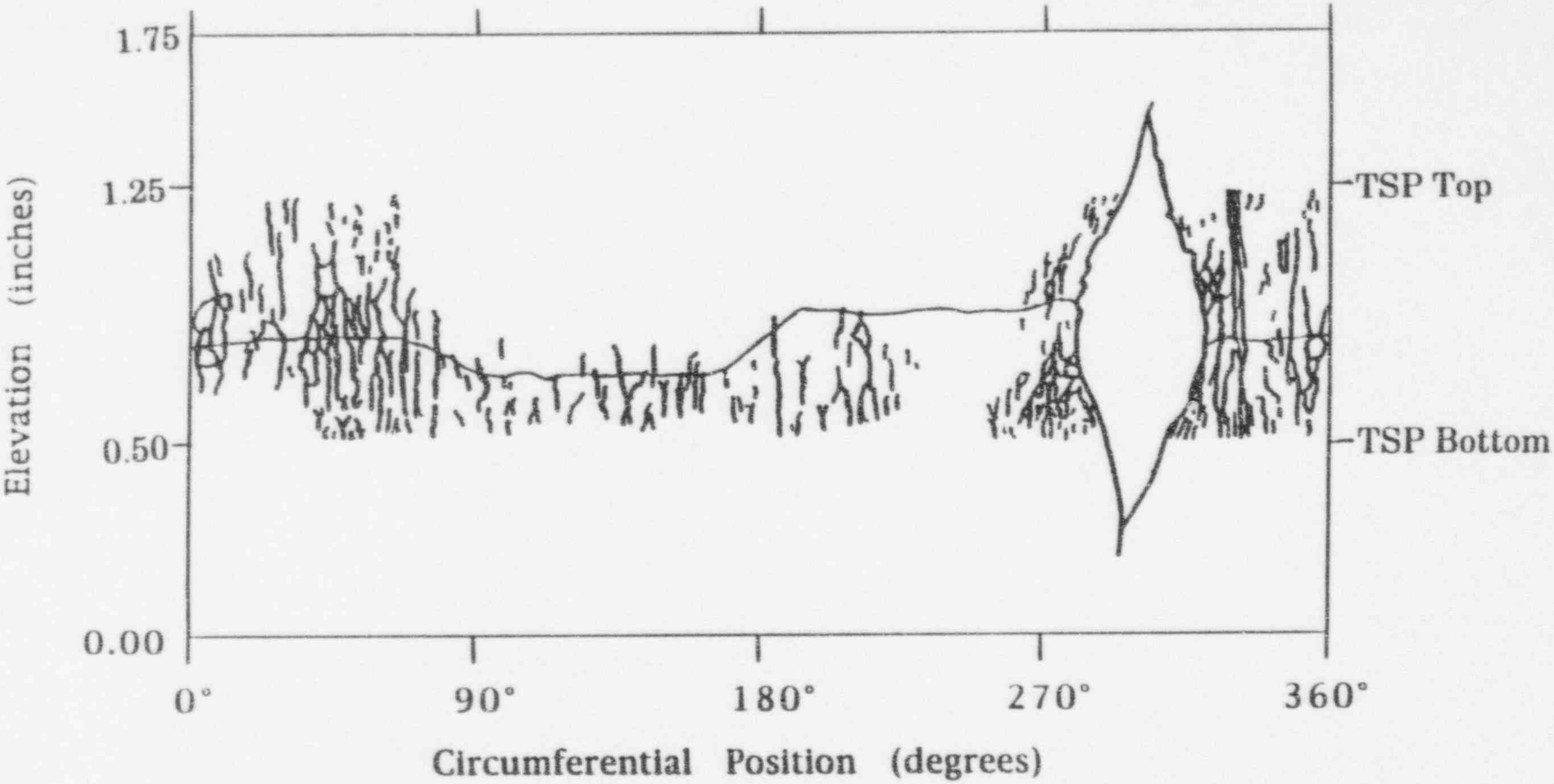


Figure 3-10 Sketch of the OD surface crack distribution found at the second tube support plate (TSP2) region of Tube R28C42 following burst testing and following subsequent tensile testing. Also shown are the locations of the axial burst opening and the circumferential tensile fracture. (The burst opening extended beyond the TSP crevice region, but the corrosion cracking on the burst fracture was confined to the crevice region.)

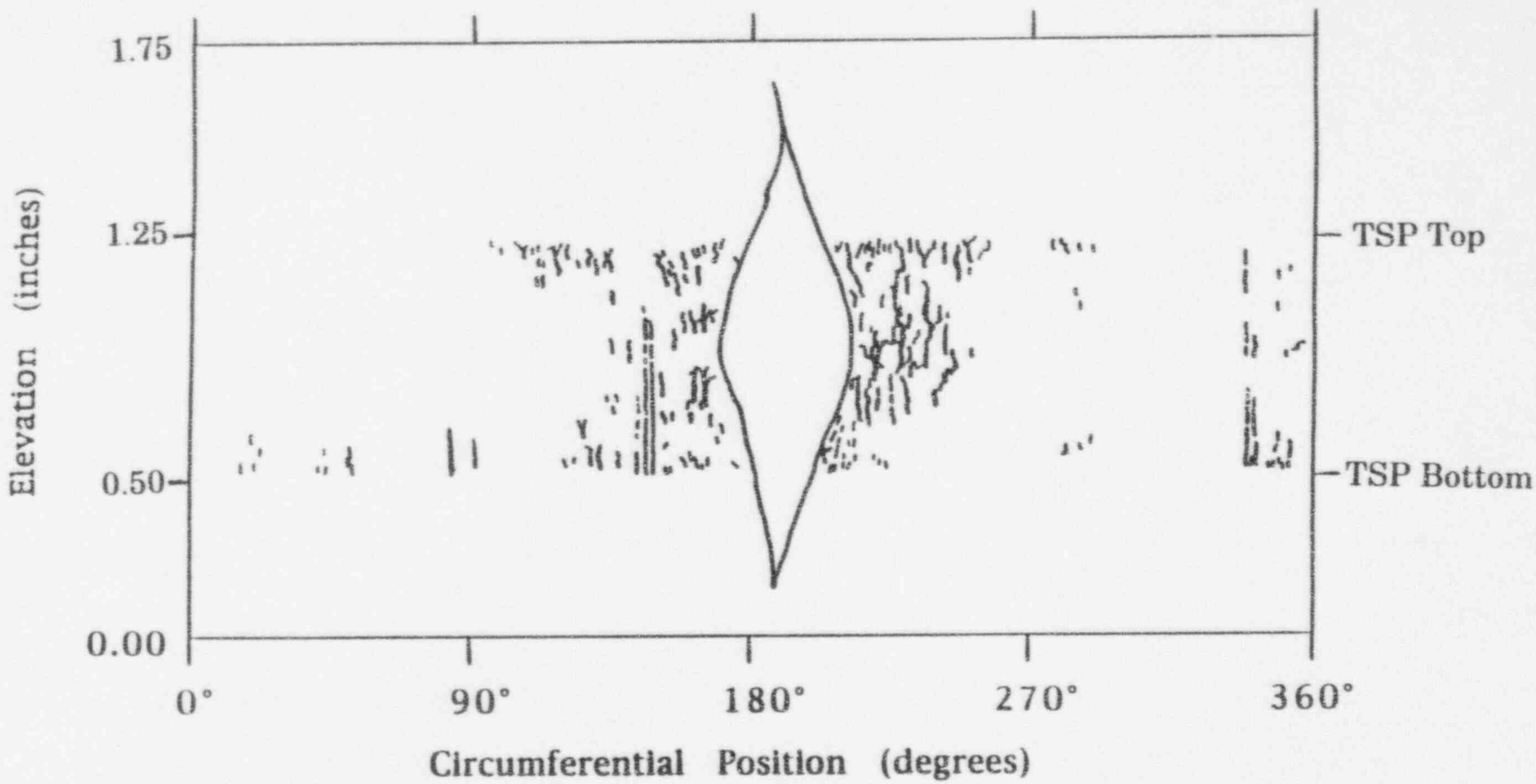


Figure 3-11 Sketch of the OD surface crack distribution found at the third tube support plate (TSP3) region of Tube R28C42 following burst testing. Also shown is the location of the axial burst opening. (The burst opening extended beyond the TSP crevice region, but the corrosion cracking on the burst fracture was confined to the crevice region.)

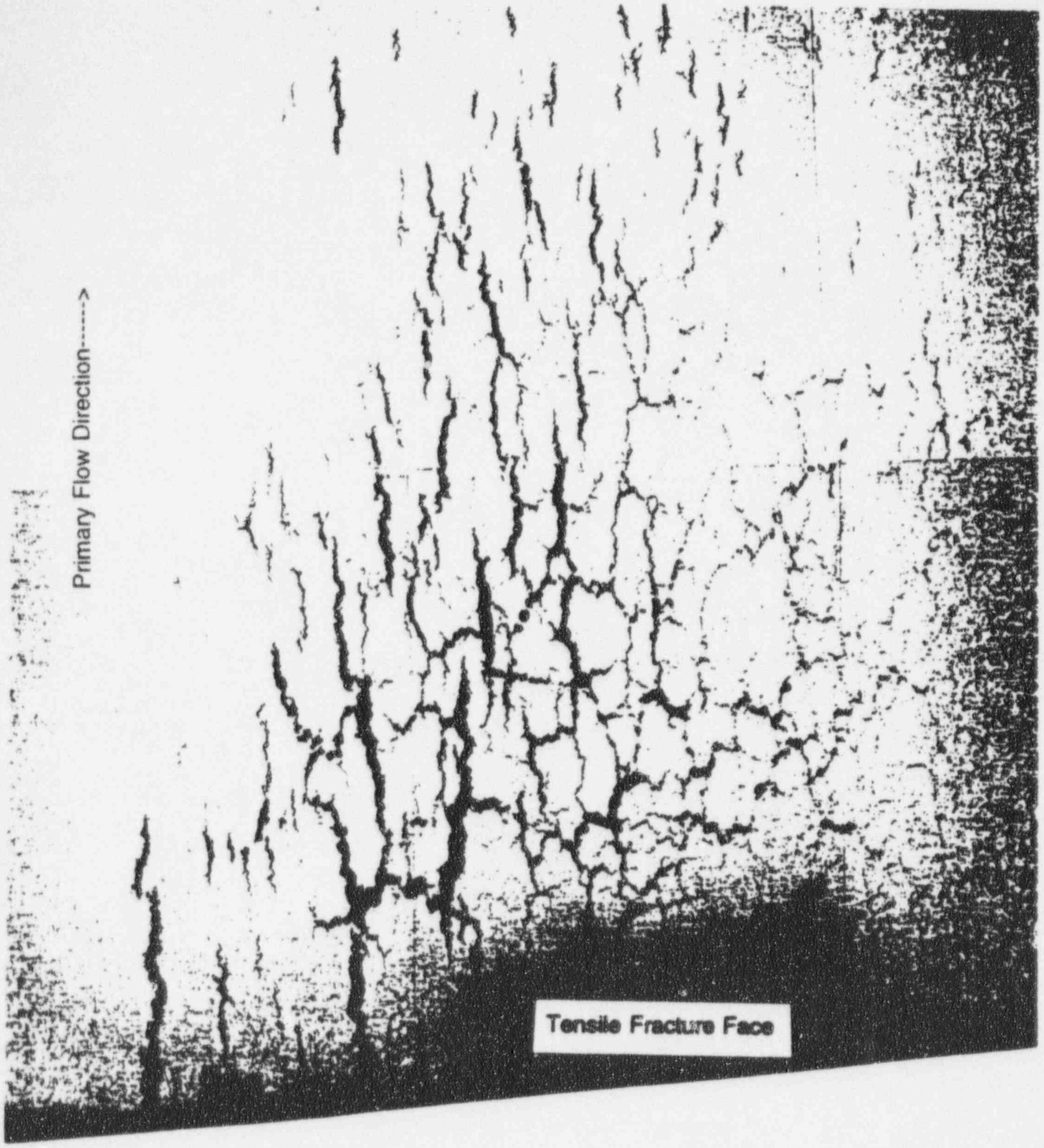


Figure 3-12a Radial metallographic section showing the TSP2 region of Tube R28C42 at a depth of 14% below the OD surface. Intergranular cellular corrosion (ICC) is observed above the transverse fracture face that was caused by tensile testing. (16X Mag.)

Figure 3-12 a

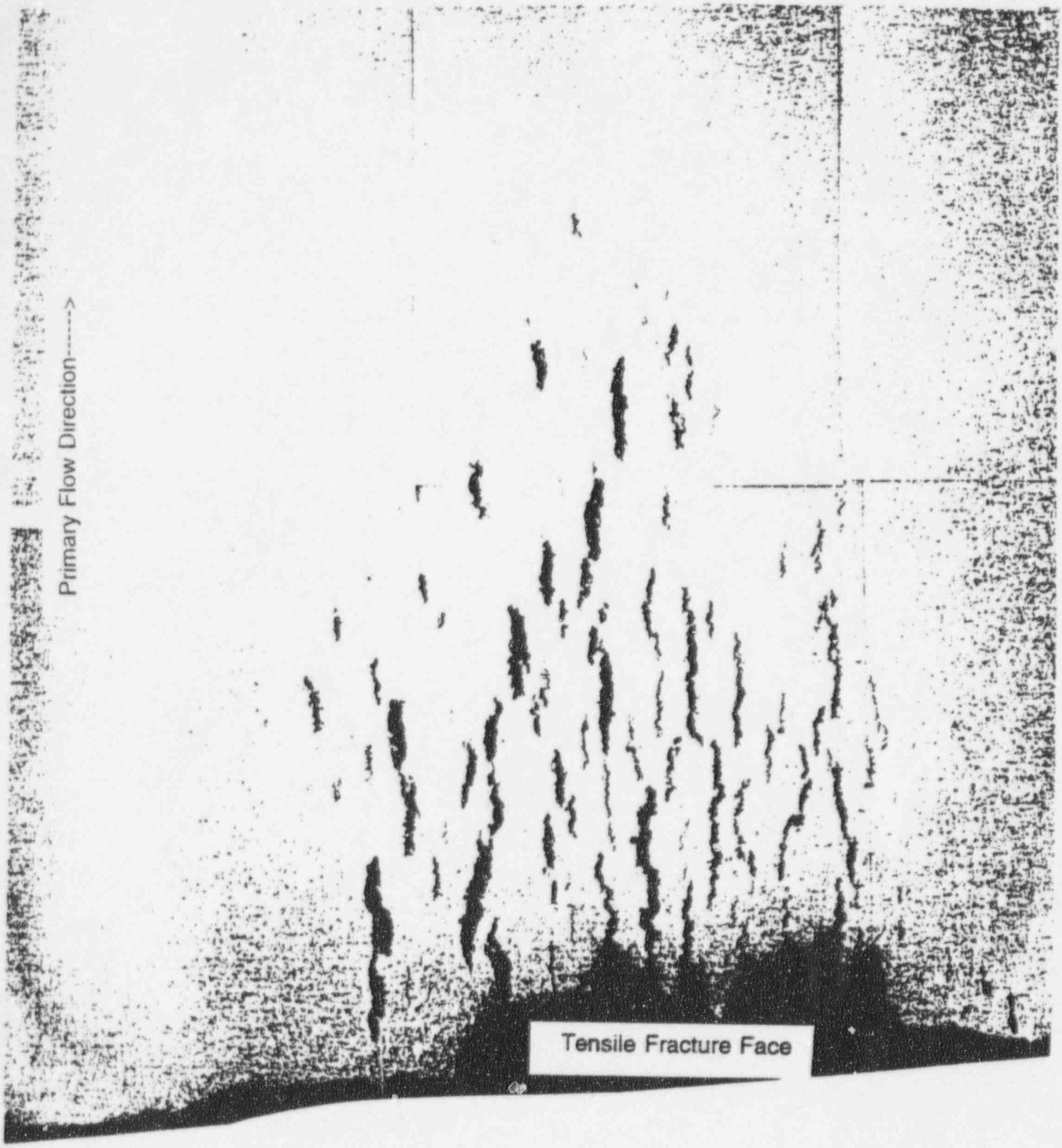


Figure 3-12b Radial metallographic section showing the TSP2 region of Tube R28C42 at a depth of 34% below the OD surface. Only axial intergranular corrosion is observed at the same location shown in Figure 3-12a (16X Mag.)

Figure 3-12 b

Figure 3-13

Burst Pressure vs Volts for 7/8" OD Alloy 600 SG Tubes

EPRI/NRC Database, Reference σ_f = 68.8 ksi @ 650°F

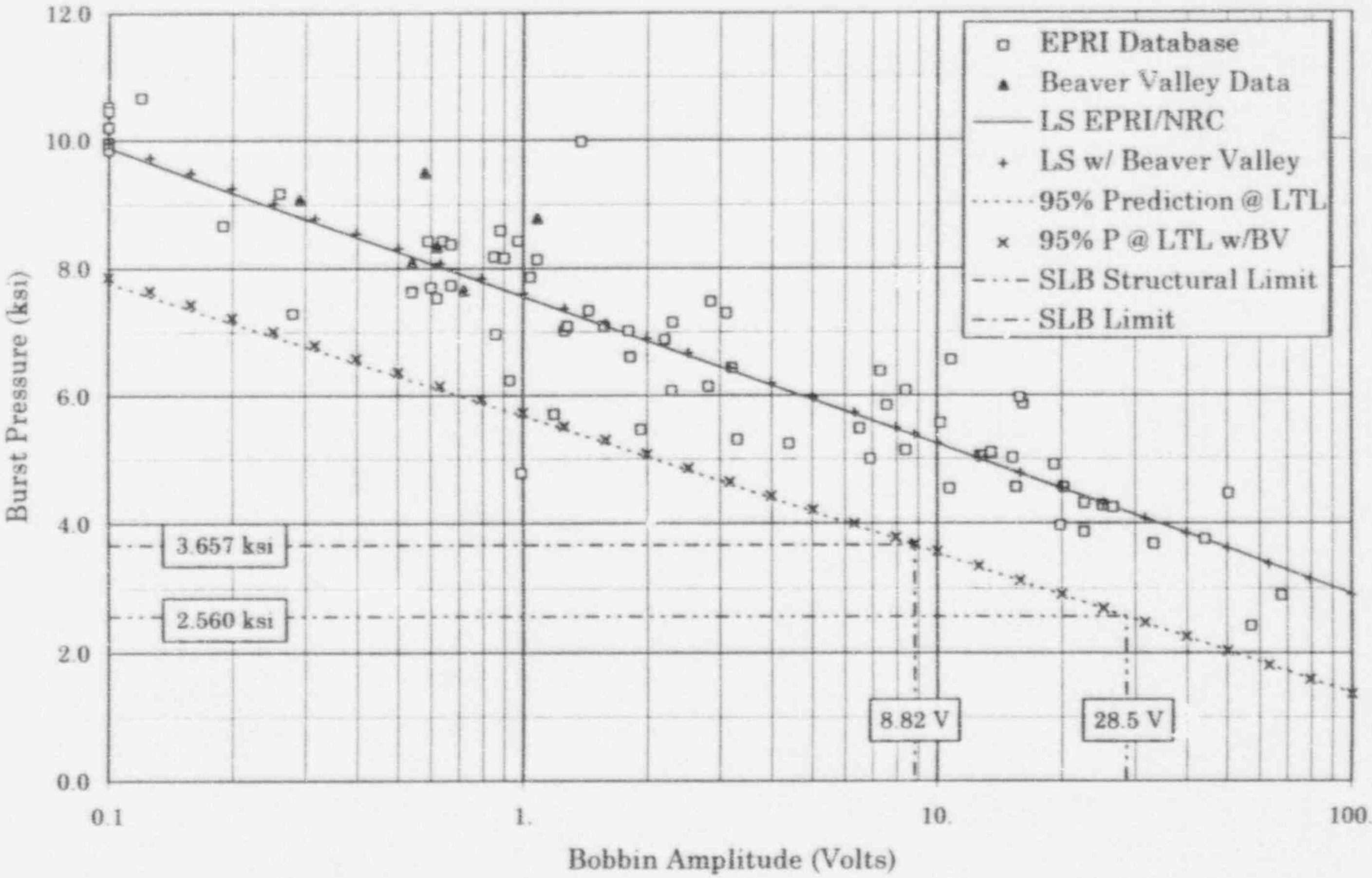
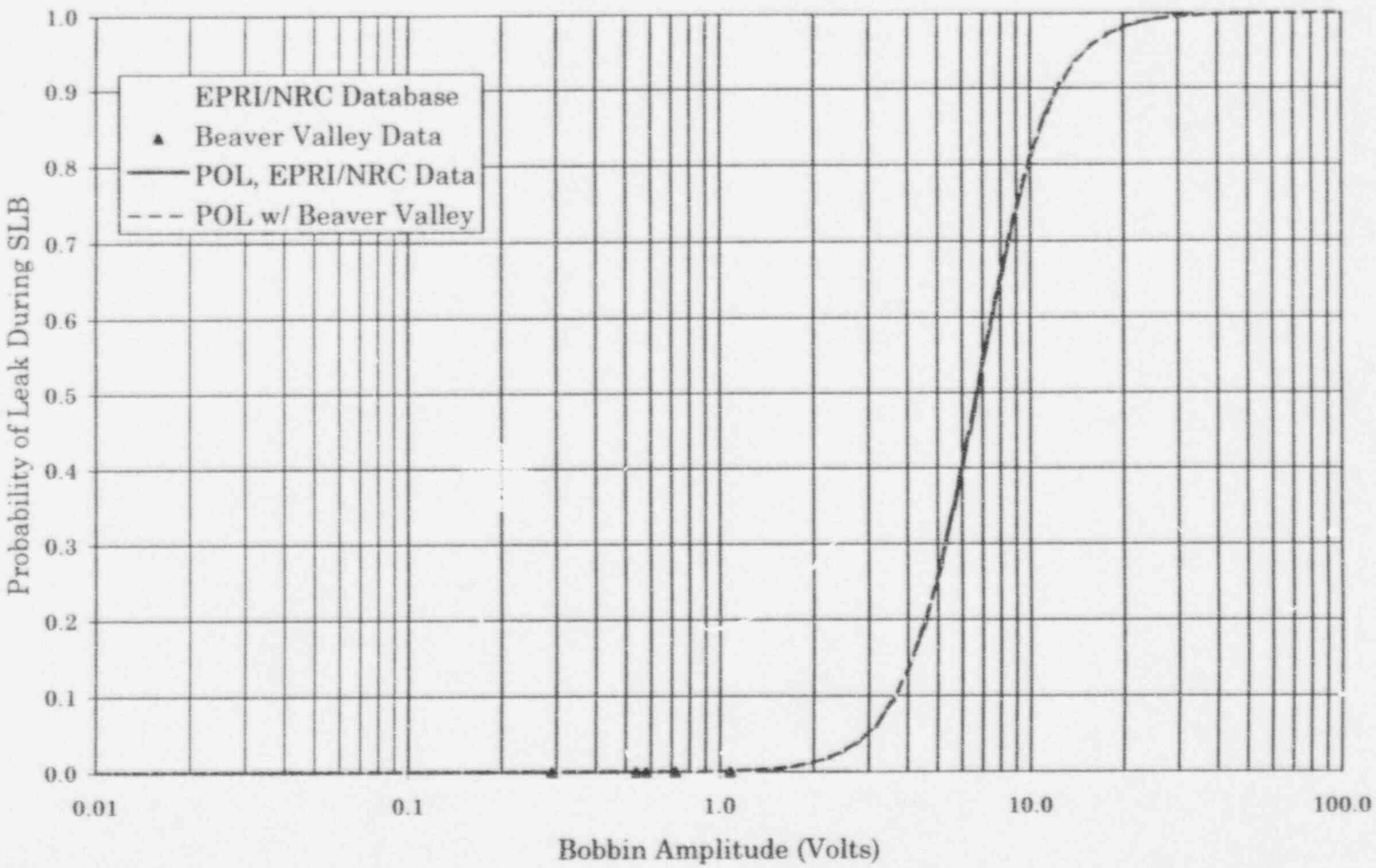


Figure 3-14

Probability of Leak for 7/8" SG Tubes

Effect of Inclusion of Beaver Valley Data



4.0 EOC-10 INSPECTION RESULTS AND VOLTAGE GROWTH RATES

4.1 EOC-10 INSPECTION RESULTS

In accordance with the IPC guidance provided in the SER of Reference 9.3, this end of cycle 10 (EOC-10) inspection of the Beaver Valley Unit 1 SGs consisted of a complete, 100% eddy current test (ECT) bobbin probe full length examination of all TSP intersections in the tube bundles of the three SGs. A 0.720 inch diameter probe was used for all hot leg TSP indications where APC was applied. Subsequently, RPC examination was performed for all bobbin indications with amplitudes > 1.0 volt. RPC confirmed indications > 1.0 bobbin volt were repaired. In addition, an augmented RPC inspection was performed consistent with the NRC SER requirements. The augmented RPC inspection included all TSP intersections (10 intersections) with dent voltages > 5.0 volts. In addition, the augmented RPC program included 161 INR (indication not reportable) and INF (indication not found) calls at supports which were DSI (distorted support indication) calls at EOC-9 but not confirmed by RPC inspection at EOC-9. Any suspected artifact signals at TSP intersections that could mask a greater than one volt flaw indication were either called DSI over 1.0 volt and inspected as part of the base RPC program or called INR and RPC tested as part of the augmented program. No RPC flaw indications were found in the augmented program. There was no evidence of any unexpected eddy current results at EOC-10. There were no RPC circumferential indications, no indications extending outside the TSPs, no RPC indications with potential PWSCC phase angles, no flaw indications at dented TSP intersections of any dent voltage and no flaw indications were found in the augmented RPC inspection. All RPC responses were consistent with that expected for ODSCC at TSP intersections.

A summary of ECT indication statistics for all three steam generators is shown on Tables 4-1 and 4-2. For those tubes that were in service during cycle 10, Table 4-1 tabulates the number of field bobbin indications, the number of these field bobbin indications that were RPC inspected, the number of RPC confirmed indications, the number of repaired/plugged indications, the number of in-service EOC-10 indications that remain active for cycle 11 (BOC-11) and the total number of BOC-11 indications including deplugged tubes that were returned to service.

During this outage, some tubes that had previously been plugged were deplugged, inspected, and either returned to service or replugged, depending on inspection results. Table 4-2 provides the same statistics for the population of indications in deplugged tubes as Table 4-1 provides for those in-service during cycle 10; together they comprise the population being returned to service for cycle 11. Together, these two tables show that:

- Out of a total of 1443 indications identified during the inspection (1089 from in-service EOC-10 and 354 deplugged EOC-10), a total of 1201 indications (978 from in-service EOC-10 and 223 deplugged EOC-10) were returned to service for cycle 11.

- Of the 1443 indications, a total of 506 were RPC inspected (152 from in-service EOC-10 and 354 deplugged EOC-10).

- Of the 506 RPC inspected, a total of 362 were RPC confirmed (88 from in-service EOC-10 and 274 deplugged EOC-10).

- A total of 242 indications were removed from service (111 from in-service EOC-10 and 131 deplugged at EOC-10). The RPC confirmed but not removed from service indications have bobbin amplitudes of ≤ 1.0 volt.

A summary of the implication of these inspection and repairs is shown on Table 4-3. A total of 94 tubes (corresponding to 111 total repaired indications) that were in service in cycle 10, which exhibited TSP ODSCC indications, were removed from service. The benefit of reevaluating prior tube plugging decisions based on implementing the 1.0 volt IPC is shown by the return to service of 164 previously plugged tubes (corresponding to 223 total indications), which offsets the tubes that were repaired for TSP ODSCC indications at EOC-10. Upon reinspection in 1995, no indication was found in two of the deplugged tubes. Consequently, these two tubes (SG B R31C13 and SG B R40C49) are not included in the Table 4-3 compilation. Additionally, seven tubes in SG A and six tubes in SG B were deplugged but not reinspected and were replugged; these 13 tubes are not included in Table 4-3.

Review of Tables 4-1 and 4-2 indicates that SG A has more in-service EOC-10 indications than SG B or C. Steam generators A and B have essentially equivalent deplugged EOC-10 populations included in their BOC-11 distributions, while SG C has none. Accordingly, the total BOC-11 indication population of SG A exceeds the other two and is considered the limiting BOC-11 SG for purposes of Monte Carlo calculations for Cycle 11.

The data shown in Tables 4-1 and 4-2 is also shown in graphical form in Figures 4-1 to 4-4. Figure 4-1 shows the bobbin voltage distribution for the in-service EOC-10 indications which were returned to service for Cycle 11; Figure 4-2 shows the bobbin voltage distribution for the deplugged EOC-10 indications which were returned to service for Cycle 11; Figure 4-3 shows the bobbin voltage distribution for the total population of indications which were returned to service for Cycle 11. Figure 4-4 shows the repaired population distribution for those in-service EOC-10 indications which were plugged.

The distribution of in-service EOC-10 indications as a function of support plate elevation, shown on Figure 4-5, confirms the presence of ODSCC predominantly in the first few hot leg TSPs. This distribution indicates a strong temperature dependence of ODSCC at Beaver Valley-1.

4.2 VOLTAGE GROWTH RATES

Voltage growth rates were developed as the difference between the February 1995 inspection results and a reevaluation of the same indications from the previous (1993) inspection. The cumulative probability distributions for the Cycle 10 growth rates are presented in Table 4-4. It is seen that the maximum growth rate for Cycle 10 is only 0.6 volt.

Average growth rates in each SG for Cycle 10 are shown in Table 4-5. The average growth rates vary between 0% and 7% between SGs. The average growth for indications $\geq$ 0.75 volt is $\leq$ 2% and significantly smaller than found for indications < 0.75 volt. Table 4-6 compares the average growth rates for Cycles 7 to 10. The data show a progressively decreasing growth rate with the implication that chemistry enhancements have been effective in reducing the growth of ODSCC indications at the TSP intersections. Between Cycles 9 and 10, the average growth decreased from 16% to 3%.

The guidance of the NRC draft generic letter recommends that the more conservative growth distribution from the last two cycles be used for projecting EOC distributions. Table 4-7 shows the Cycle 9 growth distributions which indicates larger growth rates than found for Cycle 10. The largest growth value for Cycle 9 was 1.2 volts. For conservatism consistent with the NRC guidance, the Cycle 9 growth distribution of Table 4-7 are used for the Cycle 11 projections.

4.3 PROBABILITY OF PRIOR CYCLE DETECTION (POPCD)

The inspection results at EOC-10 permit an evaluation of the probability of detection at the prior EOC-9 inspection. For APC/IPC applications, the important indications are those that could significantly contribute to EOC leakage or burst probability. These significant indications can be expected to be detected by bobbin and confirmed by RPC inspection. Thus the population of interest for APC POD assessments is the EOC RPC confirmed indications that were detected or not detected at the prior inspection. The probability of prior cycle detection (POPCD) can then be defined as:

POPCD(EOC-9) = EOC-10 RPC Confirmed and Detected at EOC-9 + EOC-9 RPC Confirmed and Plugged at EOC-9

Numerator + New EOC-10 RPC Confirmed Ind. (i.e.,not detected at EOC-9)

POPCD is evaluated at the 1993 EOC-9 voltage values (from 1995 reevaluation for growth rate) since it is a EOC-9 POPCD assessment. The indications at EOC-9 that were RPC confirmed and plugged are included as it can be expected that these indications would also have been detected and confirmed at EOC-10. It is also appropriate to include the plugged tubes for APC applications since POD adjustments

to define the BOC distribution are applied prior to reduction of the EOC indication distribution for plugged tubes.

It should be noted that the above POPCD definition includes all new EOC-10 indications not reported in the EOC-9 inspection. The new indications include EOC-9 indications present at detectable levels but not reported, indications present at EOC-9 below detectable levels and indications that initiated during Cycle 10. Thus, this definition, by including newly initiated indications, differs from the traditional POD definition. Since the newly initiated indications are appropriate for APC applications, POPCD is an acceptable definition and eliminates the need to adjust the traditional POD for new indications.

The above definition for POPCD would be entirely appropriate if all EOC-10 indications were RPC inspected. Since all EOC-10 bobbin indications were not RPC inspected, a lower bound POPCD estimate can be made by assuming that all bobbin indications not RPC inspected would have been RPC confirmed. This definition is applied only for the 1995 EOC-10 indications not RPC inspected since inclusion for the 1993 EOC-9 inspection could increase POPCD by including indications on a tube plugged for non-ODSCC causes. This lower bound POPCD can be obtained by replacing the EOC-10 RPC confirmed by RPC confirmed plus not RPC inspected in the above definition of POPCD. Inclusion of the indications not RPC inspected in POPCD primarily influences detectability below one volt since all indications > 1.0 volt are RPC inspected at Beaver Valley-1. For this report, both POPCD definitions are evaluated for Beaver Valley-1.

The EOC-9 inspection was not an IPC inspection, but can be expected to have included the general influence of IPC guidelines on industry calling criteria.

The POPCD evaluation for the 1993 EOC-9 inspection is summarized in Table 4-8 and shown in Figure 4-6. Figure 4-6 includes POPCD evaluated for only RPC confirmed indications, evaluated for RPC confirmed plus not RPC inspected indications and the EPRI POD developed by analyses of field indications for 3/4 inch diameter tubing in Model D SGs. The use of only RPC confirmed indications for POPCD leads to an unrealistically high POD below 1.0 volt due to the fact that most of the new indications in 1995 were below 1.0 volt and were not RPC inspected. Thus the lower bound POPCD based on RPC confirmed plus not RPC inspected is a more appropriate POD assessment. It is seen that the Beaver Valley-1 POPCD is in good agreement with the EPRI POD. Above 2.0 volts, POPCD is 1.0 while the EPRI POD equals 1.0 at 3.0 volts. However, there are only four Beaver Valley-1 indications above 2.0 volts. Between 1.2 and 2.0 volts, POPCD is slightly lower than the EPRI POD, but only 3 indications above 1.4 volts are new indications not detected in 1993. These indications were missed at bobbin voltages of 1.42, 1.67 and 1.88 for 1993 based on reevaluation in 1995. These indications had negligible voltage growth (~0.0, ~0.0, 0.13 volt) since 1993. Thus the calls in 1995 may reflect application of IPC guidelines since there is little change in the bobbin signals between 1993 and 1995.

In summary, the Beaver Valley-1 EOC-9 POPCD strongly supports a voltage dependent POD substantially higher than the NRC POD = 0.6 above about 0.5 volt and approaching unity above 2 to 3 volts. The Beaver Valley-1 POPCD is in general agreement with the EPRI proposed POD even though the EOC-9 inspection was not an IPC inspection. It is concluded that the POD applied for IPC leak and burst projections needs to be upgraded from the POD = 0.6 to a voltage dependent POD. This conclusion is further supported by the comparisons in Section 7 between projected and actual EOC-10 voltage distributions. The comparisons in Section 8 of SLB leak rates and tube burst probabilities calculated from the EOC-10 projected distributions by applying a POD = 1.0 exceed those calculated from the actual EOC-10 distributions.

4.4 ASSESSMENT OF RPC CONFIRMATION RATES

This section tracks the 1993 EOC-9 indications left in service at BOC-10 relative to RPC inspection results in 1995 at EOC-10. The composite results for all SGs are given in Table 4-9. For 1993 bobbin indications left in service, the indications are tracked relative to 1993 RPC confirmed, 1993 RPC NDD, 1993 bobbin indications not RPC inspected and 1993 bobbin indications with no indication found in 1995. Also included are new 1995 indications. The table shows, for each category of indications, the number of indications RPC inspected and RPC confirmed in 1995 as well as the percentage of RPC confirmed indications. There were no 1993 RPC confirmed indications left in service as this was not an IPC inspection and all RPC confirmed indications were repaired.

The 1995 RPC confirmation rate for 1993 RPC NDD indications left in service was 92.3% for bobbin indications < 1.0 volt and 50.9% for bobbin indications > 1.0 volt. The overall confirmation rate for the 1993 RPC NDD indications was 50.9%. This is a relatively high confirmation rate for RPC NDD indications left in service. For 1991 to 1993 Beaver Valley-1 Cycle 9, the confirmation rate for RPC NDD indications left in service was 27.2% (Reference 9.1). For successive IPC inspections at other plants, the confirmation rate for RPC NDD indications left in service was typically < 25%. Since the 1995 inspection was an IPC inspection, it may be possible that tighter calling criteria were applied to call RPC indications than had been applied in 1993.

For the new indications in 1995, the overall 78.8% RPC confirmation is higher than that found for the 1993 bobbin indications left in service. This is attributable to the result that 28 of the 33 new indications RPC inspected were > 1.0 volt and that all RPC confirmed indications in 1993 were plugged since the 1993 inspection was not an IPC inspection. For 1991 to 1993 Beaver Valley-1 Cycle 9, the RPC confirmation rate for new indications was 30% compared to 27.2% for RPC NDD indications left in service.

4.5 NDE UNCERTAINTIES

The NDE uncertainties applied for the EOC-11 voltage projections in this report are those given in the Beaver Valley-1 IPC report, WCAP-14123. The probe wear uncertainty has a standard deviation of 7.0 % about a mean of zero and has a cutoff at 15 % based on implementation of the probe wear standard. The analyst variability uncertainty has a standard deviation of 10.3% about a mean of zero with no cutoff. These NDE uncertainty distributions are included in the Monte Carlo analyses used to project the EOC-11 voltage distributions.

Table 4-1

Beaver Valley Unit 1 1995 TSP Voltage Statistics of Cycle 10 In-Service Indications

Summary of Bobbin, RPC, Repair Results for Return-to-Service

	S/G A							S/G B						
	Cycle 10 In Service						Total*	Cycle 10 In Service						Total*
Voltage	Field Bobbin Indications	RPC Confirmed+ Not RPC Inspected	RPC Inspected	RPC Confirmed	Indications Repaired	BOC 11 Indications	BOC 11 Indications	Field Bobbin Indications	RPC Confirmed +Not RPC Inspected	RPC Inspected	RPC Confirmed	Indications repaired	BOC 11 Indications	BOC 11 Indications
0.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0.2	2	2	0	0	0	2	2	5	5	0	0	0	5	5
0.3	24	24	0	0	2	22	25	29	29	0	0	1	28	31
0.4	52	52	1	1	3	49	55	41	41	0	0	4	37	47
0.5	73	73	2	2	1	72	79	72	72	0	0	3	69	84
0.6	66	66	4	4	4	62	81	54	54	1	1	5	49	66
0.7	66	66	2	2	1	65	81	48	47	2	1	2	46	56
0.8	69	69	3	3	6	63	77	53	53	0	0	1	52	68
0.9	27	26	2	1	1	26	49	37	36	3	2	4	33	49
1	32	32	2	2	2	30	51	24	22	2	0	1	23	43
1.1	18	9	18	9	9	9	10	12	7	12	7	8	4	4
1.2	12	9	12	9	10	2	4	7	1	7	1	1	6	8
1.3	11	4	11	4	4	7	7	8	3	8	3	3	5	5
1.4	5	2	5	2	2	3	3	2	2	2	2	2	0	0
1.5	6	4	6	4	4	2	3	4	3	4	3	3	1	1
1.6	8	6	8	6	6	2	2	1	0	1	0	0	1	1
1.7	3	0	3	0	0	3	3	2	1	2	1	1	1	1
1.8	5	3	5	3	3	2	2	1	1	1	1	1	0	0
1.9	3	3	3	3	3	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2.2	1	0	1	0	0	1	1	0	0	0	0	0	0	0
2.4	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2.6	1	1	1	1	1	0	0	0	0	0	0	0	0	0
2.8	0	0	0	0	0	0	0	0	0	0	0	0	0	1
	484	451	89	56	62	422	535	400	377	45	22	40	360	470

	S/G C							COMBINED						
	Cycle 10 In Service						Total*	Cycle 10 In Service						Total*
Voltage	Field Bobbin Indications	RPC Confirmed+ Not RPC Inspected	RPC Inspected	RPC Confirmed	Indications repaired	BOC 11 Indications	BOC 11 Indications	Field Bobbin Indications	RPC Confirmed +Not RPC Inspected	RPC Inspected	RPC Confirmed	Indications repaired	BOC 11 Indications	BOC 11 Indications
0.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0.2	0	0	0	0	0	0	0	7	7	0	0	0	7	7
0.3	7	7	0	0	0	7	7	60	60	0	0	3	57	63
0.4	17	17	0	0	0	17	17	110	110	1	1	7	103	119
0.5	35	35	1	1	0	35	35	180	180	3	3	4	176	198
0.6	31	31	1	1	0	31	31	151	151	6	6	9	142	178
0.7	31	31	0	0	0	31	31	145	144	4	3	3	142	168
0.8	23	23	0	0	0	23	23	145	145	3	3	7	138	168
0.9	25	25	1	1	1	24	24	89	87	6	4	6	83	122
1	21	21	0	0	1	20	20	77	75	4	2	4	73	114
1.1	5	2	5	2	2	3	3	35	18	35	18	19	16	17
1.2	3	1	3	1	1	2	2	22	11	22	11	12	10	14
1.3	2	2	2	2	2	0	0	21	9	21	9	9	12	12
1.4	2	0	2	0	0	2	2	9	4	9	4	4	5	5
1.5	0	0	0	0	0	0	0	10	7	10	7	7	3	4
1.6	2	1	2	1	1	1	1	11	7	11	7	7	4	4
1.7	1	1	1	1	1	0	0	6	2	6	2	2	4	4
1.8	0	0	0	0	0	0	0	6	4	6	4	4	2	2
1.9	0	0	0	0	0	0	0	3	3	3	3	3	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2.2	0	0	0	0	0	0	0	1	0	1	0	0	1	1
2.4	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2.6	0	0	0	0	0	0	0	1	1	1	1	1	0	0
2.8	0	0	0	0	0	0	0	0	0	0	0	0	0	1
	205	197	18	10	9	196	196	1089	1025	152	88	111	978	1201

*Total indications includes the deplugged indications (see Table 4-2)

Table 4-2

Beaver Valley Unit 1 1995 TSP Voltage Statistics of EOC-10 Depluged Tube Indications

Summary of Bobbin, RPC, Repair Results for Return-to-Service

	S/G A						S/G B					
	Deplugged During Outage					Total	Deplugged During Outage					Total
Voltage	Field Bobbin indications	RPC Inspected	RPC Confirmed	Indications Repaired	BOC 11 Indications	BOC 11 Indications	Field Bobbin indications	RPC inspected	RPC Confirmed	Indications repaired	BOC 11 Indications	BOC 11 indications
0.1	0	0	0	0	0	0	0	0	0	0	0	0
0.2	0	0	0	0	0	2	0	0	0	0	0	5
0.3	3	3	2	0	3	25	3	3	1	0	3	31
0.4	6	6	4	0	6	55	13	13	7	3	10	47
0.5	10	10	9	3	7	79	17	17	8	2	15	64
0.6	20	20	15	1	19	81	22	22	15	5	17	66
0.7	19	19	17	3	16	81	16	16	11	6	10	56
0.8	17	17	13	3	14	77	22	22	17	8	16	68
0.9	25	25	19	2	23	49	18	18	16	2	16	49
1	24	24	19	3	21	51	24	24	21	4	20	43
1.1	11	11	10	10	1	10	2	2	2	2	0	4
1.2	5	5	2	3	2	4	12	12	9	10	2	8
1.3	3	3	3	3	0	7	7	7	5	7	0	5
1.4	4	4	3	4	0	3	1	1	0	1	0	0
1.5	2	2	1	1	1	3	7	7	5	7	0	1
1.6	4	4	4	4	0	2	4	4	4	4	0	1
1.7	2	2	2	2	0	3	5	5	5	5	0	1
1.8	1	1	1	1	0	2	1	1	1	1	0	0
1.9	0	0	0	0	0	0	1	1	1	1	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0
2.2	2	2	2	2	0	1	3	3	3	3	0	0
2.4	0	0	0	0	0	0	2	2	2	2	0	0
2.6	0	0	0	0	0	0	0	0	0	0	0	0
2.8	0	0	0	0	0	0	2	2	1	1	1	1
3	0	0	0	0	0	0	3	3	3	3	0	0
3.2	0	0	0	0	0	0	1	1	1	1	0	0
3.4	0	0	0	0	0	0	0	0	0	0	0	0
3.6	0	0	0	0	0	0	0	0	0	0	0	0
3.8	0	0	0	0	0	0	3	3	3	3	0	0
4	0	0	0	0	0	0	2	2	2	2	0	0
4.2	0	0	0	0	0	0	1	1	1	1	0	0
4.4	0	0	0	0	0	0	0	0	0	0	0	0
4.6	0	0	0	0	0	0	0	0	0	0	0	0
4.8	0	0	0	0	0	0	1	1	1	1	0	0
5	0	0	0	0	0	0	1	1	1	1	0	0
5.2	0	0	0	0	0	0	1	1	1	1	0	0
5.4	0	0	0	0	0	0	1	1	1	1	0	0
	158	158	128	45	113	535	196	196	148	86	110	470

	S/G C						COMBINED					
	Deplugged During Outage					Total	Deplugged During Outage					Total
Voltage	Field Bobbin indications	RPC inspected	RPC Confirmed	Indications repaired	BOC 11 indications	BOC 11 indications	Field Bobbin indications	RPC inspected	RPC Confirmed	Indications repaired	BOC 11 indications	BOC 11 indications
0.1	0	0	0	0	0	0	0	0	0	0	0	0
0.2	0	0	0	0	0	0	0	0	0	0	0	7
0.3	0	0	0	0	0	7	6	6	3	0	6	63
0.4	0	0	0	0	0	17	19	19	11	3	16	119
0.5	0	0	0	0	0	35	27	27	17	5	22	198
0.6	0	0	0	0	0	31	42	42	30	6	38	178
0.7	0	0	0	0	0	31	35	35	28	9	26	168
0.8	0	0	0	0	0	23	39	39	30	9	30	168
0.9	0	0	0	0	0	24	43	43	35	4	39	122
1	0	0	0	0	0	20	48	48	40	7	41	114
1.1	0	0	0	0	0	3	13	13	12	12	1	17
1.2	0	0	0	0	0	2	17	17	11	13	4	14
1.3	0	0	0	0	0	0	10	10	8	10	0	12
1.4	0	0	0	0	0	2	5	5	3	5	0	5
1.5	0	0	0	0	0	0	9	9	6	8	1	4
1.6	0	0	0	0	0	1	8	8	8	8	0	4
1.7	0	0	0	0	0	0	7	7	7	7	0	4
1.8	0	0	0	0	0	0	2	2	2	2	0	2
1.9	0	0	0	0	0	0	1	1	1	1	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0
2.2	0	0	0	0	0	0	5	5	5	5	0	1
2.4	0	0	0	0	0	0	2	2	2	2	0	0
2.6	0	0	0	0	0	0	0	0	0	0	0	0
2.8	0	0	0	0	0	0	2	2	1	1	1	1
3	0	0	0	0	0	0	3	3	3	3	0	0
3.2	0	0	0	0	0	0	1	1	1	1	0	0
3.4	0	0	0	0	0	0	0	0	0	0	0	0
3.6	0	0	0	0	0	0	0	0	0	0	0	0
3.8	0	0	0	0	0	0	3	3	3	3	0	0
4	0	0	0	0	0	0	2	2	2	2	0	0
4.2	0	0	0	0	0	0	1	1	1	1	0	0
4.4	0	0	0	0	0	0	0	0	0	0	0	0
4.6	0	0	0	0	0	0	0	0	0	0	0	0
4.8	0	0	0	0	0	0	1	1	1	1	0	0
5	0	0	0	0	0	0	1	1	1	1	0	0
5.2	0	0	0	0	0	0	1	1	1	1	0	0
5.4	0	0	0	0	0	0	1	1	1	1	0	0
	0	0	0	0	0	196	354	354	274	131	223	1201

Table 4-3
Beaver Valley Unit 1 1995 Steam Generator Inspection Consolidated Data

Voltage Bin		S/G A EOC-10 In Service: Bobbin	S/G A EOC-10 In Service: Repaired	S/G A EOC-10 In Service: Left in Service	S/G A EOC-10 Deplugged: Bobbin	S/G A EOC-10 Deplugged: Returned to Service	S/G B EOC-10 In Service: Bobbin	S/G B EOC-10 In Service: Repaired	S/G B EOC-10 In Service: Left in Service	S/G B EOC-10 Deplugged: Bobbin	S/G B EOC-10 Deplugged: Returned to Service
≤ 1.0V	No. of Indications	411	20	391	124	109	363	21	342	135	107
	No. of Tubes	353	11	342	80	76	307	15	292	86	81
>1.0V ≤2.0V	No. of Indications	71	41	30	32	4	37	19	18	40	2
	No. of Tubes	70	40	30	29	4	37	19	18	29	2
>2.0V	No. of Indications	2	1	1	2	0	0	0	0	21	1
	No. of Tubes	2	1	1	2	0	0	0	0	16	1
All Volts	No. of Indications	484	62	422	158	113	400	40	360	196	110
	No. of Tubes	425	52	373	111	80	344	34	310	131	84

Voltage Bin		S/G C EOC-10 In Service: Bobbin	S/G C EOC-10 In Service: Repaired	S/G C EOC-10 In Service: Left in Service	S/G C EOC-10 Deplugged: Bobbin	S/G C EOC-10 Deplugged: Returned to Service	Combined EOC-10 In Service: Bobbin	Combined EOC-10 In Service: Repaired	Combined EOC-10 In Service: Left in Service	Combined EOC-10 Deplugged: Bobbin	Combined EOC-10 Deplugged: Returned to Service
≤ 1.0V	No. of Indications	190	2	188	0	0	984	43	921	259	216
	No. of Tubes	164	1	163	0	0	824	27	797	166	157
>1.0V ≤2.0V	No. of Indications	15	7	8	0	0	123	67	56	72	6
	No. of Tubes	14	7	7	0	0	121	66	55	58	6
>2.0V	No. of Indications	0	0	0	0	0	2	1	1	23	1
	No. of Tubes	0	0	0	0	0	2	1	1	18	1
All Volts	No. of Indications	205	9	196	0	0	1089	111	978	354	223
	No. of Tubes	178	8	170	0	0	947	94	853	242	164

Note : Any tube may have more than one indication, but the tube is counted only once in its highest voltage bin (i.e. that tube will not be included in count of lower voltage bins).

Table 4-4
Beaver Valley Unit 1 IPC Statistics 1995 Outage
Cumulative Probability Distributions for Voltage Growth - Indications Remaining in Service

Delta Voltage	S/G A		S/G B		S/G C		Combined	
	No. obs	CPDF	No. obs	CPDF	No. obs	CPDF	No. obs	CPDF
0	252	52.07	145	36.25	72	35.12	469	43.07
0.1	163	85.74	153	74.50	91	79.51	407	80.44
0.2	45	95.04	69	91.75	33	95.61	147	93.94
0.3	16	98.35	23	97.50	4	97.56	43	97.89
0.4	7	99.79	7	99.25	3	99.02	17	99.45
0.5	0	99.79	2	99.75	1	99.51	3	99.72
0.6	1	100.00	1	100.00	1	100.00	3	100.00
	484		400		205		1089	

CPDF = Cumulative Probability Distribution Function

Table 4-5
Beaver Valley Unit 1 Bobbin Voltage Growth for Cycle 10

		Number of Indications	BOC Voltage		Voltage Growth		Average dV
			Ave.	Std. Dev	Ave.	Std. Dev	%/Cycle
S/G A	Entire Range	484	0.71	0.35	0.00	0.13	0%
	$V_{BOC}<.75$	311	0.51	0.14	0.02	0.11	3%
	$V_{BOC}\geq.75$	173	1.07	0.34	-0.04	0.16	-4%
S/G B	Entire Range	400	0.60	0.27	0.04	0.12	7%
	$V_{BOC}<.75$	293	0.48	0.15	0.05	0.11	10%
	$V_{BOC}\geq.75$	107	0.95	0.20	0.02	0.14	2%
S/G C	Entire Range	205	0.64	0.25	0.04	0.11	6%
	$V_{BOC}<.75$	148	0.52	0.14	0.05	0.11	10%
	$V_{BOC}\geq.75$	57	0.94	0.19	0.00	0.09	0%

dV = Change in voltage

Table 4-6
Beaver Valley Unit 1 Historical Bobbin Voltage Growth

		Number of Indications	BOC Voltage		Voltage Growth		Average dV
			Ave.	Std. Dev	Ave.	Std. Dev	%/Cycle
Cycle 10	Entire Range	1089	0.66	0.31	0.02	0.12	3%
1993-1995	V_{BOC}<.75	751	0.50	0.15	0.04	0.11	7%
	$V_{BOC}\geq$.75	338	1.01	0.29	-0.01	0.15	-1%
Cycle 9	Entire Range	1125	0.57	0.27	0.09	0.23	16%
1991-1993	V_{BOC}<.75	918	0.47	0.14	0.09	0.20	19%
	$V_{BOC}\geq$.75	207	1.02	0.30	0.09	0.31	6%
Cycle 8	Entire Range	952	0.95	0.44	0.18	0.24	19%
1989-1991	V_{BOC}<.75	366	0.58	0.12	0.16	0.19	28%
	$V_{BOC}\geq$.75	586	1.18	0.41	0.19	0.26	16%
Cycle 7	Entire Range	918	0.66	0.31	0.29	0.27	44%
1987-1989	V_{BOC}<.75	622	0.49	0.15	0.27	0.22	55%
	$V_{BOC}\geq$.75	296	1.01	0.28	0.34	0.33	34%

dV = Change in voltage

Beaver Valley Unit 1 Cumulative Probability Distributions for Voltage Growth												
					1991 to 1993 Laboratory Re-evaluation							
	1987-1989		1989-1991		S/G A		S/G B		S/G C		Combined Data	
Voltage	# obs	CPDF	# obs	CPDF	# obs	CPDF	# obs	CPDF	# obs	CPDF	# obs	CPDF
0	86	9.37	195	20.48	150	26.27	146	50.17	106	40.30	402	35.73
0.1	119	22.33	172	38.55	129	48.86	60	70.79	78	69.96	267	59.47
0.2	171	40.96	184	57.88	111	68.30	48	87.29	39	84.79	198	77.07
0.3	155	57.84	154	74.05	62	79.16	19	93.81	23	93.54	104	86.31
0.4	150	74.18	114	86.03	45	87.04	9	96.91	11	97.72	65	92.09
0.5	82	83.12	59	92.23	22	90.89	6	98.97	4	99.24	32	94.93
0.6	55	89.11	28	95.17	22	94.75	2	99.66	1	99.62	25	97.16
0.7	32	92.59	20	97.27	7	95.97	0	99.66	1	100.00	8	97.87
0.8	20	94.77	12	98.53	9	97.55	1	100.00	0	100.00	10	98.76
0.9	21	97.06	6	99.16	8	98.95	0	100.00	0	100.00	8	99.47
1	8	97.93	3	99.47	4	99.65	0	100.00	0	100.00	4	99.82
1.1	7	98.69	1	99.58	0	99.65	0	100.00	0	100.00	0	99.82
1.2	4	99.13	0	99.58	2	100.00	0	100.00	0	100.00	2	100.00
1.3	4	99.56	1	99.68	0	100.00	0	100.00	0	100.00	0	100.00
1.4	1	99.67	1	99.79	0	100.00	0	100.00	0	100.00	0	100.00
1.5	2	99.89	1	99.89	0	100.00	0	100.00	0	100.00	0	100.00
1.6	0	99.89	1	100.00	0	100.00	0	100.00	0	100.00	0	100.00
1.7	0	99.89		100.00	0	100.00	0	100.00	0	100.00	0	100.00
1.8	0	99.89		100.00	0	100.00	0	100.00	0	100.00	0	100.00
1.9	0	99.89		100.00	0	100.00	0	100.00	0	100.00	0	100.00
2	0	99.89		100.00	0	100.00	0	100.00	0	100.00	0	100.00
2.1	1	100.00		100.00	0	100.00	0	100.00	0	100.00	0	100.00
	918		952		571		291		263		1125	

EXTRACTED FROM WCAP-14123 (SG-94-07-002)

TABLE 4-7

Table 4 - 8
Beaver Valley Unit - 1
1993 EOC-9 POPCD Evaluation
Composite of All Steam Generator data

Voltage Bin	New Indications 1993 Volts		1995 Bobbin, Field Call in 1993 1993 Volts		1993 Bobbin Field Call 1993 Volts	POPCD			
	1995 RPC Confirmed	1995 RPC Confirmed plus not Inspected	1995 RPC Confirmed	1995 RPC Confirmed plus not Inspected	1993 Confirmed and Plugged	RPC Confirmed		RPC Confirmed Plus Not Inspected	
						Frac.	Count	Frac.	Count
> 0 - 0.2	0	20	0	1	5	1	5 / 5	0.23	6 / 26
0.2 - 0.4	0	153	3	64	64	1	67 / 67	0.46	128 / 281
0.4 - 0.6	1	180	7	174	137	0.99	144 / 145	0.63	311 / 491
0.6 - 0.8	4	93	9	177	104	0.97	113 / 117	0.75	281 / 374
0.8 - 1.0	5	29	8	82	54	0.93	62 / 67	0.82	136 / 165
1.0 - 1.2	9	9	15	15	22	0.80	37 / 46	0.80	37 / 46
1.2 - 1.4	4	4	8	8	18	0.87	26 / 30	0.87	26 / 30
1.4 - 1.6	1	1	6	6	3	0.90	9 / 10	0.90	9 / 10
1.6 - 1.8	1	1	4	4	7	0.92	11 / 12	0.92	11 / 12
1.8 - 2.0	1	1	1	1	4	0.83	5 / 6	0.83	5 / 6
2.0 - 2.2	0	0	0	0	1	1	1 / 1	1	1 / 1
2.2 - 2.5	0	0	0	0	1	1	1 / 1	1	1 / 1
2.5 - 3.0	0	0	1	1	1	1	2 / 2	1	2 / 2
TOTAL	26	491	62	533	421				
> 1V	16	16	35	35	57				

DL WPOPCD XLS|COMB-POPCD-TABL-SUM|6/6/95|6 02 PM

Table 4 - 9
Beaver Valley Unit -1
Analysis of RPC Data from 1993 and 1995 Inspections
Composite of All Three Steam Generator Data

Group of Indications	Total 1993 Bobbin Indication	Total 1995 Bobbin Indication	Total 1995 RPC Inspected	Total 1995 RPC Confirmed	Percent 1995 RPC Confirmed
Less than or Equal to 1.0 Volt in 1995					
93 Bobbin Left in Service	667	493	22	18	81.8
- 93 RPC Confirmed	0	0	0	0	-
- 93 RPC NDD	430	430	19	16	84.2
- 93 RPC Not Inspected	63	63	3	2	66.7
- No 95 Bobbin *	174	-	-	-	-
New 95 Indications	-	470	5	4	80.0
Sum of All 95 Indications	667	963	27	22	81.5
Greater than 1.0 Volt in 1995					
93 Bobbin Left in Service	103	97	97	44	45.4
- 93 RPC Confirmed	0	0	0	0	-
- 93 RPC NDD	89	89	89	38	42.7
- 93 RPC Not Inspected	8	8	8	6	75.0
- No 95 Bobbin *	6	-	-	-	-
New 95 Indications	-	28	28	22	78.6
Sum of All 95 Indications	103	125	125	66	52.8
All Voltages in 1995					
93 Bobbin Left in Service	770	590	119	62	52.1
- 93 RPC Confirmed	0	0	0	0	-
- 93 RPC NDD	519	519	110	56	50.9
- 93 RPC Not Inspected	71	71	9	6	66.7
- No 95 Bobbin *	180	-	-	-	-
New 95 Indications	-	498	33	26	78.8
Sum of All 95 Indications	770	1088	152	88	57.9

* Indications split is based on '93 bobbin voltage

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Figure 4-1
Beaver Valley Unit 1 In-Service BOC-11 Bobbin Voltage Distribution

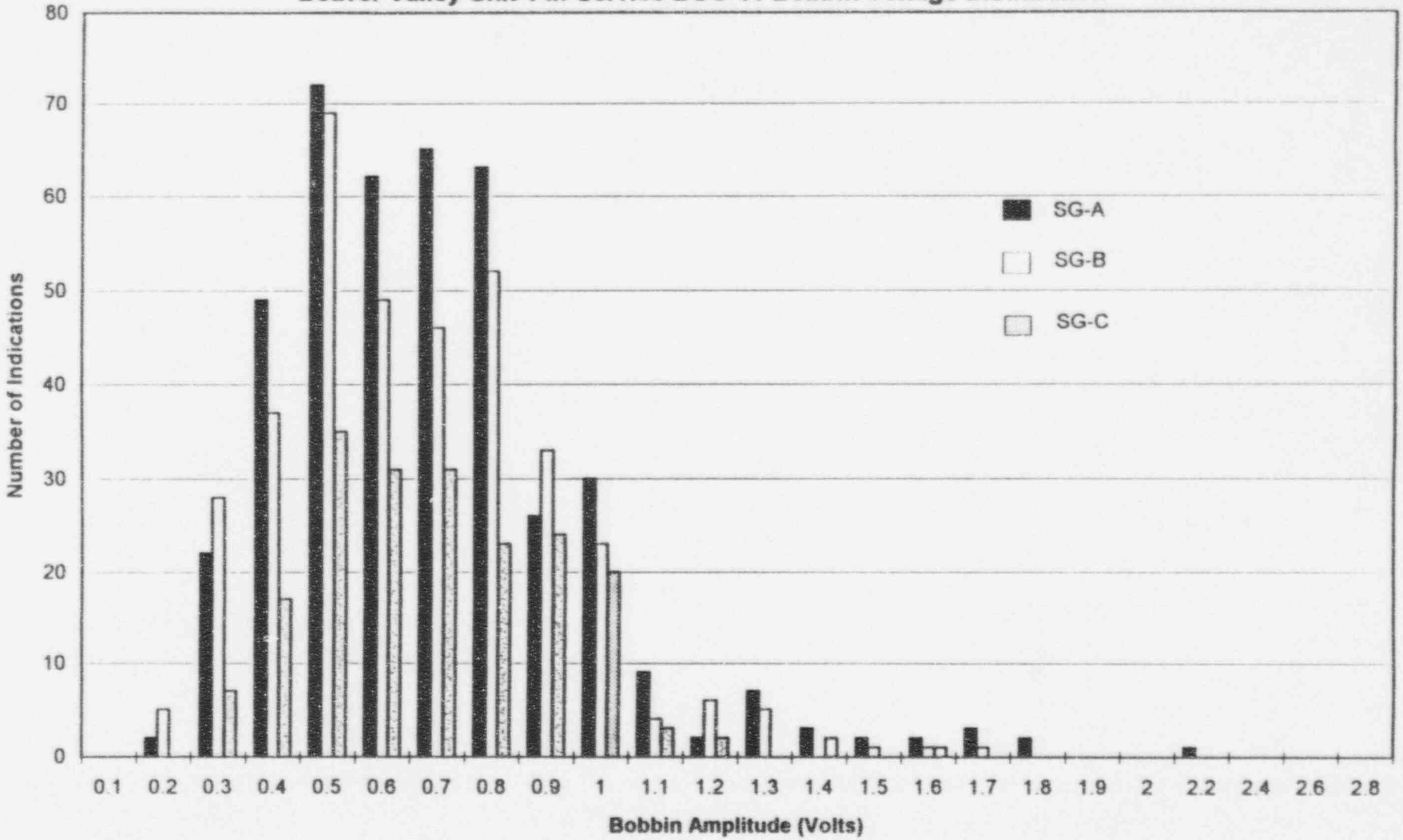


Figure 4-2
Beaver Valley Unit 1 Deplugged BOC-11 Bobbin Voltage Distribution

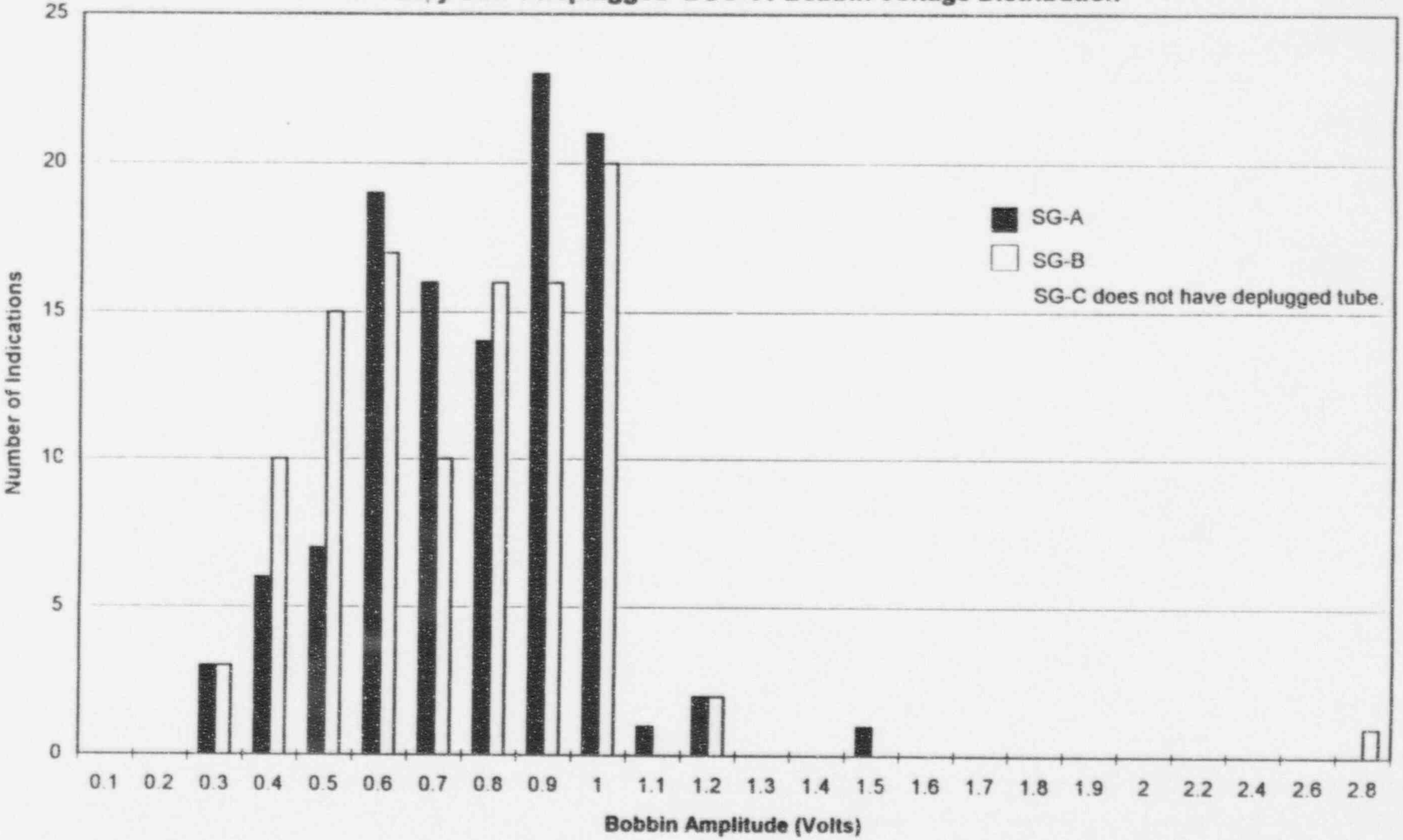


Figure 4-3
Beaver Valley Unit 1 Total BOC-11 Bobbin Voltage Distribution

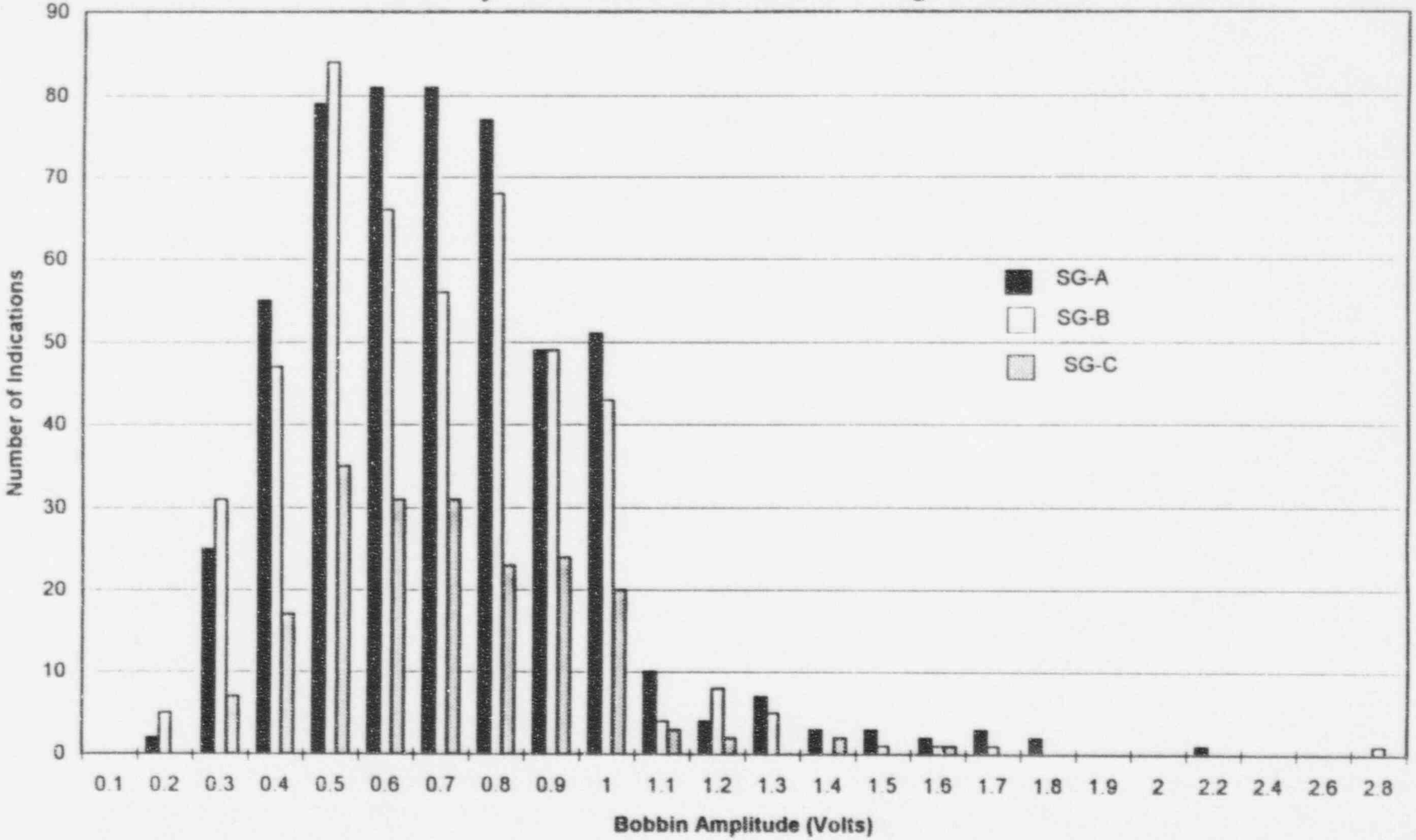


Figure 4-4
Beaver Valley Unit 1 In-Service EOC-10 Repaired Indication Distribution

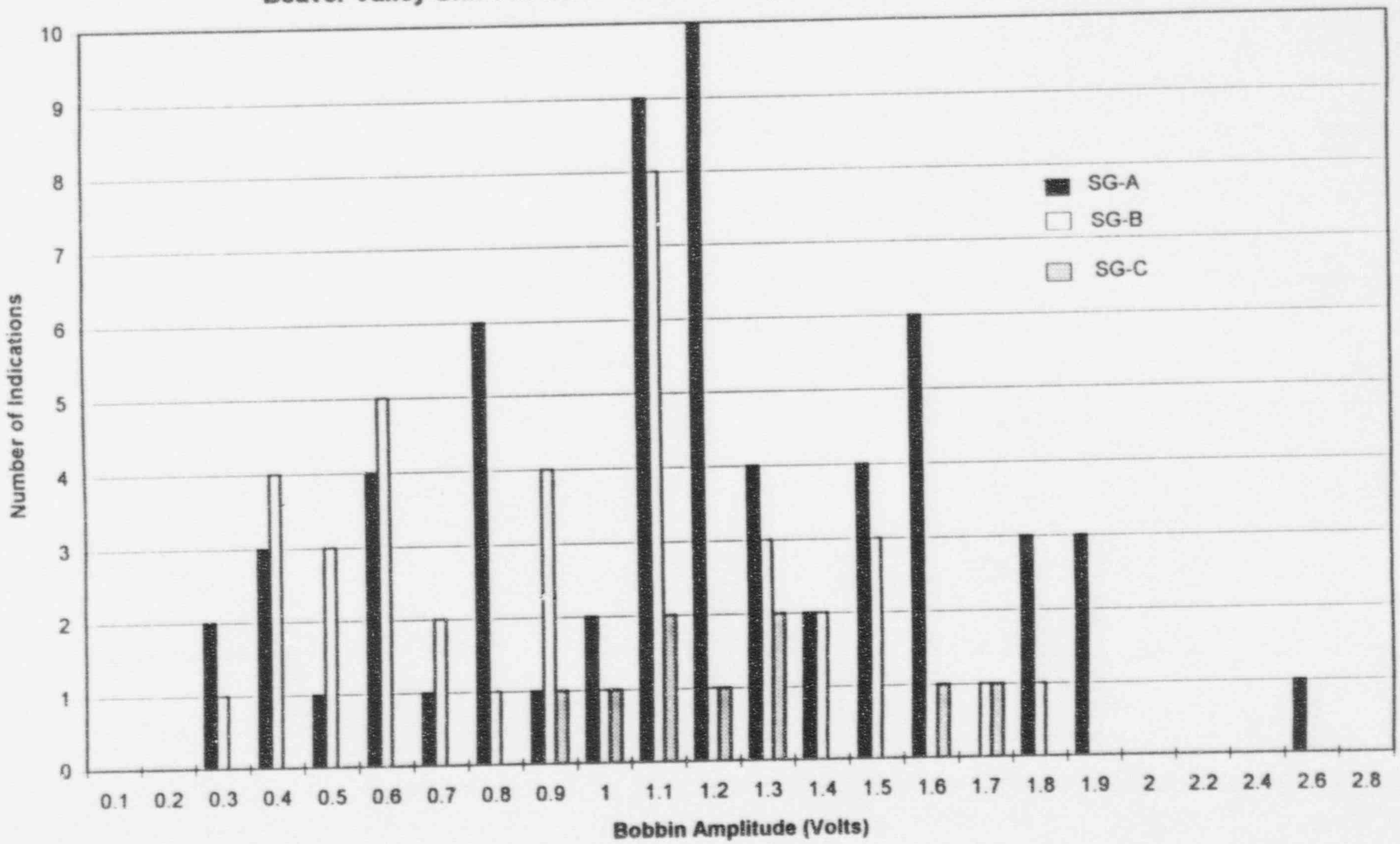


Figure 4-5
Beaver Valley Unit 1 In-Service EOC-10 ODSCC Axial Distribution

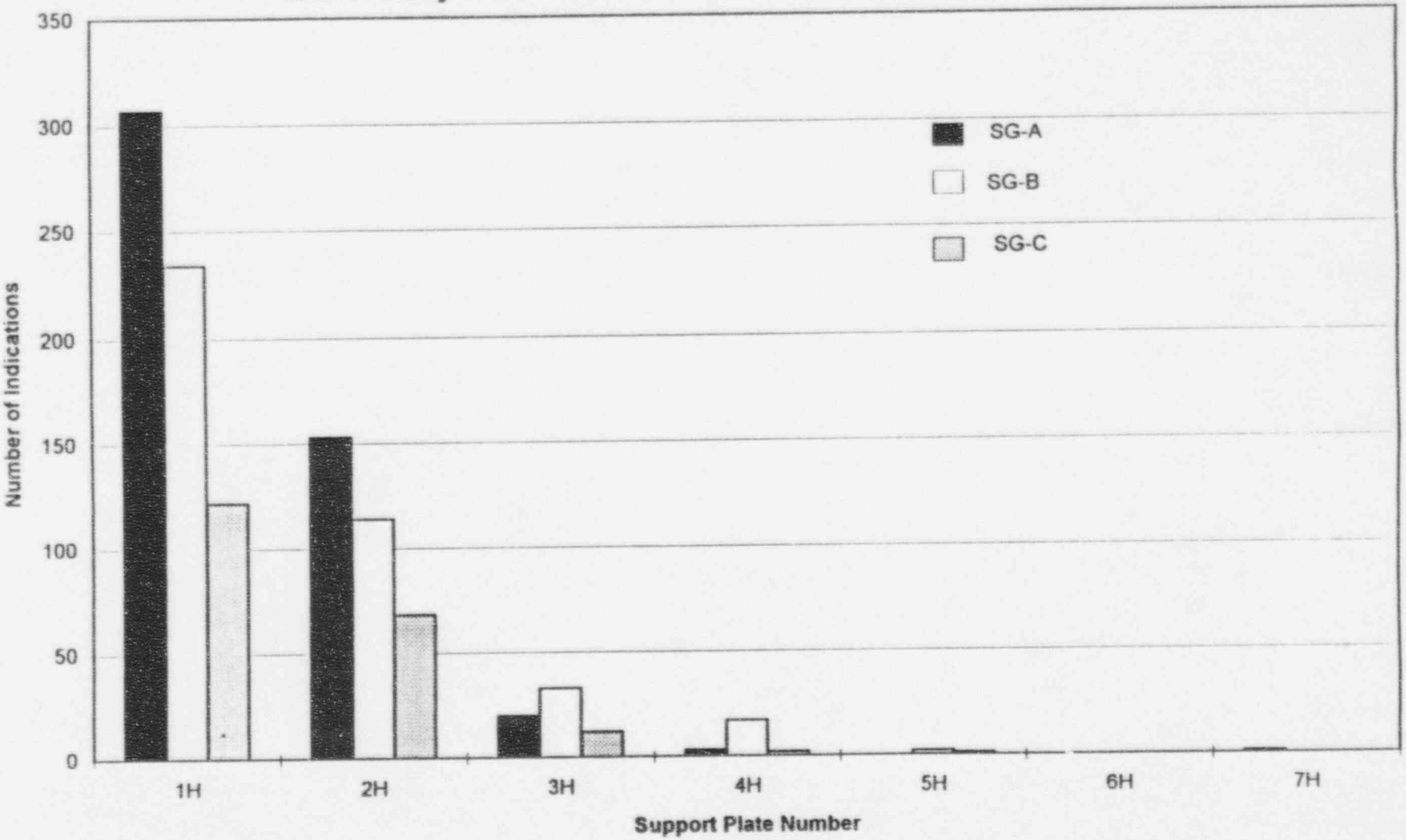
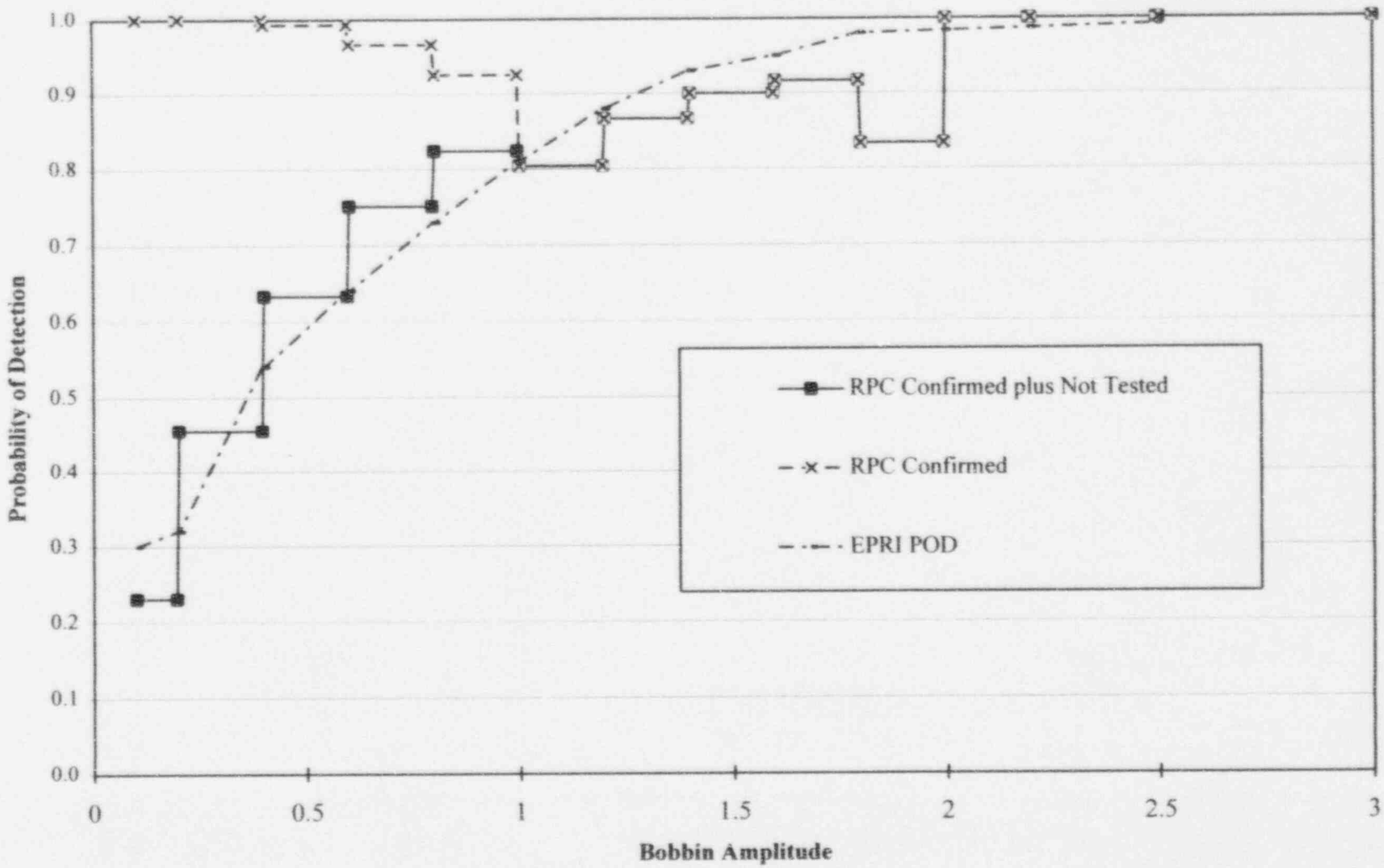


Figure 4 - 6
1993 EOC-9 POPCD Distribution
Beaver Valley Unit - 1



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5.0 DATA BASE APPLIED FOR IPC CORRELATIONS

The Beaver Valley-1 SER specifies the database to be used for the IPC correlations. For the burst pressure correlation, the SER recommended data is the same as the EPRI recommended database as described in WCAP-14123. The burst pressure correlation is also given in WCAP-14123 and is applied in the analyses of this report.

For the SLB leak rate correlation, the NRC SER recommends that Model Boiler specimen 542-4 and Plant J-1 pulled tube R8C74, TSP1 be included in the database. This database is referred to as the NRC database in WCAP-14123 and is applied for the leak rate analyses of this report. The probability of leakage correlation of WCAP-14123 is also accepted by the NRC SER and applied in this report.

6.0 SLB ANALYSIS METHODS

Monte Carlo analyses are used to project the EOC-11 voltage distributions and to calculate the SLB leak rates and tube burst probabilities for both the actual EOC-10 voltage distribution and the projected EOC-11 voltage distribution. These methods are consistent with the requirements of the Beaver Valley-1 NRC SER and are described in the IPC report of WCAP-14123 and the generic methods report of WCAP-14277.

Based on the NRC SER recommended leak rate database, the leak rate data do not satisfy the requirement for applying the SLB leak rate versus bobbin voltage correlation. The NRC requirement is that the p value obtained from the regression for the slope parameter be less than or equal to 5%. For the NRC recommended data, the p value is about 6.5% and the leak rate versus voltage correlation is not applied. The SLB leak rate correlation applied is based on an average of all leak rate data independent of voltage. The analysis methods for applying this leak rate model are given in Section 4.6 of WCAP-14277. A Monte Carlo analysis is applied to account for parameter uncertainties even though the leak rate is independent of voltage. This method of leak rate analysis is similar to that of draft NUREG-1477 except for the uncertainty treatment. The analyses of this report found that the Monte Carlo analyses for the SLB leak rate with the leak rate independent of voltage results in leak rates within 10% of that obtained using the draft NUREG-1477 methodology.

7.0 PROJECTED EOC VOLTAGE DISTRIBUTIONS

7.1 COMPARISON OF ACTUAL AND PROJECTED EOC-10 VOLTAGE DISTRIBUTION

Analyses previously performed to project the EOC-10 voltage distribution are documented in Reference 9.1. Comparisons of the actual EOC-10 bobbin indication distribution for RPC confirmed plus not RPC inspected indications with the projected distributions for POD of 1.0 and 0.6 are shown on Figures 7-1 and 7-2, respectively. The actual 451 indications include 56 RPC confirmed and 395 not RPC inspected indications. It can be expected that RPC inspection of all indications < 1.0 volt would have resulted in considerably < 451 RPC confirmed indications. The projections include 366 indications for POD = 1.0 and 747 indications for POD = 0.6.

It is seen from Figures 7-1 and 7-2 that both projections exceed the actual indications for > 1.0 volt indications. Below 1.0 volt, the POD = 0.6 projection exceeds the actual above 0.5 volt and is less than the actual below 0.5 volt, while the POD = 1.0 projection is lower than the actual below 0.8 volts. These results indicate a high POD above about 0.8 volt at the EOC-9 inspection while the POD below about 0.5 volts is typical of a value about 0.6. A voltage dependent POD is necessary to improve the projections over the entire voltage range. Based on the projections exceeding actuals above 1.0 volt even for a POD = 1.0, it would be expected, and is shown in Section 8, that SLB leak and burst projections would both exceed the values obtained for the actual EOC-10 distribution.

7.2 PROJECTED EOC-11 VOLTAGE DISTRIBUTIONS

The IPC indication voltage distribution for BOC-11 has been developed in Table 4-1. SG A is the limiting SG and the total of 535 indications at BOC-11 includes the 422 EOC-10 indications from prior active tubes, as well as the additional 113 indications from tubes deplugged during the outage that satisfied the repair limits and were returned to service.

Growth projections are based on rates determined in Reference 9.1 for SG A during Cycle 9 (Table 4-7), which are more conservative than the Cycle 10 growth rates, as previously discussed in Section 4.2. The operating periods used in the voltage projection calculations are:

Cycle 9 -	492.75 EFPD.
Cycle 10 -	435.79 EFPD.
Cycle 11 -	344.00 EFPD.

Cycle 11 is projected to be a shorter fuel cycle than either Cycle 9 or Cycle 10. For the SLB analyses, the Cycle 9 growth rates were scaled by the Cycle 11 to Cycle 10 EFPD ratio of 0.789 to more conservatively predict EOC-11 conditions.

For the Monte Carlo calculations, the net total number of indications returned to service for cycle 11 ($N_{Tot\ RTS}$) is determined from

$$N_{Tot\ RTS} = N_i / POD - N_{repaired} + N_{RTS}$$

where

N_i	=	Number of bobbin indications at EOC-10
POD	=	Probability of Detection
$N_{repaired}$	=	Number of N_i which are repaired (plugged) before BOC-11
N_{RTS}	=	Number of plugged tubes returned to service at BOC-11.

The IPC voltage distribution projected to EOC-11 is shown on Figure 7-3 for POD = 1.0 and on Figure 7-4 for POD = 0.6. Per the Beaver Valley-1 SER, the POD = 0.6 distribution is applied for the reference SLB leak rate and burst analyses.

Figure 7-1
Beaver Valley 1 S/G A
Comparison of Actual and Predicted EOC-10 Voltage Distribution POD = 1.0

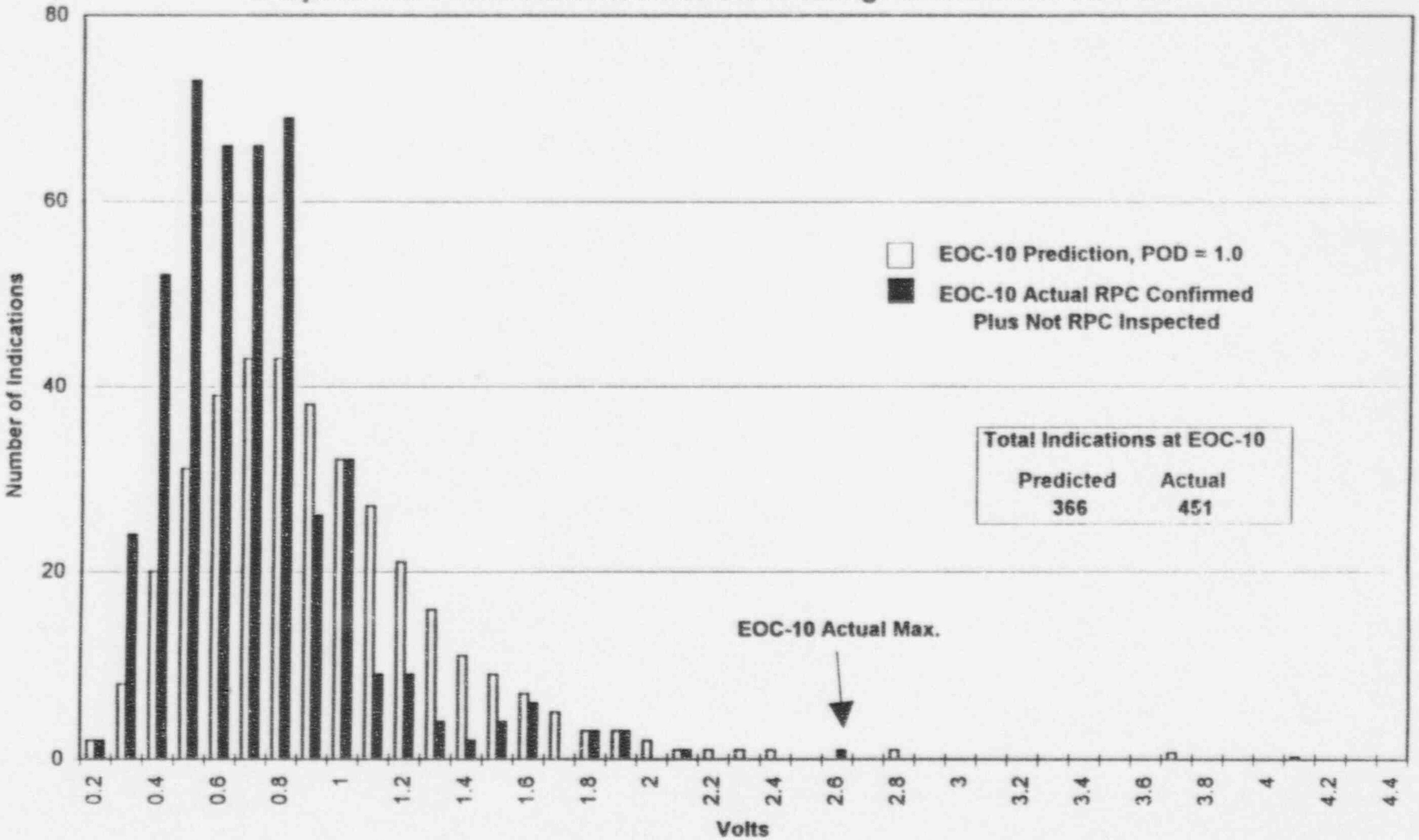


Figure 7-2
Beaver Valley 1 S/G A
Comparison of Actual and Predicted EOC-10 Voltage Distribution POD = 0.6

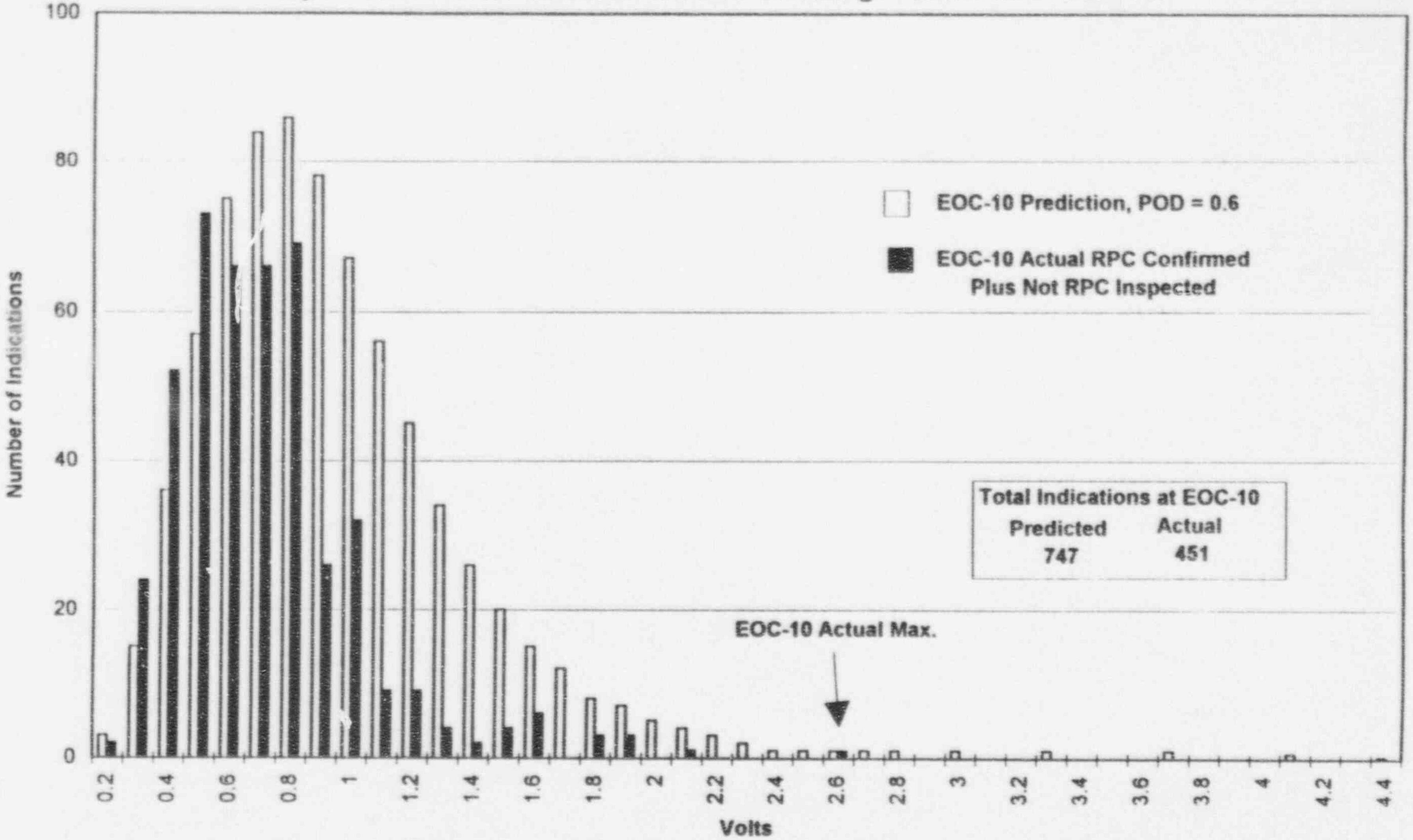


Figure 7-3
Beaver Valley Unit 1 - SG/A
Cycle 11 BOC and EOC Voltage Distribution POD = 1.0

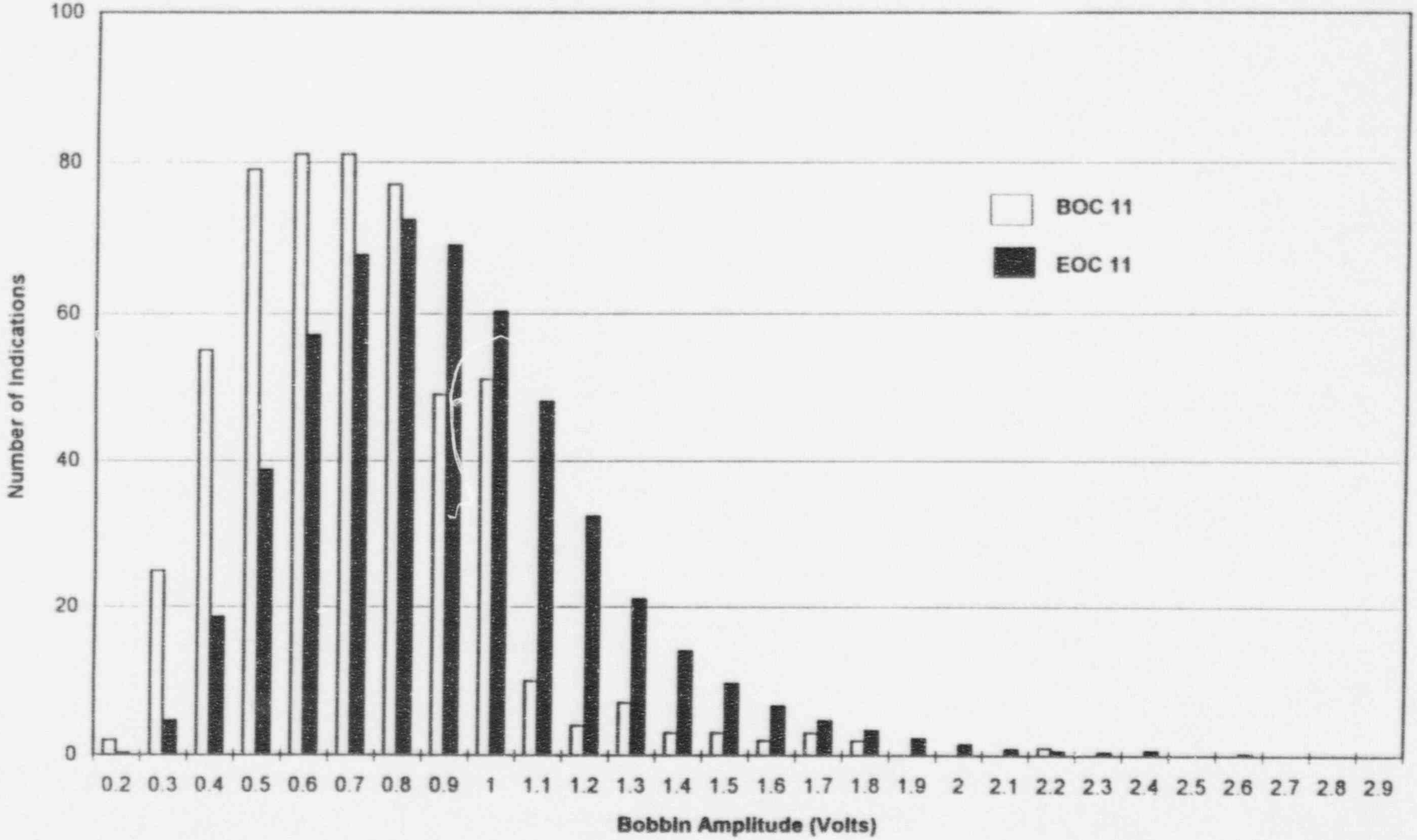
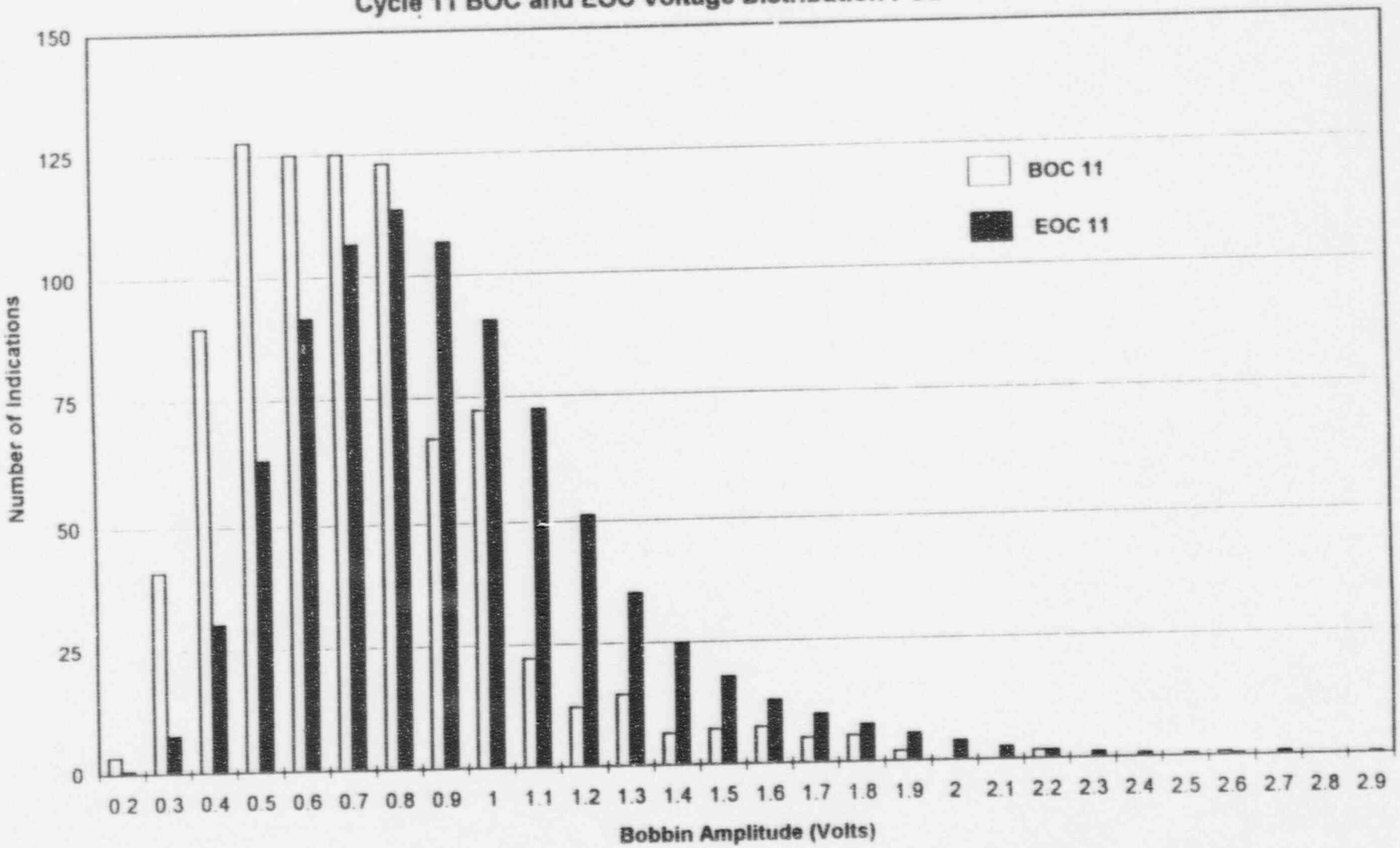


Figure 7-4
Beaver Valley Unit 1 - SG/A
Cycle 11 BOC and EOC Voltage Distribution POD = 0.6



8.0 SLB LEAK RATE AND BURST PROBABILITY ANALYSES

8.1 COMPARISON OF PROJECTED AND ACTUAL EOC-10 LEAK & BURST

The calculated predictions for performance of the limiting steam generator during Cycle 10 operation of Beaver Valley Unit 1 is documented in Reference 9.1. A comparison of these predictions with the corresponding actual parameters as determined from inspection data during the EOC-10 outage and from calculations based on those data is shown on Table 8-1. In all cases, the projected SLB leak rates and tube burst probabilities are significantly more conservative than that obtained from the actual EOC-10 distribution. The calculated SLB leak rate for the actual EOC-10 distribution is 0.15 gpm (based on the NRC data base) and the tube burst probability is 3.84×10^{-5}; leakage rates based on the EPRI data base are an order of magnitude lower than those based on the NRC data base.

8.2 PROJECTED EOC-11 LEAK RATE AND BURST PROBABILITY

Calculations have been conducted to predict the performance of the limiting steam generator in Beaver Valley Unit 1 at EOC-11 conditions. The methodology used in these predictions is described in Reference 9.2 and is essentially the same as that used in Reference 9.1 for the Cycle 10 predictions. Results of the EOC-11 predictions are summarized on Table 8-2. At POD = 0.6, the projected EOC-11 SLB leak rate for S/G A of 0.31 gpm (based on the NRC data base) is much lower than the allowable limit of 6.6 gpm for the affected loop; leakage rates based on the EPRI data base are an order of magnitude lower than those based on the NRC data base. Similarly, the EOC-11 SLB tube burst probability of 9.7×10^{-5} (at POD = 0.6) is much lower than the NRC 1.0×10^{-2} threshold value requiring further assessment as given in the Beaver Valley-1 SER (Reference 9.3). In addition, the actual EOC-10 SLB leak rate of 0.15 gpm and burst probability of 3.84×10^{-5} are both lower than the allowable limits. It is therefore concluded that the actual EOC-10 and projected EOC-11 SLB leak rates and tube burst probabilities show large margins against the allowable limits.

A comparison of the performance of the individual steam generators is shown on Table 8-3, which further confirms that the limiting steam generator for Cycle 11 of Beaver Valley Unit 1 is SG A. The burst probability of SG B is dominated by the effect of a single RPC NDF of 2.8 volts which was left in service. The difference in tube burst probabilities between SG A and SG B is considered negligibly small and SG A is more limiting in other aspects.

TABLE 8-1

BEAVER VALLEY UNIT 1 SG A
Comparison of Cycle 10 Performance
Projected vs. Actual
IPC > 1.0 volt

	Projected	**Projected**	**Actual**
POD	1.0	0.6	---
No. of Indications	366	747	484
Max. EOC Volts	4.1	4.4	2.6
SLB Leak Rate (gpm/SG) NRC Data base EPRI Data base	 0.22 0.021	 0.38 0.038	 0.15 0.012
SLB NRC Burst Prob.	1.8×10^{-4}	4.7×10^{-4}	3.84 x 10[illegible]

TABLE 8-2

BEAVER VALLEY UNIT 1 SG A
Prediction of EOC-11
Leak Rate and Burst Probability
IPC > 1.0

POD	1.0	0.6
Number of Indications	535	857.67
Max IPC Volt BOC EOC	 2.2 2.6	 2.6 2.9
Leak Rate (gpm/SG) NRC Data base EPRI Data base	 0.195 0.015	 0.31 0.031
Total Burst Probability o Single Burst o Two Tube Burst o Three Tube Burst	4.3×10^{-5} 4.3×10^{-5} 4.0×10^{-6}* 4.0×10^{-6}*	9.7×10^{-5} 9.7×10^{-5} 7.3×10^{-6} 4.0×10^{-6}*

* No tube burst in 10^6 Monte Carlo samples. Probability limited on 95% confidence.

TABLE 8-3

BEAVER VALLEY UNIT 1
Comparison of Individual S/G Performance for EOC-11
POD = 1.0 IPC > 1.0

S/G	A	B	C
Number of Indications	535	470	196
Max IPC Volt BOC EOC	 2.2 2.6	 2.8 3.2	 1.6 2.1
Leak Rate (gpm/SG) NRC Data base EPRI Data base	 0.195 0.015	 0.164 0.012	 0.072 0.004
Burst Probability	4.3×10^{-5}	6.4×10^{-5}	1.45×10^{-5}

9.0 REFERENCES

9.1 WCAP-14123 (SG-94-07-009), "Beaver Valley Unit 1 Steam Generator Tube Plugging Criteria for Indications at Tube Support Plates July 1994".

9.2 WCAP-14277, "SLB Leak Rate and Tube Burst Probability Analysis Methods for ODSCC at TSP Intersections", Westinghouse Nuclear Services Division, January 1995.

9.3 U.S. N.R.C. Letter, "Safety Evaluation by the Office of Nuclear Regulation Related to Amendment No. 184 to Facility Operating License No. DPR-66 Duquesne Light Company Beaver Valley Power Station, Unit No. 1 Docket No. 50-334".