ATTACHMENT A

BYRON UNIT 1

END-OF-CYCLE 6
INTERIM PLUGGING CRITERIA REPORT

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BYRON UNIT 1 END-OF-CYCLE 6 INTERIM PLUGGING CRITERIA REPORT

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Prepared By:

T. A. Pitterle
R. F. Keating
R. M. Wepfer

Westinghouse Electric Corporation
Nuclear Services Division
P.O. Box 158
Madison, PA 15663

Byron Unit 1 End-of-Cycle 6
Interim Plugging Criteria Report

TABLE OF CONTENTS

Section			Page
1.0	Introduction		1-1
2.0	Summary and Conclusions		2-1
	2.1	Overall Conclusions	2-1
	2.2	1994 EOC-6 Inspection Results	2-2
	2.3	Voltage Growth	2-2
	2.4	Projected MOC-7 and EOC-7 Voltages	2-3
	2.5	SLB Leak Rate Analyses	2-3
	2.6	Tube Burst Probability Assessments	2-3
3.0	Byron-1 Pulled Tube Examination Summary		3-1
	3.1	Pulled Tube Examination Results	3-1
	3.2	Evaluation of Byron-1 Pulled Tube Data for ARC Applications	3-5
	3.3	Comparison of Byron-1 Data with Existing IPC Correlations	3-8
4.0	EOC-6 Inspection Results and Voltage Growth Rates		4-1
	4.1	EOC-6 Inspection Results	4-1
	4.2	Voltage Growth Rates	4-3
	4.3	NDE Uncertainties	4-4
	4.4	Distributions Requested by Draft Generic Letter	4-5
5.0	Database Applied for IPC Correlations		5-1
6.0	Analysis Methods for Voltage Projections, Leak Rates and Burst Probability		6-1
7.0	Alternate POD Distributions		7-1
8.0	Projected Cycle 7 Voltage Distributions		8-1
	8.1	Limiting SG Evaluation	8-1
	8.2	Input Distributions	8-1
	8.3	Projected MOC-7 Voltage Distribution	8-2
	8.2	Projected EOC-7 Voltage Distribution	8-2
9.0	SLB Leak Rate Analysis Results		9-1
	9.1	SLB Leak Rates for EOC-6 Actual and BOC-7 Distribution	9-1
	9.2	Projected SLB Leak Rates for Potential Mid-Cycle Voltage Distribution	9-1
	9.3	Projected SLB Leak Rates for EOC-7 Voltage Distribution	9-1

Byron Unit 1 End-of-Cycle 6
Interim Plugging Criteria Report

TABLE OF CONTENTS (Cont'd)

Section		Page
10.0	SLB Tube Burst Probability Analysis Results	10-1
10.1	SLB Burst Probability Based on Byron-1 Limited TSP Displacements	10-1
10.2	Free Span SLB Burst Probability for Actual EOC-6 Distribution	10-1
10.3	Projected Free Span SLB Burst Probability for Potential Mid-Cycle Voltage Distribution	10-2
10.4	Projected Free Span SLB Burst Probability for EOC-7 Distribution	10-2
10.5	Burst Probability Dependence on POD	10-2
11.0	References	11-1

Byron Unit 1 End-of-Cycle 6
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1.0 INTRODUCTION

This report provides the Byron-1 steam generator steam line break (SLB) leak rate and tube burst probability analysis results in support of the implementation of the 1.0 volt Interim Plugging Criteria (IPC) at end-of-cycle 6 (EOC-6). It supplies information required by the NRC Safety Evaluation Report (Reference 11.1) and the draft generic letter (Reference 11.2), and it supplements the Byron-1 EOC-6 IPC letter report (Reference 11.3). The analysis results are provided for steam generator C, which is the limiting steam generator (SG) for the actual EOC-6 and for the projected EOC-7 bobbin voltage distributions. Conditional leak rate and SLB burst probability results are provided for EOC-6, beginning-of-cycle BOC-7, mid-cycle 7 (MOC-7) and EOC-7. A sensitivity analysis to the assumed probability of detection (POD) is also provided for the NRC required POD = 0.6, a POD developed by the Electric Power Research Institute (EPRI) based on qualified data analyst (QDA) testing, a POD developed as the average of four plants that had IPC assessments performed, and an ideal POD = 1.0.

The Monte Carlo methods required by the draft generic letter are applied to the BOC voltage distributions to project the EOC distributions. This is consistent with the Nuclear Regulatory Commission (NRC) guidance given in the Byron-1 Safety Evaluation Report (SER). SLB leak rates are calculated using the NRC methodology of draft NUREG-1477, the database of the EPRI report in Reference 11.4 with modifications as discussed with the NRC, as well as the IPC/APC methods described in the Westinghouse methods report of Reference 11.5, which utilizes methods applying the IPC correlations for probability of leakage and SLB leak rate. This methods report has been prepared to document the analysis methods applied to obtain SLB leak rate and burst probabilities consistent with the guidelines of the draft generic letter. The latest EPRI correlations are applied in this report. The database used for the leak rate and burst pressure correlations is summarized for completeness.

Three tubes were pulled from Byron-1 at EOC-6 to provide supporting leak rate, burst pressure and crack morphology data for application of the IPC at Byron-1. The pulled tube results are described in this report consistent with the guidance of the draft generic letter for the 90-day reporting requirements.

Table 4-9 relates the data requested by draft generic letter 94-xx to the report section, table and figure which provides the data.

2.0 SUMMARY AND CONCLUSIONS

2.1 Overall Conclusions

Three tubes with twelve tube support plate (TSP) intersections including three flow distribution baffle (FDB) locations were pulled at EOC-6 in support of application of the IPC at Byron-1. The pulled tubes included the largest bobbin indication of 10.95 volts found at EOC-6 as well as 5.92 and 2.58 volt indications. Nine of the intersections were burst tested and destructively examined. Five intersections were leak tested of which two intersections (5.92 and 10.95 volts) had leakage. All leak and burst test results are consistent with the EPRI leak rate and burst correlations, and inclusion of the Byron-1 data in the correlations would result in negligible changes to the correlations. Crack morphologies found were dominantly outside diameter stress corrosion cracking (ODSCC) with some small cellular patches which is typical of the EPRI database. As expected, the 10.95 volt indication had the lowest measured burst pressure of 4,500 psi and the highest SLB leak rate of 22.1 liters/hr.

The Byron-1 pulled tube results show that the tube integrity requirements of Regulatory Guide (R.G.) 1.121 were satisfied at EOC-6 and a similar conclusion would be expected at EOC-7. Although the calculated tube burst probabilities of 1.90×10^{-2} at EOC-6 and 3.29×10^{-2} for the projected EOC-7 with POD=0.6 exceed the draft generic letter guidance of 1.0×10^{-2}, the pulled tube burst pressures show that the actual EOC-6 burst probability would be negligibly small. That is, the measured burst pressures for the largest, 5.92 and 10.95 volt, indications exceed 4,500 psi, as compared to the SLB structural margin requirement of $1.43\Delta P_{SLB}$ of 3,660 psi, while the largest indications dominate the calculated burst probability. This large Byron-1 burst margin is attributed to the Byron-1 tubes, similar to the Braidwood-1 tubes, having burst pressures close to the mean of the burst pressure versus voltage correlation. Per the draft generic letter guidance to assess the safety implications of the calculated burst probabilities exceeding 1.0×10^{-2}, it is concluded that the pulled tube results demonstrate that the EOC-6 burst probability was significantly less than 1.0×10^{-2} and R.G. 1.121 tube integrity requirements were satisfied. Similar results would be expected at EOC-7.

Consistent with the Byron-1 SER for Cycle 7 and the draft generic letter, EOC-7 projections were made by applying the NRC model of Draft NUREG-1477 to define the BOC distribution with a probability of detection (POD) adjustment factor of 0.6, and by applying Monte Carlo analysis to the correlations of burst pressure and leak rate with voltage to obtain the SLB tube burst probability and leak rates. The projections for Cycle 7 were based on SG-C which had the most limiting EOC-6 actual and projected EOC-7 voltage distributions.

The resulting EOC-7 SLB leak rate is estimated at 5.1 gpm which is well below the allowable limit of 12.5 gpm in the faulted SG for Byron-1 Cycle 7. The projected EOC-7 SLB total tube burst probability by Monte Carlo analysis is 3.29×10^{-2}. Overall, it is concluded that SLB leakage acceptance limits are satisfied in Cycles 6 and 7, although the calculated tube burst probabilities exceed the draft generic letter guideline of 1.0×10^{-2}. As noted above, however, the Byron-1 pulled tube results show burst pressures exceeding structural margin requirements, which results in negligibly low burst probabilities.

2.2 1994 EOC-6 Inspection Results

A total of 3075 ODSCC indications were reported at Byron-1 TSP intersections at EOC-6, of which 802 were in SG-A, 914 in SG-B, 899 in SG-C, and 460 in SG-D. The median voltage bin for EOC-6 indications among the four SGs was 0.6 volts (indications between 0.51 and 0.60, inclusive). RPC (rotating pancake coil) examination was performed of all indications greater than 1.0 volts, plus a number of smaller indications. Of the 967 RPC-tested indications, 717 were confirmed, for a 74% overall confirmation rate. Above 1.0 volt, 535 of 659 indications or 81% of indications were RPC confirmed, while below 1.0 volt, 182 of 308 or 59% of indications were confirmed. All indications greater than 2.2 volts were RPC confirmed. These are relatively high confirmation rates compared to other inspections.

The largest bobbin voltage indications found in 1994 were 10.95 volts in SG-C; 7.64, 7.10 and 5.92 volts in SG-A; 4.56 volts in SG-B; and 4.09 volts in SG-D. The 10.95 and 5.92 volt indications were included among the pulled tubes, and it is shown in Section 3 that the measured burst pressures for these indications exceeded the R.G. 1.121 structural margins. Thus, tube integrity requirements were satisfied at EOC-6.

A total of 659 indications exceeded the approved 1.0 volt IPC repair limit for this inspection; all of these were RPC inspected and 535 were confirmed and repaired.

2.3 Voltage Growth

Growth rates were developed for all potential flaws. The growth rate analysis was performed in accordance with guidance of draft NUREG-1477 in that growth rates were not calculated for the 1993 indications which were reanalyzed as NDD (no detectable degradation). Thus the total number of voltage growth values (2851) is smaller than the total number of EOC-6 indications (3075).

The Cycle 6 average percentage growth of 67% is similar to the Cycle 4 and 5 values of 80% and 68%, although the Cycle 4 and 5 data are for plugged tubes only and are therefore expected to be higher than for the entire population of Cycle 4 and 5 indications. SG-A experienced the largest growth rates during Cycle 6, an average of 117%, while SG-D, -C and -B values followed at 69%, 66% and 39%, respectively. In all cases, percentage growth rates were significantly lower for BOC voltages above 0.75 volts than for those below 0.75 volts.

SG-C R20C7 3H had the largest Cycle 6 growth value of 9.86 volts, which was based on an EOC-6 voltage of 10.95 volts and BOC voltage of 1.09 volts. This intersection was pulled and metallurgical results are included in Section 3.1 of this report. Three other indications, all in SG-A, had growth values larger than 5.0 volts: R3C3 3H (6.71 volts), R20C7 3H (5.96 volts), and R3C107 3H (5.48 volts). All of the remaining voltage growths were less than 4.0 volts.

2.4 Projected MOC-7 and EOC-7 Voltages

SG-C BOC distributions were prepared for each of four POD methods: POD=0.6; POD1, developec by EPRI based on qualified data analyst (QDA) testing; POD2, developed as the average of four plants that had IPC assessments performed; and a POD=1.0. The 1215 indications for a POD of 0.6 is about twice as many as the 616 indications for a POD of 1.0. POD1 (EPRI) and POD2 (POPCD) provide intermediate BOC distributions to the 0.6 and 1.0 PODs, with POD2 being slightly more conservative in the total number of indications and largest indications. The largest projected voltages for MOC-7 and EOC-7 for the POD=0.6 adjusted BOC-7 distribution were 11.5 and 11.7 volts, respectively.

2.5 SLB Leak Rate Analyses

The projected EOC-7 leak rate for SG-C with a POD = 0.6 (NRC draft generic letter) is 5.1 gpm. These leak rates are less than the allowable SLB leak rate for Byron-1 and thus are acceptable to the guidelines of the NRC draft generic letter.

SLB leak rates were also calculated for the projected EOC-7 distribution based on the alternate POD distributions. The more realistic, voltage-dependent POD1 and POD2 analyses result in SLB leak rates of 3.1 and 3.5 gpm, which approach the ideal POD = 1.0 resul. f 1.7 gpm. This is as expected, since the POD1 and POD2 distributions more appropriately reflect tha. all of the larger bobbin indications (29 above 1.8 volts with 3 above 2.7 volts) were plugged at EOC-6. The POD = 0.6 results in 0.67 indications left in service for each plugged indication, while the voltage-dependent POD1 and POD2 yield smaller fractional indications left in service below 3.0 volts and no indications left in service above 3.0 volts.

2.6 Tube Burst Probability Assessments

The total (sum of single and multiple tube bursts) tube burst probabilities for the assumed POD = 0.6 are 1.90×10^{-2} at EOC-6 and 3.29×10^{-2} for the projected EOC-7 distribution. The total and single tube burst probabilities are approximately equal since the probabilities of multiple tube ruptures are small at 4.74×10^{-6} at EOC-6 and 1.46×10^{-3} at EOC-7. No occurrences of multiple tube ruptures with more than two ruptures were found in the Monte Carlo analyses. The reported burst probability values for three tube ruptures reflect only the 95% confidence limit for the number of Monte Carlo samples with no occurrences. A few occurrences of multiple ruptures (two) occurred but the burst probabilities are significantly lower than the single tube burst probability.

3.0 BYRON-1 PULLED TUBE EXAMINATION SUMMARY

3.1 Pulled Tube Examination Results

3.1.1 Introduction

Three hot leg steam generator tube segments from Byron Unit 1 (Tube R3C107 from SG-A and Tubes R20C7 and R20C102 from SG-C) were examined at the Westinghouse Science and Technology Center in support the Byron-1 IPC. The examination was conducted to characterize corrosion at steam generator hot leg support plate crevice loc tions. The tubes were selected to obtain a sampling of the indications observed in the 1994 field eddy current inspection. The first (Flow Distribution Baffle), third, fifth and seventh support plate crevice regions (1H, 3H, 5H and 7H) were removed for examination. Four of these locations had original field eddy current indications of outside diameter (OD) origin.

After nondestructive laboratory examination by eddy current testing, ultrasonic testing, radiography, dimensional characterization and visual examination, five support plate regions were leak tested at elevated temperature. Subsequently, room temperature burst testing was conducted on the five TSP regions, as well as four non-leak tested TSP regions and a free span section fro. each of the three tubes pulled. Four of the burst tested TSP specimens were destructively examined using metallographic and scanning electron micrograph (SEM) fractography techniques to characterize the corrosion, and an additional four TSP burst tested specimens were examined using only SEM fractography of the burst crack opening. As of the date of this report, the SEM fractographic examinations have been completed, but no metallographic data are yet available.

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.

Field and laboratory eddy current inspections (bobbin and RPC probes) produced similar data for most regions examined. The field bobbin data for the field NDD calls at TSP locations were reevaluated to derive the most appropriate amplitude measurements, where possible, for these very small signals. This review indicated that four field NDD calls (R3C107 5H; R3C107 7H; R20C7 5H; and R20C7 7H) could be assigned a bobbin flaw voltage. For these four field NDD calls, the bobbin signals were reevaluated as distorted indications wherein the selection of the flaw segment was aided by use of the 300 kHz data. The reevaluated field RPC data for these four NDD calls continued to be NDD with no discernible flaw separable from the background level. In the laboratory, these four TSP locations were identified to have both bobbin and RPC indications, except for R20C7 7H which was dented by the tube

pulling operation. (The dent obscured any potential bobbin signal although an indication was observed by the RPC inspection.)

Some increase in signal strength (voltage) was observed in the laboratory eddy current inspections, which was attributed to the tube pulling operation. Field bobbin probe signal strengths ranged from 1.25 to 10.95 volts (1.11 and 10.9 volts after data reevaluation) while post-pull bobbin strengths ranged from 2.05 to 13.8 volts. The largest increase was for Tube R20C102 5H, where the bobbin probe signal strength increased from 1.11 volts to 4.64 volts. This is considered a moderate increase suggesting that there was no significant tearing of ligaments between microcracks.

All TSP region NDE indications were confined to their crevice regions. Each of the three 1H regions (flow distribution baffle) had no detectable degradation (NDD) in the field and laboratory eddy current and ultrasonic (UT) examinations and in the laboratory radiographic examination. Some of the eddy current TSP indications had considerable width in the RPC data, and in the laboratory UT data, suggesting the possibility of intergranular cellular corrosion (ICC) or three dimensional intergranular attack (IGA) in addition to and in association with axial cracking. UT inspections confirmed the eddy current observations and further suggested the presence of even more extensive corrosion at some TSP crevice locations. Radiographic indications, all axial ones, were observed for the three support plate regions with the largest bobbin probe signal strengths.

3.1.3 Leak Testing

Five TSP crevice regions, which included the four original field eddy current indications and one of the field reevaluated distorted eddy current indications, were leak tested at elevated temperature and pressure at conditions that ranged from a simulated normal operating condition to that of a simulated steam line break condition. Two of the specimens, the ones with the largest voltages, developed leaks: Tube R3C107 3H (5.3 volt field bobbin indication) and Tube R20C7 3H (10.1 volt field bobbin indication). The leak rates ranged from 0.047 liters/hour to 0.065 liters/hour for normal operating conditions and from 4.70 liters/hour to 18.3 liters/hour for steam line break conditions. Table 3-2 presents leak rate data for the five tested specimens.

As shown in Table 3-2, some of the leak tests were repeated with minor variations in temperature and pressure conditions for the tests. No significant differences were found in the leak rates between repeat tests.

3.1.4 Burst Testing

Nine TSP crevice regions and three free span regions were burst tested at room temperature at a pressurization rate of 1000 to 2000 psi per second. The burst tests were performed simulating free span conditions with no TSP enveloping the indications, and the test methods were the same as those employed in developing the industry database in Reference 11.4. The

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. Due to the limited crack opening and crack length extension for the initial burst tests of R3C107 3H and R20C7 3H, the burst tests for these indications were repeated using a slightly larger foil and a faster (2000 psi/sec) pressurization rate. The retest was successful in obtaining crack extension for R20C7 3H but two retests did not result in crack extension for R3C107 3H. The larger burst pressure of 4500 psi is the appropriate value for R20C7 3H while the initial 4800 psi represents a minimum burst pressure for R3C107 3H. 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 the same as the location of the deepest UT indications for the specimens having corrosion indications. The eddy current RPC data does not provide an absolute circumferential position. The lowest burst pressure for the TSP crevice regions (Tube R20C7 3H, the 10.9 volt indication) was 4,500 psi, 39% of the burst pressure of its free span equivalent and typical of a 0.75 inch diameter specimen with a 10.9 volt indication.

Table 3-3 also provides room temperature tensile properties obtained from free span sections of the tubes. The tensile and burst strengths for the free span sections are typical for Westinghouse tubing of this type.

3.1.5 Destructive Examination Results

Figures 3-1 to 3-8 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. While no metallographic data is yet available, the visual inspection data and the SEM inspection data suggested that intergranular cellular corrosion was present in addition to the more prevalent axial intergranular stress corrosion cracking (IGSCC). The corrosion in all TSP regions was centered within and confined to the crevice regions.

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 specimens. The data in Table 3-4 was used to plan destructive examination work efforts. Corrosion cracks were observed on eight of the nine of the burst tested TSP specimens. These eight specimens were candidates for destructive examination. The only burst tested TSP region without corrosion was the only 1H region (flow distribution baffle region) tested, R20C7 1H. All four specimens with original field NDD calls that were subsequently called low voltage distorted indications (Tube R3C107 5H, Tube R3C107 7H, Tube R20C7 5H, and Tube R20C7 7H) had corrosion present. The free span sections of Tubes R3C107, R20C7 and R20C102, selected for a reference burst pressure and tensile property test, had no degradation, as would be expected. Four specimens, shown in Table 3-4, which included both specimens with measured SLB leakage, were selected for complete destructive examination of their crevice

region corrosion. These examinations include SEM fractography of the burst openings and metallography of secondary corrosion within the crevice regions. An additional four specimens, the low voltage distorted indication specimens, were characterized by SEM fractography of their burst openings.

The burst fracture faces of these selected 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 all eight examined specimens that had corrosion. The data of Table 3-5 indicate that most of the TSP regions from Byron Unit 1 pulled tubes had a typical number of remaining uncorroded ligaments between microcracks comprising the burst macrocracks. All intergranular corrosion was confined to and centered within the crevice regions. The burst opening macrocrack depths and lengths for the TSP crevice regions had maximum depths ranging from 26% to 100% throughwall, with average depths ranging from 12% to 69% throughwall and with macrocrack lengths ranging from 0.38 to 0.602 inch. Two of the eight specimens had throughwall burst cracks. Tube R3C107 3H had a crack that was throughwall for 0.13 inch.

Tube R20C7 3H had two parallel throughwall cracks: one was throughwall for 0.24 inch at the 100° location and the other was throughwall for 0.268 inch at the 70° location. A third, partial depth crack was located at the 140° location. Only the 70° location throughwall crack had a ductile ligament present in the throughwall portion of the crack. (Since the 100° location crack opened significantly more than the 70° location crack during the burst test, even though the two cracks were roughly the same size, it would appear that the 3 mil thick ligament did not tear during the leak test and that most of the R20C7 3H leakage occurred through the 100° location crack.) Typical of the edges of burst openings, the horizontal markings shown on Figure 3-4 are expected to primarily indicate the opening of cellular corrosion between the two axially-oriented burst openings; preliminary metallographic data confirms the presence of cellular corrosion between the two burst cracks. Corrosion was centered within and confined to the crevice region.

Four TSP regions were initially called bobbin NDD in the field and subsequently were found by reevaluation of the field data to have small (0.23 to 0.38 volts) indications prior to the tube exam. The maximum crack depths for these four locations were 26%, 38%, 45% and 53% for the 7H region of Tube R20C7, the 5H region of Tube R20C7, the 7H region of Tube R3C107 and the 5H region of Tube R3C107, respectively. The corresponding average macrocrack depths were 12%, 20%, 21% and 32%, respectively.

3.1.6 Pulled Tube Examination Conclusions

The visually inspected burst specimens from the TSP crevice regions of Tubes R3C107,

R20C7 and R20C102 had corrosion present at the locations that had eddy current and/or UT indications. All eight of the nine burst tested TSP crevice regions found to have corrosion were from true support plate crevice regions (i.e., from 3H, 5H or 7H where only a 0.008 inch nominal radial crevice gap existed). The ninth TSP burst specimen (Tube R20C7 1H) was without corrosion and was from a flow distribution baffle region where the nominal radial crevice gap was 0.039 inch. While metallographic data are not yet available, visual and SEM inspection data suggest that the corroded TSP crevice regions had combinations of axially oriented OD origin IGSCC and ICC. All corrosion was confined to the crevice regions. The examinations performed to date show the corrosion morphology to be 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. Four TSP crevice regions were initially called bobbin NDD in the field and subsequently were found by reevaluation of the field data to have small (0.23 to 0.38 volts) indications prior to the tube exam. Each of these regions had corrosion ranging from 26% to 53% throughwall, maximum depth. Consequently, these locations had corrosion near the eddy current detection threshold. These four locations also serve in determining the UT detection threshold. Three of the four were called by field UT inspections as having corrosion while two of the four were called by lab UT inspections as having corrosion. The maximum corrosion depth not called was 26% for the field inspection and 53% for the lab inspection. (Lab UT inspection data suggested that surface deposits were responsible for the corrosion present.) Consequently, these locations had corrosion near the UT detection threshold.

Leak rate testing performed at elevated temperatures and pressures produced leak rates that ranged from 0.047 liters/hour to 0.065 liters/hour for normal operating conditions and from 4.70 liters/hour to 18.3 liters/hour for steam line break conditions for the two specimens which had leakage. The lowest field bobbin probe signal strength specimen which had leakage was 5.89 volts and the highest field bobbin probe signal strength specimen which did not have leakage was 2.58 volts. The TSP crevice region burst pressures ranged from 4,500 to 11,300 psi. All burst pressures were above safety limitations required by R.G. 1.121 including the 10.9 volt indication at 3H of Tube R20C7. The burst tests were performed simulating free span conditions with no TSP enveloping the indications. The leak and burst pressure data were generally consistent with the ARC burst pressure and leak rate correlations as described below.

3.2 Evaluation of Byron-1 Pulled Tube Data for ARC Applications

The pulled tube examination results were evaluated for application to the EPRI database for alternate repair criteria (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 3-6 provides a summary of the eddy current data evaluations for the Byron-1 pulled tubes. For the field indications, there is little difference in the bobbin voltage calls between the field and the laboratory results. This supports the field analyst training on voltage measurements while recognizing that the larger voltage indications typical of the field calls are typically less difficult to size than the lower voltage indications such as below 1.0 volt. For inclusion of the data in the EPRI database, it is desirable to minimize analyst variability in the voltage calls since this variability is separately accounted for in ARC applications as an NDE uncertainty. Most of the pulled tube EPRI database has been analyzed by the same analyst who performed the field reevaluation of Table 3-6. Thus the reevaluated field bobbin voltages are applied for application to the ARC correlations.

The field bobbin data for the field NDD calls were reevaluated to derive, where possible, the most appropriate amplitude measurements for these very small signals. This review indicated that four field NDD indications, R3C107 5H, R3C107 7H, R20C7 5H and R20C7 7H, could be assigned a bobbin flaw voltage. For each of these indications, called NDD in the field, the signals are distorted indications and selection of the flaw segment was aided by use of the 300 kHz data. The reevaluated field bobbin data for these indications are shown in Figures 3-9 to 3-12. The reevaluated RPC data continues to be NDD with no discernible flaw separable from the background level. The reevaluated bobbin voltages for these four indications are used for application to the ARC database and correlations.

The data for all three tubes at 1H (FDB) were found to be NDD by all field and laboratory eddy current and UT inspection results. The indications at R3C107 5H and 7H, and R20C7 5H, which were field NDD but had identifiable indications by reevaluation of the field data, were identified as having both bobbin and RPC indications in the laboratory post-pull bobbin and RPC inspections. The indication at R20C7 7H was apparently dented in the tube pull process and the dent obscured any potential bobbin call although an indication was identified by the post-pull RPC inspection.

The indications at R3C107 5H and 7H, and R20C7 5H and 7H, which were field NDD but had identifiable indications by reevaluation of the field data, were found to have average crack depths of 32%, 21%, 20% and 12%, respectively and maximum depths of 53%, 45%, 38% and 26%. The two R3C107 indications could be interpreted as above the detection threshold for eddy current but were distorted indications that are difficult to call under field conditions.

The increases of up to 3.7 volts for the post-pull bobbin voltages are typical of many pulled tubes in the EPRI database. Some tearing of ligaments between microcracks may have occurred, but significant tearing of ligaments to strongly affect accident condition leakage or burst capability is not expected for these levels of post-pull voltage increases. Thus, the pre-pull voltage measurements are acceptable for ARC applications.

3.2.2 Byron-1 Data for ARC Applicatio~

The Byron-1 pulled tube leak test, burst test and destructive exam results are summarized in Table 3-7. The measured leak rate data, given in Table 3-2, were adjusted in Table 3-7 to the reference normal operating and SLB conditions by applying the leak rate adjustment procedure of the EPRI database report. The reference SLB conditions are a pressure differential of 2560 psid at a primary pressure of 2575 psi and a secondary pressure of 15 psi at a temperature of 616° F. 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 3-7 should be used in EPRI ARC burst pressure, SLB probability of leakage and SLB leak rate versus voltage correlations.

The 10.9 volt response for R20C7 3H versus the 5.89 volt response for R3C107 3H indicate the strong influence of throughwall crack length on the bobbin voltage amplitude and the influence of the two parallel throughwall cracks found for R20C7 3H (see Table 3-7). Both of the throughwall cracks in R20C7 3H are similar but the burst crack had a slightly longer macrocrack length (0.602" versus 0.562") and few remaining uncorroded ligaments (3 versus 9). Only these two throughwall indications resulted in leakage at SLB conditions. The 2.58 volt indication at R20C102 3H, with a maximum crack depth of 96% and a ~0.1" length at > 90% depth, did not break through or leak.

The Byron-1 pulled tube results were evaluated for potential exclusions from the database against the EPRI data exclusion criteria. Criteria 1a to 1e apply primarily to unacceptable voltage, burst or leak rate measurements and indications without leak test measurements. Of these criterion, only Criterion 1b, unacceptable burst test due to incomplete burst, requires further evaluation for the Byron-1 tubes. As shown in Table 3-3, the burst tests of R3C107 3H and R20C7 3H required repeat burst tests due to lack of a fishmouth opening with tearing at the crack tips as required for the definition of burst. The repeat burst test of R20C7 3H, with a faster pressurization rate and a slightly larger foil, resulted in crack extension and the repeat test at a 4500 psi burst pressure was a successful burst test. Two repeat tests were tried for R3C107 3H but neither repeat test resulted in crack extension although the crack width increased slightly with each test and the burst capability of the indication decreased with the successive tests. The results of the repeat tests indicate that even with crack tearing to achieve a well-defined burst, it is not likely that the burst pressure would have significantly increased above the initial test result of 4800 psi. The initial 4800 psi burst pressure is therefore reasonable and is retained in the EPRI database although representing a minimum burst capability of the indication. Criterion 2b applies only to indications greater than 20 volts which is not applicable to the Byron-1 indications.

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 having ≤ 2 uncorroded ligaments in shallow cracks < 60% deep shall be excluded from the database. The indications at R20C7 5H and 7H have maximum depths of 38% and 26% with two uncorroded ligaments which satisfy the ≤ 2 ligament Criterion 2a. The 0.25

volt indication at 5H does not have a high burst pressure relative to the burst correlation (See Section 3.3) and thus cannot be excluded from the database. However, the 0.38 volt indication at 7H has a maximum depth of 26% with two remaining ligaments and has a high burst pressure relative to the correlation. Thus, this indication satisfies Criterion 2a and should be excluded from the EPRI database for application to the ARC correlations.

Criterion 3 relates to potential test errors in the leakage measurement and would exclude indications having less than a 10% increase in leakage between normal operating and SLB conditions or exclude indications having a measured leak rate for throughwall cracks without ligaments which is more than a factor of 50 below the mean leak rate expected for the associated throughwall crack length. Both of the indications that leaked had more than a 10% increase in leakage between normal operating and SLB conditions so that this criterion for exclusion does not apply to the Byron-1 tubes. The indications R3C107 3H and R20C7 3H have throughwall crack lengths with no ligaments within the throughwall length and are evaluated for low leak rates against the factor of 50 criterion. Figure 3-13 shows the addition of the Byron-1 data to the prior EPRI 3/4 inch diameter database for SLB leak rate as a function of throughwall crack length. It is seen that the Byron-1 indications are not below the mean leak rate for their respective crack lengths and the indications should not be excluded from the database.

All the Byron-1 TSP intersections of Table 3-7 with bobbin indications were leak and burst tested or have no leakage inferred from the shallow depths and, with the exception of R20C7 7H, should be included in the EPRI database for IPC/APC correlations. The indications with no leakage are appropriate for the probability of leakage and burst pressure correlations and those with SLB leakage would be included in all three correlations including the leak rate correlation. The bobbin NDD indications, while not needed for the EPRI correlations, are applicable for probability of detection assessments. The field bobbin calls for the Byron-1 indications were defined prior to considerations for pulling tubes and are not influenced by tube pull considerations. The field calls for R3C107 5H and 7H, and R20C7 5H and 7H, were NDD and the bobbin calls for these four indications were made subsequent to the tube pull and are more typical of laboratory review than typical field experience.

3.3 Comparison of Byron 1 Data with Existing IPC Correlations

This section reports on the evaluations performed utilizing leak rate and burst test results of tube sections which were removed from Byron Unit 1 in the fall of 1994. The Byron 1 pulled tube data for ARC applications are given in Section 3.2, and are compared to the database[1] of similar test results for 3/4" outside diameter steam generator tubes. In addition, the

[1] The database consisted of the EPRI recommended database, plus test results from model boiler specimen 598-3, plus the leak rate for specimen S-R28C41-F being taken as 2496 lph, plus Braidwood 1 test results reported in WCAP-14046, revison 1 (except for specimen R16C42-5, which was excluded by EPRI criterion 2.a).

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. These comparisons and evaluations are discussed below.

3.3.1 Burst Pressure vs. Bobbin Amplitude

Results from eight (8) 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 Byron 1 specimens is depicted on Figure 3-14 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. The burst pressure for specimen R03C107-3, is somewhat lower than would have been expected for 5.9 volts, but is not significantly lower, and the result represents a lower bound value. Thus, the visual examination doesn't indicate any significant departures from the reference database. Although the upper bound is not shown, all of the data fall within a 90% non-simultaneous prediction band about the regression line (the one-sided 95% prediction curve depicted is the lower bound of a two-sided 90% prediction band). Since a two-sided simultaneous prediction band for the eight data points would be wider than the non-simultaneous band, no statistically significant anomalies are indicated.

Since the Byron 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 3-8. The intercept of the burst pressure, P_B, as a linear function of the common logarithm of the bobbin amplitude regression line is decreased by 0.04%, and the slope is decreased by ~0.6%, i.e., the slope is a larger negative number. Regression predictions obtained by including these data in the regression analysis are also shown on Figure 3-14. Since the intercept and slope are both reduced by the inclusion of the Byron 1 data, predicted burst pressures at all voltages would be slightly less than the value obtained using the reference regression line. There is also a decrease of ~3% in the standard error of the residuals. The effect of this change would be reflected in a smaller deviation of the 95% prediction line from the regression line. The net effect of both of these changes on the SLB structural limit, using 95%/95% lower tolerance limit material properties, would be to increase it by 0.11 volts, i.e., from 4.64 volts to 4.75 volts, which is judged to be not significant. The decrease in the standard error of the residuals would also slightly reduce the probability of burst for bobbin indications over most of the structural range of interest. Based on the judged insignificant change in the structural limit, the change in the probability of burst would also likely not be significant. It is noted that for high voltages, e.g., near the SLB structural limit, the effect of the lower intercept and slope would offset the advantage of the lower standard error and the probability of burst would slightly increase.

One additonal comparison was made. A linear regression analysis of the Byron 1 data alone was performed. Based on those results, the intercept of the reference database is within a 44% band relative to the intercept from the Byron 1 database. The reference slope is within a 71% band relative to the slope from the Byron 1 database. Thus, a null hypothesis that the Byron 1 data represent a sample from a different population than the reference database would be rejected. Hence, inclusion of the Byron 1 data in the reference database is justified.

3.3.2 Probability of Leak

The same eight 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 3-15 illustrates the Byron 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 Byron 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 3-9. These results indicate a 3% reduction in the *logistic* intercept parameter and an 3% increase in the *logistic* slope parameter. The Pearson standard error increased by 3% from 0.88 to 0.91. This is a positive indicator since the ideal value would be 1.0. In order to assess whether or not these changes are significant the reference correlation and the new correlation were also plotted on Figure 3-15. An examination of Figure 3-15 reveals essentially no change, in an absolute sense, in the correlation below a bobbin amplitude of 1 volt, or above a bobbin amplitude of about 15 volts. The PoL is less than the reference correlation up to a bobbin amplitude of about 4 volts, and slightly greater for indications with amplitues greater than 4 volts. A listing of comparative values is provided in Table 3-10. At 1 volt the decrease in the PoL is on the order of 0.001. In conclusion, the Byron 1 data are consistent with the reference database.

3.3.3 Leak Rate vs. Bobbin Amplitude

As previously noted, two of the removed tube specimens exhibited leakage under SLB conditions. The leak rates are provided in Table 3-7, and depicted on Figure 3-16 relative to the correlation obtained using the reference database. One of the actual leak rates was found to be slightly above, and the other slightly below, the median prediction (the regression fit on the plot) of the regression. It is implied from the visual examination, using the relative distance of the 95% confidence bound on the arithmetic average from the arithmetic average, that all of the data points would fall well within a 90% non-simultaneous, two-sided prediction band. Thus, the visual appearance of the data indicate strong support for the trend of the prior correlation.

As for the previously discussed correlations, a regression analysis was performed to assess the influence of the Byron 1 data on the leak rate to bobbin amplitude correlation. The results of repeating the regression analysis with the Byron 1 data included are given in Table 3-11. Inclusion of the Byron 1 data results in a 1% decrease in the logarithmic intercept parameter and a 2% decrease in the logarithmic slope parameter. In addition, the standard error of the logarithmic residuals is decreased by ~8%, the index of determination of the regression is increased by about 0.3%, and the *p*-value for the slope parameter is reduced by about 50%. Thus, the addition of the data increases the strength of the correlation. Since the intercept, the slope, and the residuals standard error are all reduced, the net effect of including the new data is to reduce the expected, i.e., arithmetic average, leak rate for bobbin amplitudes over the entire range of the data.

3.3.4 General Conclusions

The review of the effect of the Byron 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 likely that the conclusions relative to EOC probability of burst and EOC total leak rate based on correlations obtained using the reference database would not be significantly affected by repeating those analyses using an expanded database which includes the Byron 1 test data.

Table 3-1
Comparison of NDE Indications Observed at Byron Unit 1
on SG Tubes at Hot Leg Locations

Tube/ Location	Field E/C	Lab E/C	Field UT	Lab UT	Lab X-Ray
R3C107 1H	Bobbin: NDD RPC: NDD	Bobbin: NDD RPC: NDD	NDD	NDD	NDD
R3C107 3H	Bobbin: 5.92V OD Ind, 78% deep (5.89V)* RPC: 4.03V, 0.37" SAI (4.2V SAI, 0.38")*	Bobbin: 7.0V OD Ind, 78% deep RPC: 5.4V SAI	Two areas with many short axial Inds: one 115° by 0.61"; the other 75° by 0.30"	0.4" axial OD Ind at 30° that is near 100% deep; plus Short, shallow, MAI in crevice between 10° & 45°, 235° & 290° and near 350°	0.3" SAI
R3C107 5H	Bobbin: NDD (0.25V DI)* RPC: NDD	Bobbin: 0.21V DI RPC: 0.58V Volumetric Ind	One area with many short axial Inds: 80° by 0.47" Possible Axial Ind, 0.36" long in same area	NDD	NDD

Legend of Abbreviations:

()* = field reevaluation value (using cross calibration of ASME std. to ref. lab std.)
NDD = No Detectable Degradation
RPC= Rotating Pancake Coil
ICC = intergranular cellular corrosion
TSP = Tube Support Plate
Ind = Indication
SAI = Single Axial Ind
V = Voltage
MAI = Multiple Axial Inds
#C = number of cracks
Circ = circumferential
Max = maximum
DI = Distorted Indication

Table 3-1 (Continued)
Comparison of NDE Indications Observed at Byron Unit 1
on SG Tubes at Hot Leg Locations

Tube/ Location	Field E/C	Lab E/C	Field UT	Lab UT	Lab X-Ray
R3C107 7H	Bobbin: NDD (0.26V DI)* RPC: NDD	Bobbin: 0.30V DI RPC: 0.22V SAI	Two areas with many short, low amplitude axial Inds: one 70^0 by 0.26"; the other 50^0 by 0.20"	NDD	NDD
R20C7 1H	Bobbin: NDD RPC: NDD	Bobbin: NDD RPC: NDD	NDD	NDD	NDD
R20C7 3H	Bobbin: 10.95V OD Ind, 79% deep (10.9V,80% deep)* RPC: MAI (2C), 0.45 & 0.37" long with some Circ involvement, 4.59V Max (4.7V & 1.3V)*	Bobbin: 13.8V OD Ind, 81% deep RPC: MAI (3C), 6.5V & 1.6V	Short OD origin MAI (6C with Circ involvement) distributed around circumference, ID SAI with Circ involvement at same location as OD Ind	OD MAI (4C): at 70^0 (0.1" & near 100% TW), at 80^0 (0.19" long & near 100%), 100^0, 160^0 (0.25" long & 50%)	MAI (7+C), longest 0.3" long
R20C7 5H	Bobbin: NDD (0.23V DI)* RPC: NDD	Bobbin: 1.49V DI (noisy) RPC: 0.43V Volumetric Ind	0.2" SAI	0.2" axial OD Ind at 85^0, 45% deep; plus many short shallow MAI between 310^0 to 335^0	NDD
R20C7 7H	Bobbin: NDD (0.38V DI)* RPC: NDD	Bobbin: 6.7V dent RPC: 0.40V Volumetric Ind	NDD	Many short shallow OD MAI (<20% deep) near 100^0 & near 115^0	NDD

Table 3-1 (Continued)
Comparison of NDE Indications Observed at Byron Unit 1
on SG Tubes at Hot Leg Locations

Tube/ Location	Field E/C	Lab E/C	Field UT	Lab UT	Lab X-Ray
R20C102 1H	Bobbin: NDD RPC: NDD	Bobbin: NDD RPC: NDD	NDD	NDD	NDD
R20C102 3H	Bobbin: 2.58V OD Ind, 60% deep (2.58V, 63%)* RPC: 0.37" SAI, 1.76V	Bobbin: 4.92V OD Ind, 61% deep RPC: MAI (3C), 4.24V Max	MAI (3C)	0.2" axial OD Ind at 165°, 40% deep, may be 0.5" long with nearby shallow Inds; plus short shallow MAI at 30°, 100° & 130°	0.[illegible]" SAI
R20C102 5H	Bobbin: 1.25V OD Ind, 81% deep (1.11V, 79% deep)* RPC: 0.27" SAI with some Circ Involvement, 0.18V Max (Volumetric Ind in 2 areas, 0.52V)*	Bobbin: 4.64V OD Ind, 44% deep RPC: Volumetric Ind in 2 areas, 2.05V Max	MAI, two areas with many short axial Inds: one 50° by 0.4"; the other 70° by 0.3" 0.23" SAI	0.07" axial OD Ind at 85°, 30% deep; plus short shallow MAI near 15°, 85° to 150°, & near 300°; plus possible OD Circ Ind between 285° & 305°, 30% deep	NDD
R20C102 7H	Bobbin: NDD RPC: NDD	Bobbin: NDD RPC: NDD	NDD	NDD	NDD

Table 3-2
Byron Unit 1 Leak Test Results for Steam Generator Tubing

Tube No., Location	Test Type: Differential Pressure (psi)	Leak Rate (liters/hour)	Test Conditions
R3C107 3H	NOC: 1305 NOC: 1269 ITC1: 1874 ITC2: 2269 SLB: 2545	0.054 0.047 0.410 2.40 4.70	P_p= 2265, P_s= 960, T_p= 584, T_s= 597 P_p= 2224, P_s= 955, T_p= 589, T_s= 602 P_p= 2390, P_s= 516, T_p= 550, T_s= 583 P_p= 2679, P_s= 410, T_p= 539, T_s= 503 P_p= 2955, P_s= 410, T_p= 546, T_s= 472
R20C7 3H	NOC: 1286 ITC1: 1862 ITC2: 2302 SLB: 2510	0.065 0.473 8.50 18.3	P_p= 2237, P_s= 951, T_p= 615, T_s= 623 P_p= 2380, P_s= 518, T_p= 578, T_s= 598 P_p= 2690, P_s= 388, T_p= 570, T_s= 476 P_p= 2936, P_s= 426, T_p= 570, T_s= 471
R20C7 7H	NOC: 1286 ITC1: 1882 SLB: 2545	zero zero zero	P_p= 2219, P_s= 933, T_p= 619, T_s= 617 P_p= 2396, P_s= 514, T_p= 623, T_s= 619 P_p= 2763, P_s= 218 T_p= 621, T_s= 615
R20C102 3H	NOC: 1320 ITC1: 1925 SLB: 2545	zero zero zero	P_p= 2270, P_s= 950, T_p= 612, T_s= 614 P_p= 2460, P_s= 535, T_p= 620, T_s= 622 P_p= 2745, P_s= 200, T_p= 622, T_s= 624
R20C102 5H	NOC: 1280 ITC1: 1900 SLB: 2555	zero zero zero	P_p= 2245, P_s= 965, T_p= 607, T_s= 609 P_p= 2400, P_s= 500, T_p= 618, T_s= 619 P_p= 2765, P_s= 210, T_p= 620, T_s= 622

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 Byron Unit 1 Hot Leg SG Tubing

Location	Burst Pressure (psig)	Ductility (% Dia.)	Burst Length (inches)	Burst Width (inches)	0.2% Offset Tensile YS (psi)	Tensile UTS (psi)	Tensile Elongation (%)
R3C107, FS	11,500	33.7	1.494	0.288	54,000	101,600	31.3
R3C107 3H+	4,800+ 4,000 3,550	5.4 5.8 5.9	0.462 0.477 0.465	0.089 0.093 0.103			
R3C107 5H	9,800	17.7	1.057	0.256			
R3C107 7H	10,300	18.7	1.057	0.266			
R20C7, FS	11,500	32.1	1.588	0.299	55,700	102,450	31.2
R20C7 1H	11,300	29.7	1.521	0.317			
R20C7 3H+	3,750+ 4,500	6.9 9.1	0.500 0.695	0.079 0.164			
R20C7 5H	10,200	18.1	2.114	0.293			
R20C7 7H	11,300	25.4	1.356	0.359			
R20C102, FS	11,900	30.9	1.503	0.295	57,400	106,250	26.2*
R20C102 3H+	7,050+	11.7	1.111	0.320			
R20C102 5H+	9,050+	16.5	1.198	0.366			
Control (NX7368)	12,050	34.5	1.963	0.411	57,300	108,500	25.7*

Legend: TSP = Tube support plate crevice region location; FS = free span location
* = Tensile specimen broke outside of gage length, possibly reducing elongation value.
+ = Burst specimen used a bladder and foil over largest defect area and was burst in a semi-restraint condition. In addition, after burst testing, the foil was observed to be centered under the burst opening. All other burst specimens were burst without bladders and foils and without a restraint conditions. Specimens R3C107, TTS and R20C7 3H were reburst with a larger size foil following the initial burst test that used a standard size foil (1.75 inch high x 1.0 inch wide versus 0.75 inch high x 0.5 inch wide). The reburst was performed to produce true tensile tearing at the tips of the burst opening. The reburst apparently was successful for R20C7 3H. A second reburst for R3C107 3H still did not produce a true burst opening.

Table 3-4
Byron Destructive Examination Planning Data

Specimen	E/C Data (field bobbin probe)	Burst & Ductility Ratios (specimen/ FS value)	FF Corrosion* (visually observed)	Crevice Region* Corrosion (visually observed)	DE Plan
R3C107, FS	NDD	1.00/ 1.00	No	No	No
R3C107 3H	5.9V IND (5.9V)	0.42/ 0.16	Yes	Yes	Yes, both metallography and SEM FF
R3C107 5H	NDD (0.25V DI)	0.85/ 0.52	Yes	Yes (almost 360°)	Yes, SEM FF only
R3C107 7H	NDD (0.26V DI)	0.90/ 0.55	Yes	Yes (360°)	Yes, SEM FF only
R20C7, FS	NDD	1.00/ 1.00	No	No	No
R20C7 1H	NDD	0.98/ 0.92	No	No	No
R20C7 3H	11.0V IND (10.9V)	0.33/ 0.21	Yes	Yes	Yes, both metallography and SEM FF
R20C7 5H	NDD (0.23V DI)	0.89/ 0.56	Yes	Yes (almost 360°)	Yes, SEM FF only
R20C7 7H	NDD (0.38V DI)	0.98/ 0.79	No(1)	Yes (360°)	Yes, SEM FF only
R20C102, FS	NDD	1.00/ 1.00	No	No	No
R20C102 3H	2.6V IND (2.6V)	0.59/ 0.38	Yes	Yes	Yes, both metallography and SEM FF Also, extra chemistry of deposits and FF
R20C102 5H	1.2V IND (1.1V)	0.76/ 0.53	Yes	Yes (360°)	Yes, both metallography and SEM FF

* = All bursts occurred centered within the crevice regions or at the tubesheet top.
FS = free span; TSP = tube support plate; FF = fracture face
(1) Visual observation subsequently invalidated by crevice corrosion observation.

Table 3-5
Byron Unit 1 SG Tube Burst Opening Macrocrack Profiles

Tube, Location	Length vs. Depth (inches/% throughwall)	Ductile Ligament Location/ Width (inches)	Comments
R3C107 3H	0.00/00 0.04/50 <—Ligament 1 0.08/46 0.12/21 <—Ligament 2 0.16/50 <—Ligament 3 0.20/71 0.24/79 0.28/92 0.32/92 (0.34/100) <--Throughwall tip 0.36/100 0.40/100 (Throughwall over 0.13 inch) 0.44/100 (0.47/100) <--Throughwall tip 0.48/87 0.52/79 0.56/37 <—Ligament 4 (0.59/00) (Ave. depth = 67%, Macrocrack Length = 0.59 inch)	Crack Bottom <—Ligament 1/0.013" wide <—Ligament 2/0.003" wide <—Ligament 3/0.004" wide <—Ligament 4/0.002" wide Crack Top	The axially oriented burst macrocrack had four ductile ligaments with dimple rupture features occurring over more than 50% of their length.

Table 3-5 (Continued)
Byron Unit 1 SG Tube Burst Opening Macrocrack Profiles

Tube, Location	Length vs. Depth (inches/% throughwall)	Ductile Ligament Location/ Width (inches)	Comments
R3C107 5H	0.00/00 0.04/42 0.08/32 <---Ligament 3 0.12/37 0.16/35 0.20/45 <---Ligament 2 0.24/45 0.28/49 (0.26/53) <--(Max. depth = 53%) 0.32/38 0.36/30 0.40/23 0.44/31 <---Ligament 1 0.48/23 0.52/22 (0.550/00) (Ave. depth = 32%, Macrocrack Length = 0.550 inch)	Crack Top <---Ligament 3/0.015" wide <---Ligament 2/0.003" wide <---Ligament 1/0.003" wide Crack Bottom	The axially oriented burst macrocrack had three ductile ligaments with dimple rupture features occurring over more than 50% of their length.
R3C107 7H	0.00/00 0.04/19 0.08/14 <---Ligament 8 0.12/23 <---Ligament 7 0.16/26 0.20/23 <---Ligament 6 0.24/37 (0.26/45) <--(Max. depth = 45%) 0.28/40 0.32/37 0.36/34 <---Ligament 5 0.40/19 <---Ligament 4 0.44/16 <---Ligament 3 0.48/19 0.52/00 <---Ligament 2 0.56/14 <---Ligament 1 (0.592/00) (Ave. depth = 21%, Macrocrack Length = 0.592 inch)	Crack Top <---Ligament 8/0.003" wide <---Ligament 7/0.006" wide <---Ligament 6/0.004" wide <---Ligament 5/0.006" wide <---Ligament 4/0.014" wide <---Ligament 3/0.012" wide <---Ligament 2/0.036" wide <---Ligament 1/0.002" wide Crack Bottom	The axially oriented burst macrocrack had eight ductile ligaments with dimple rupture features occurring over more than 50% of their length.

Table 3-5 (Continued)
Byron Unit 1 SG Tube Burst Opening Macrocrack Profiles

Tube, Location	Length vs. Depth (inches/% throughwall)	Ductile Ligament Location/ Width (inches)	Comments
R20C7 3H (Right Face of Burst Opening @ 100^{0})	0.00/00 <—Ligaments 1 & 2 0.04/31 0.08/38 0.12/48 0.16/76 0.20/84 (0.22/100) <--Throughwall tip 0.24/100 0.28/100 0.32/100 (Throughwall over 0.36/100 0.24 inch) 0.40/100 0.44/100 (0.46/100) <--Throughwall tip 0.48/86 0.52/57 0.56/38 <—Ligament 3 0.60/31 (0.602/00) (Ave. depth = 68%, Macrocrack Length = 0.602 inch)	Crack Bottom <--Ligaments 1 & 2/.002 & 0.014" wide <--Ligament 3/0.001" wide Crack Top	The axially oriented burst macrocrack had three ductile ligaments with dimple rupture features occurring over more than 50% of their length.

Table 3-5 (Continued)
Byron Unit 1 SG Tube Burst Opening Macrocrack Profiles

Tube, Location	Length vs. Depth (inches/% throughwall)	Ductile Ligament Location/ Width (inches)	Comments
R20C7 3H (Left Face of Throughwall Crack @ 70°)	0.00/00 <---Ligament 1 0.04/36 <---Ligaments 2 & 3 0.08/27 0.12/73 0.16/75 (0.195/100) <--Throughwall tip 0.20/100 0.24/100 0.28/100 (Throughwall over 0.32/100 0.268 inch) 0.36/100 <---Ligament 4 0.40/100 0.44/100 (0.463/100) <--Throughwall tip 0.48/64 <---Ligaments 5, 6 & 7 0.52/32 <---Ligaments 8 & 9 0.56/23 (0.562/00) (Ave. depth = 69 %, Macrocrack Length = 0.562 inch)	Crack Bottom <--Ligament 1/0.005" wide <--Ligaments 2 & 3/0.004 & 0.009" wide <--Ligament 4 /0.003" wide <--Ligaments 5, 6 & 7/0.004" wide, each" <--Ligaments 8 & 9/0.004 & 0.006" wide Crack Top	The axially oriented burst macrocrack had nine ductile ligaments with dimple rupture features occurring over more than 50% of their length.

Table 3-5 (Continued)
Byron Unit 1 SG Tube Burst Opening Macrocrack Profiles

Tube, Location	Length vs. Depth (inches/% throughwall)	Ductile Ligament Location/ Width (inches)	Comments
R20C7 5H	0.00/00	Crack Top	The axially oriented burst macrocrack had two ductile ligaments with dimple rupture features occurring over more than 50% of their length.
	0.04/02		
	0.08/01		
	0.12/02		
	0.16/10		
	0.20/26		
	0.24/32 <---Ligament 1	<---Ligament 1/0.002" wide	
	0.28/26		
	0.32/32		
	0.36/29 <---Ligament 2	<---Ligament 2/0.002" wide	
	0.40/25		
	(0.43/38) <--(Max. depth = 38%)		
	0.44/31		
	0.48/30		
	0.52/27		
	0.56/00 (Ave. depth = 20%, Macrocrack Length=0.560 inch)	Crack Bottom	
R20C7 7H	0.00/00	Crack Top	The axially oriented burst macrocrack had two ductile ligaments with dimple rupture features occurring over more than 50% of their length.
	0.04/04		
	0.08/02		
	0.12/14		
	0.16/23		
	0.20/25		
	(0.22/26) <--(Max. depth = 26%)		
	0.24/23		
	0.28/18 <---Ligament 1	<---Ligament 1/0.004" wide	
	0.32/13		
	0.36/05		
	0.40/04		
	0.44/07 <---Ligament 2	<---Ligament 2/0.006" wide	
	(0.442/00) (Ave. depth = 12%, Macrocrack Length=0.442 inch)	Crack Bottom	

Table 3-5 (Continued)
Byron Unit 1 SG Tube Burst Opening Macrocrack Profiles

Tube, Location	Length vs. Depth (inches/% throughwall)	Ductile Ligament Location/ Width (inches)	Comments
R20C102 3H	0.00/00<---Ligament 1 0.04/50 0.08/86 0.12/91 0.16/91 (0.18/96) <--(Max. depth = 96%) 0.20/95 0.24/88 0.28/60 0.32/00<--Ligament 2 0.36/20 (0.38/00) (Ave. depth = 58%, Macrocrack Length=0.38 inch)	Crack Top<---Ligament 1/0.007" wide <--Ligament 2/0.004" wide Crack Bottom	The axially oriented burst macrocrack had two ductile ligaments with dimple rupture features occurring over more than 50% of their length.
R20C102 5H	0.00/00 0.04/37 0.08/46 0.12/46 0.16/58 0.20/60 0.24/65 <--(Max. depth = 65%) 0.28/58 0.32/48 0.36/37<---Ligament 1 0.40/22<---Ligament 2 (0.41/00) (Ave. depth = 43%, Macrocrack Length=0.41 inch)	Crack Top <---Ligament 1/0.010" wide <---Ligament 2/0.002" wide Crack Bottom	The axially oriented burst macrocrack had two ductile ligaments with dimple rupture features occurring over more than 50% of their length.

Table 3-6. Summary of Byron-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	UT Results	Bobbin Volts	RPC Volts
Steam Generator A												
R3C107	1	NDD	NDD	NDD	NDD				NDD	NDD	NDD	NDD
	3	5.92	4.03	MAI	5.26	1.12	5.89	78%	4.2	MAI	7.0	5.4
	[illegible]	NDD	NDD	MAI	0.22	1.12	0.25	DI	NDD	NDD	0.21	0.58
	7	NDD	NDD	MAI	0.23	1.12	0.26	DI	NDD	NDD	0.30	0.22
Steam Generator C												
R20C7	1	NDD	NDD	NDD	NDD				NDD	NDD	NDD	NDD
	3	10.95	4.59	MAI	10.12	1.073	10.9	80%	4.7	MAI	13.8	6.5
	5	NDD	NDD	SAI	0.21	1.073	0.23	DI	NDD	MAI	1.49	0.43
	7	NDD	NDD	NDD	0.35	1.073	0.38	DI	NDD	MAI	Dent	0.40
R20C102	1	NDD	NDD	NDD	NDD				NDD	NDD	NDD	NDD
	3	2.58	1.76	MAI	2.40	1.073	2.58	63%	2.0	MAI	4.92	4.24
	5	1.25	0.18	MAI	1.03	1.073	1.11	79%	0.52	MAI	4.64	2.05
	7	NDD	NDD	NDD	NDD				NDD	NDD	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 IPC volts.

Table 3-7. Byron-1 Pulled Tube Data for ARC Applications															
Tube	TSP	Bobbin Data		RPC Volts	Destructive Exam Results					Leak Rate-l/hr		Burst Pressure Data - ksi			
		Volts	Depth		Max. Depth	Avg. Depth	Crack Length	TW Length	No. Lig.[2]	N. O. 1300 psid[1]	SLB 2560 psid[1]	Meas. Burst Press.	σ_y	σ_u	Adj. Burst Press.
Steam Generator A															
R3C107	1	NDD		NDD	Note 3	-	-	-	-	Note 3	-	Note 3	54.0	101.6	-
	3	5.89	78%	4.2	100%	67%	0.590"	0.130"	4	0.037	4.15	>4.800[5]			>4.627[5]
	5	0.25	DI	NDD	53%	32%	0.550"	-	3	0.0[4]	0.0[4]	9.800			9.447
	7	0.26	DI	NDD	45%	21%	0.592"	-	8	0.0[4]	0.0[4]	10.300			9.929
Steam Generator C															
R20C7	1	NDD		NDD	~ 0%	-	-	-	-	0.0[4]	0.0[4]	11.300	55.7	102.45	10.718
	3	10.9	80%	4.7	100% 100%[7]	68% 69%	0.602" 0.562"	0.240" 0.268"	3 9	0.037	22.1	4.500			4.268
	5	0.23	DI	NDD	38%	20%	0.560"	-	2	0.0[4]	0.0[4]	10.200			9.674
	7	0.38 Note 6	DI	NDD	26%	12%	0.442"	-	2	0.0	0.0 Note 6	11.300			10.718 Note 6
R20C102	1	NDD		NDD	Note 3	-	-	-	-	Note 3	-	Note 3	57.4	106.25	-
	3	2.58	63%	2.0	96%	58%	0.380"	-	2	0.0	0.0	7.050			6.462
	5	1.11	79%	0.52	65%	43%	0.410"	-	2	0.0	0.0	9.050			8.295
	7	NDD		NDD	Note 3	-	-	-	-	Note 3	-	Note 3			-

Notes:
1. Measured leak rates adjusted to reference conditions by applying methods of EPRI data report.
2. Number of uncorroded ligaments with > 50% of ligament length remaining in burst crack face.
3. Archive specimen.
4. Inferred from destructive exam depth, leak test not performed. Corrosion depth too shallow for leakage at SLB conditions.
5. Burst test showed insignificant crack extension at the corrosion crack tips. Burst pressure is therefore a minimum value since burst is defined to include crack extension and the burst pressure therefore represents a minimum value.
6. Data excluded from EPRI database per data exclusion criterion 2a which excludes indications having high burst pressures on the burst pressure versus voltage correlation with cracks <60% deep with ≤ 2 ligaments.
7. Second throughwall crack 30° from burst crack.

Table 3-8: Effects of the Byron 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 Byron 1 Data
α_1	7.834	7.831
α_2	-3.109	-3.127
σ_{Error}	0.934	0.906
N (data pairs)	80	87
p Value for α_2	$7 \cdot 10^{-31}$	$4 \cdot 10^{-35}$
r^2	81.3%	82.9%

Table 3-9: Effect of Byron Unit 1 Data on the Probability of Leak Correlation

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

Parameter	Reference Database Value	Database with Byron 1 Data
β_1	-5.014	-5.171
β_2	8.410	8.669
V_{11}	1.432	1.471
V_{12}	-2.031	-2.101
V_{22}	3.256	3.370
Pearson σ_{Error}	0.88	0.91

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

Table 3-10: Effect of Byron 1 Data on the Probability of Leak as a Function of Bobbin Amplitude		
Bobbin Amplitude (Volts)	PoL (Reference)	PoL (w/Byron)
0.60	0.0010	0.0008
0.70	0.0018	0.0015
0.90	0.0029	0.0024
1.00	0.0066	0.0056
2.00	0.0771	0.0717
3.00	0.2686	0.2621
5.00	0.7036	0.7085
6.00	0.8220	0.8284
7.00	0.8902	0.8961
9.00	0.9531	0.9706

Table 3-11: Effects of Byron Unit 1 Data on the Leak Rate vs. Bobbin Volts Correlation $\log(Leak\ Rate) = \beta_3 + \beta_4 \log(Volts)$		
Parameter	Reference Database Value	Database with Byron 1 Data
β_3	-2.067	-2.044
β_4	3.329	3.272
β_5 (σ_{Error})	0.695	0.636
N (Data pairs)	41	43
p Value for β_4	$7 \cdot 10^{-10}$	$3 \cdot 10^{-10}$
r^2	60.8%	61.0%

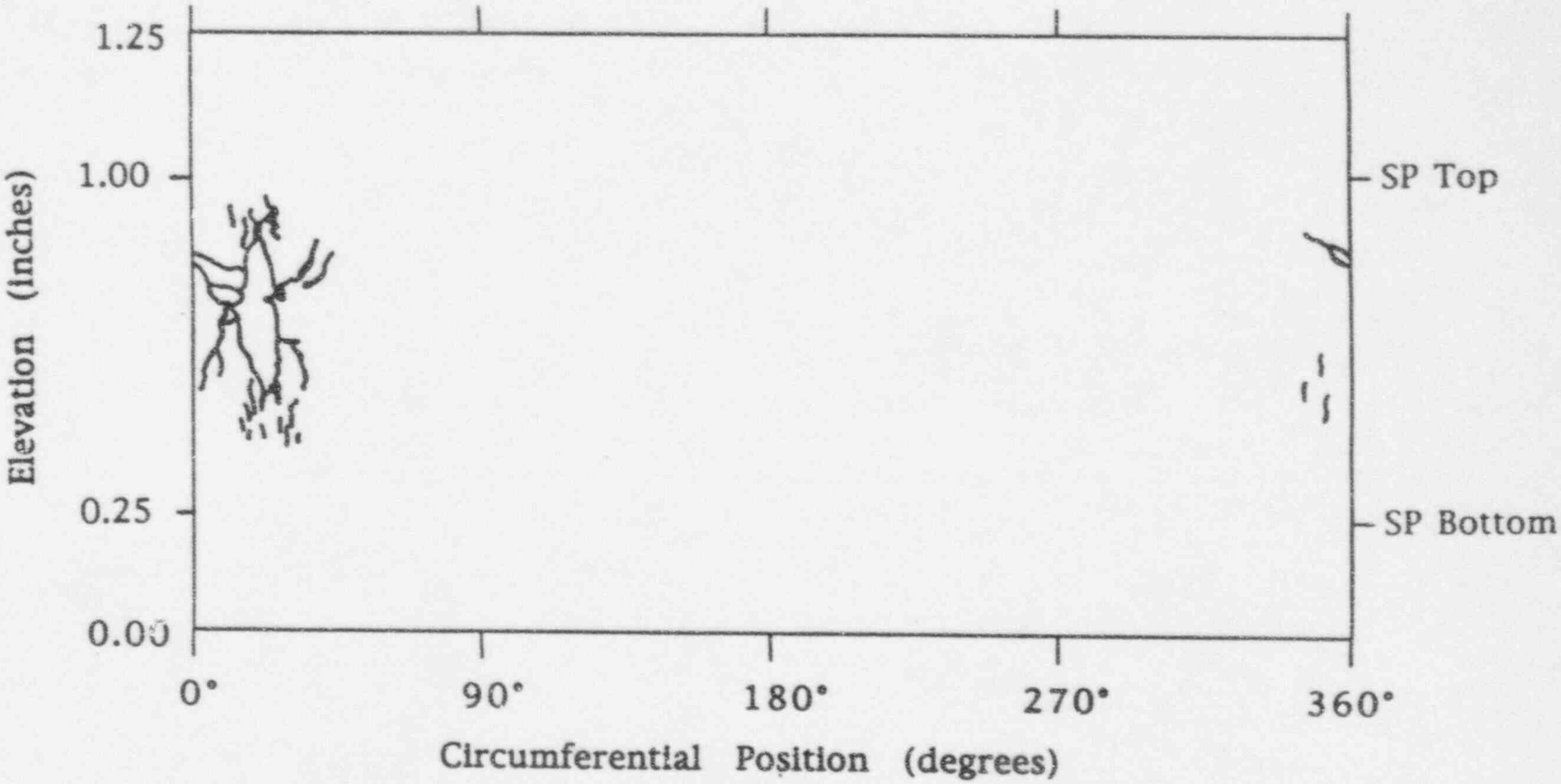


Figure 3-1 Sketch of the OD surface crack distribution found at the third tube support plate (TSP3) region of Tube R3-C107. Also shown is the location of the burst fracture opening. The corrosion cracking and the burst fracture were confined to the crevice region.

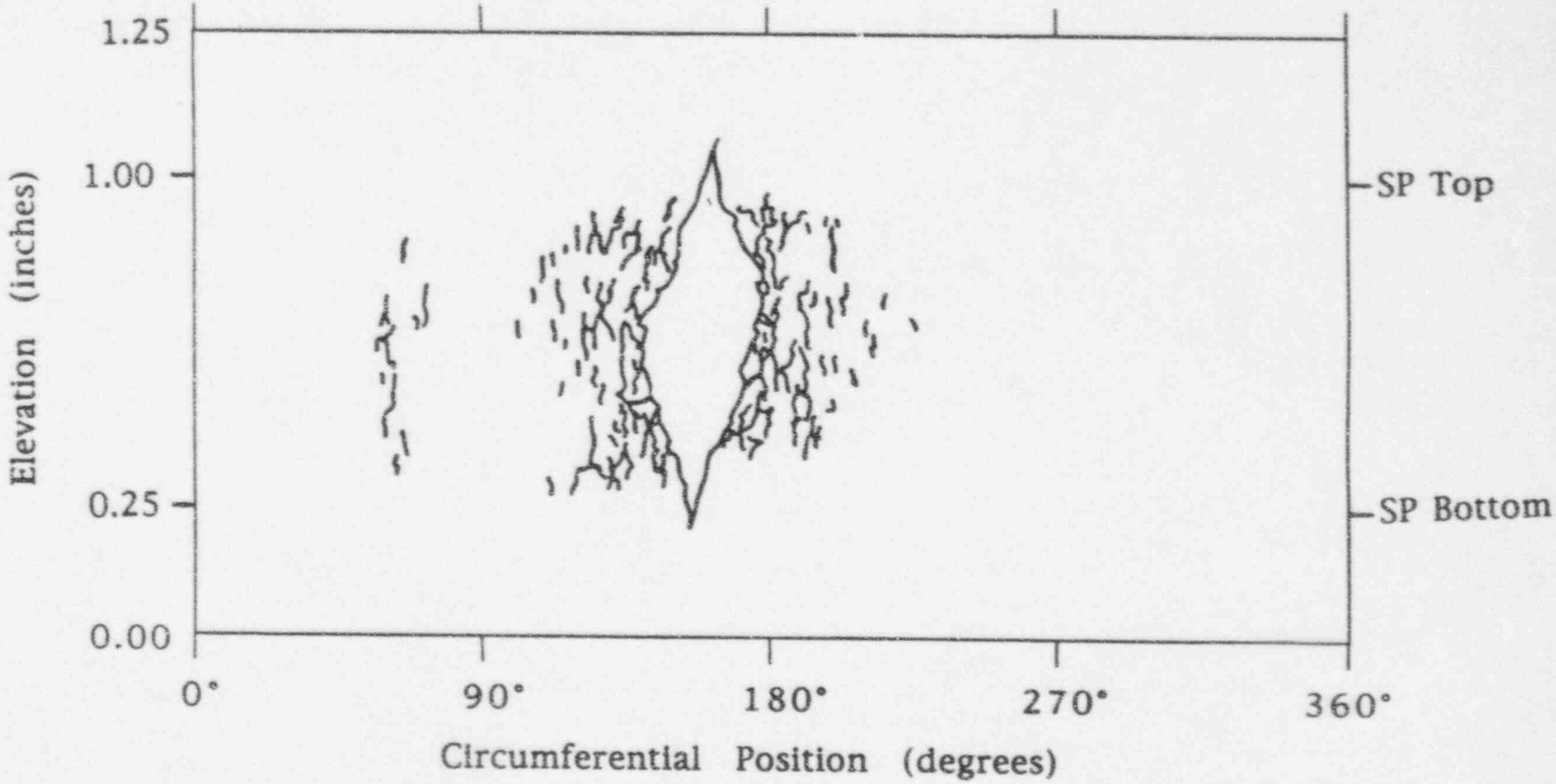


Figure 3-2 Sketch of the OD surface crack distribution found at the fifth tube support plate (TSP5) region of Tube R3-C107. Also shown is the location of the burst fracture opening. The burst opening extended beyond the TSP crevice region, but the corrosion cracking on the burst fracture was confined to the crevice region.

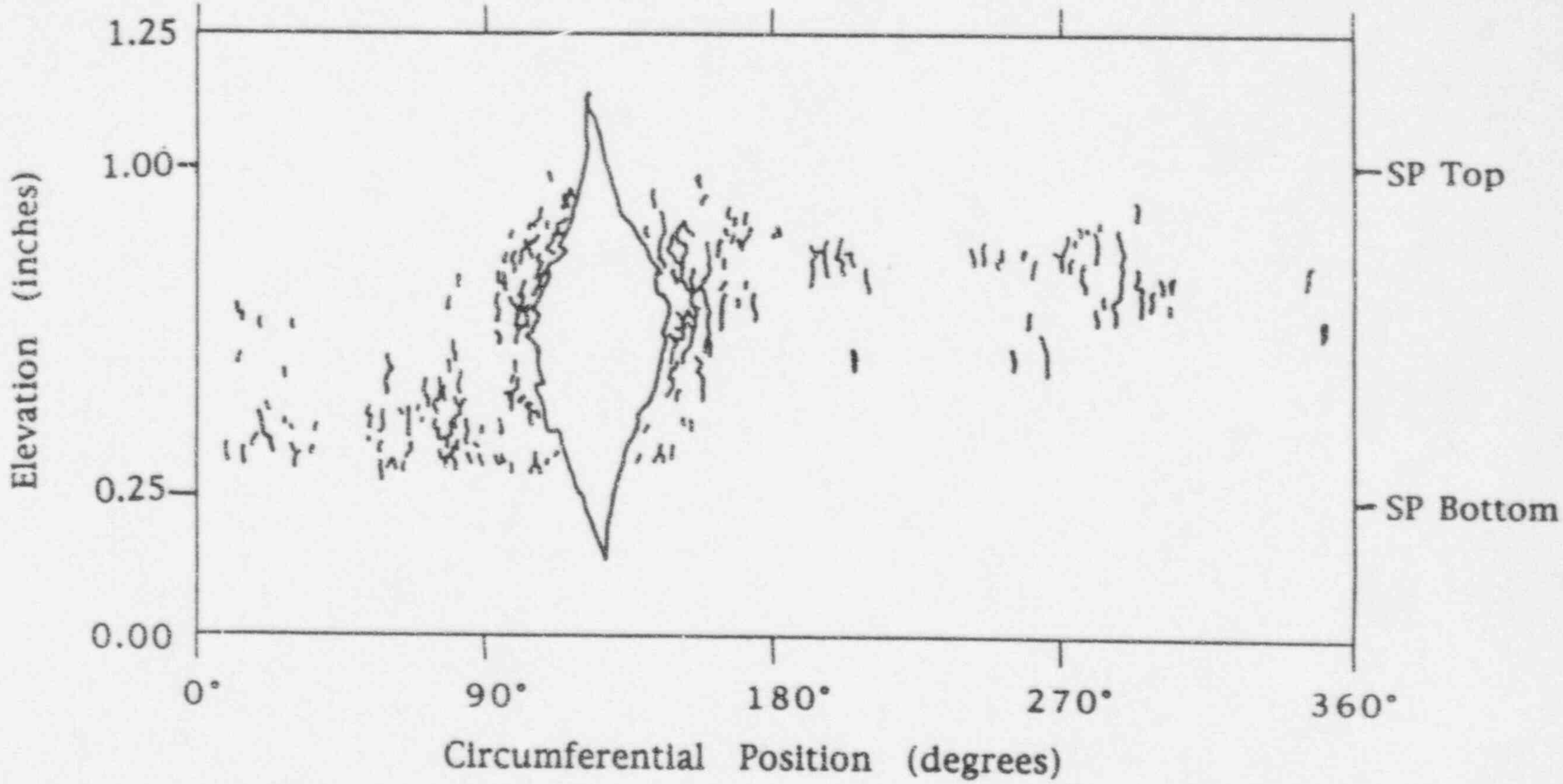


Figure 3-3 Sketch of the OD surface crack distribution found at the seventh tube support plate (TSP7) region of Tube R3-C107. Also shown is the location of the burst fracture opening. The burst opening extended beyond the TSP crevice region, but the corrosion cracking on the burst fracture was confined to the crevice region.

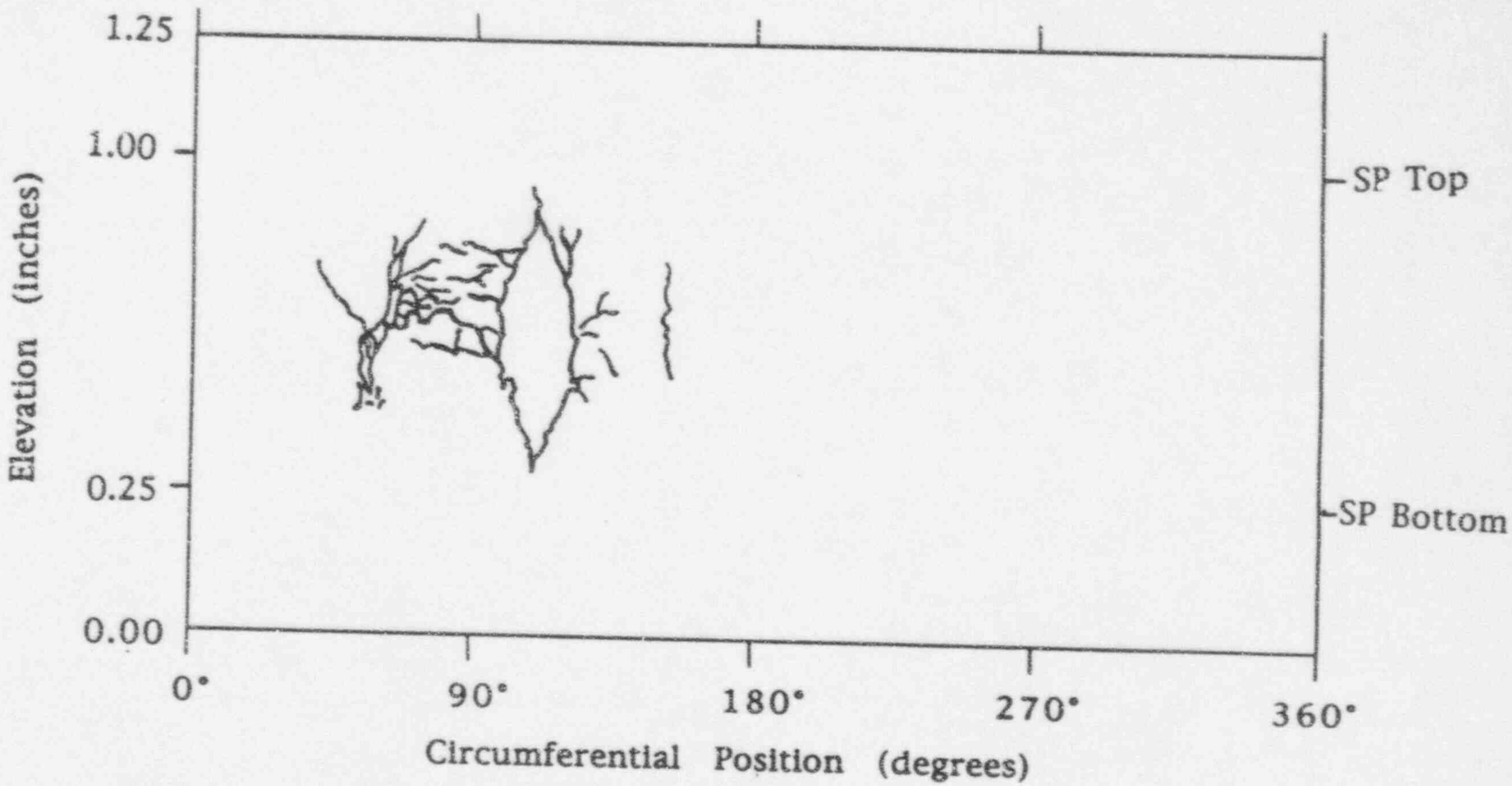


Figure 3-4 Sketch of the OD surface crack distribution found at the third tube support plate (TSP3) region of Tube R20-C7. Also shown are the locations of the burst fracture openings which occurred at circumferential positions of 45° and 110°. The corrosion cracking and the burst fractures were confined to the crevice region.

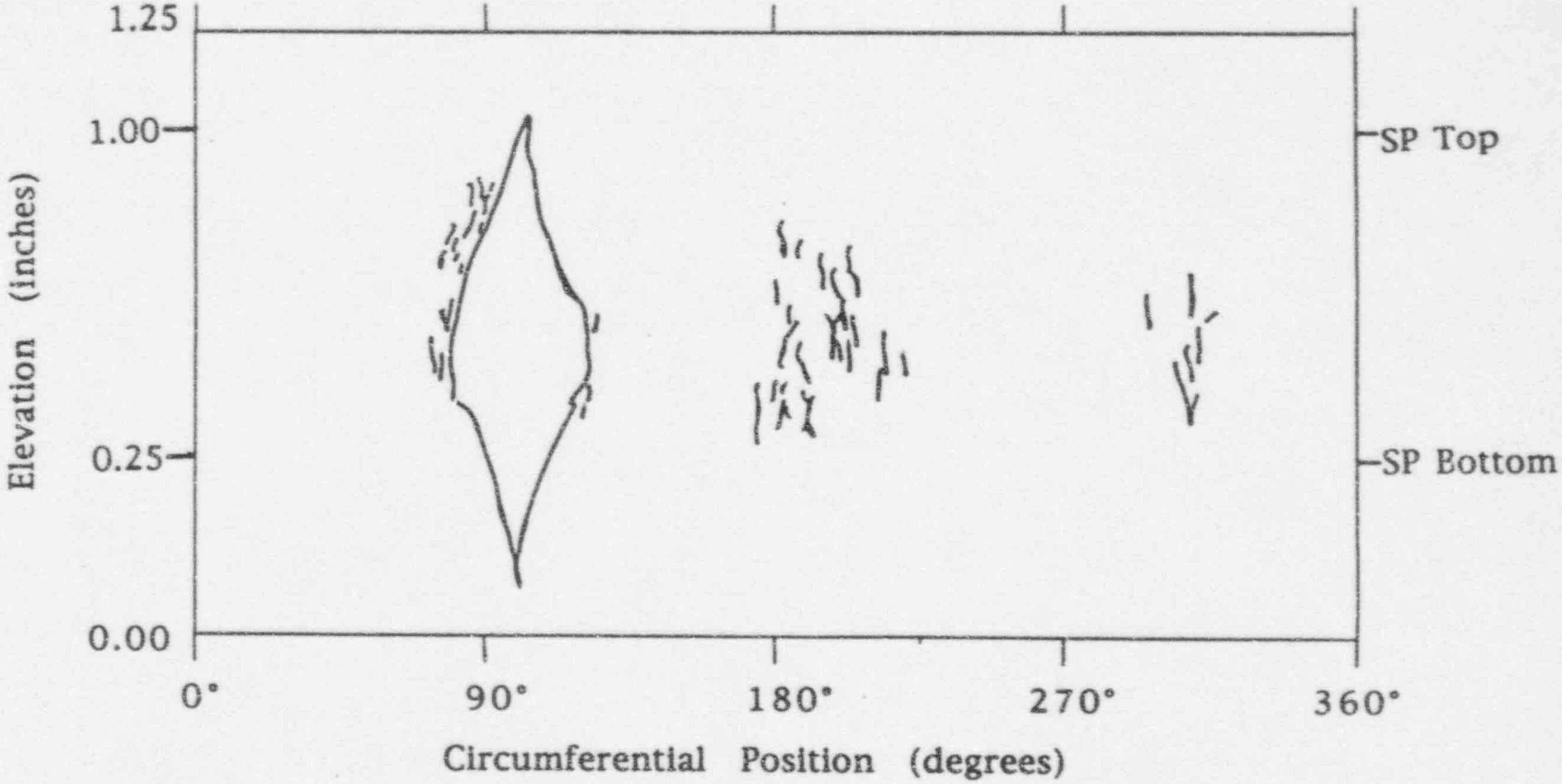


Figure 3-5 Sketch of the OD surface crack distribution found at the fifth tube support plate (TSP5) region of Tube R20-C7. Also shown is the location of the burst fracture opening. The burst opening extended beyond the TSP crevice region, but the corrosion cracking on the burst fracture was confined to the crevice region.

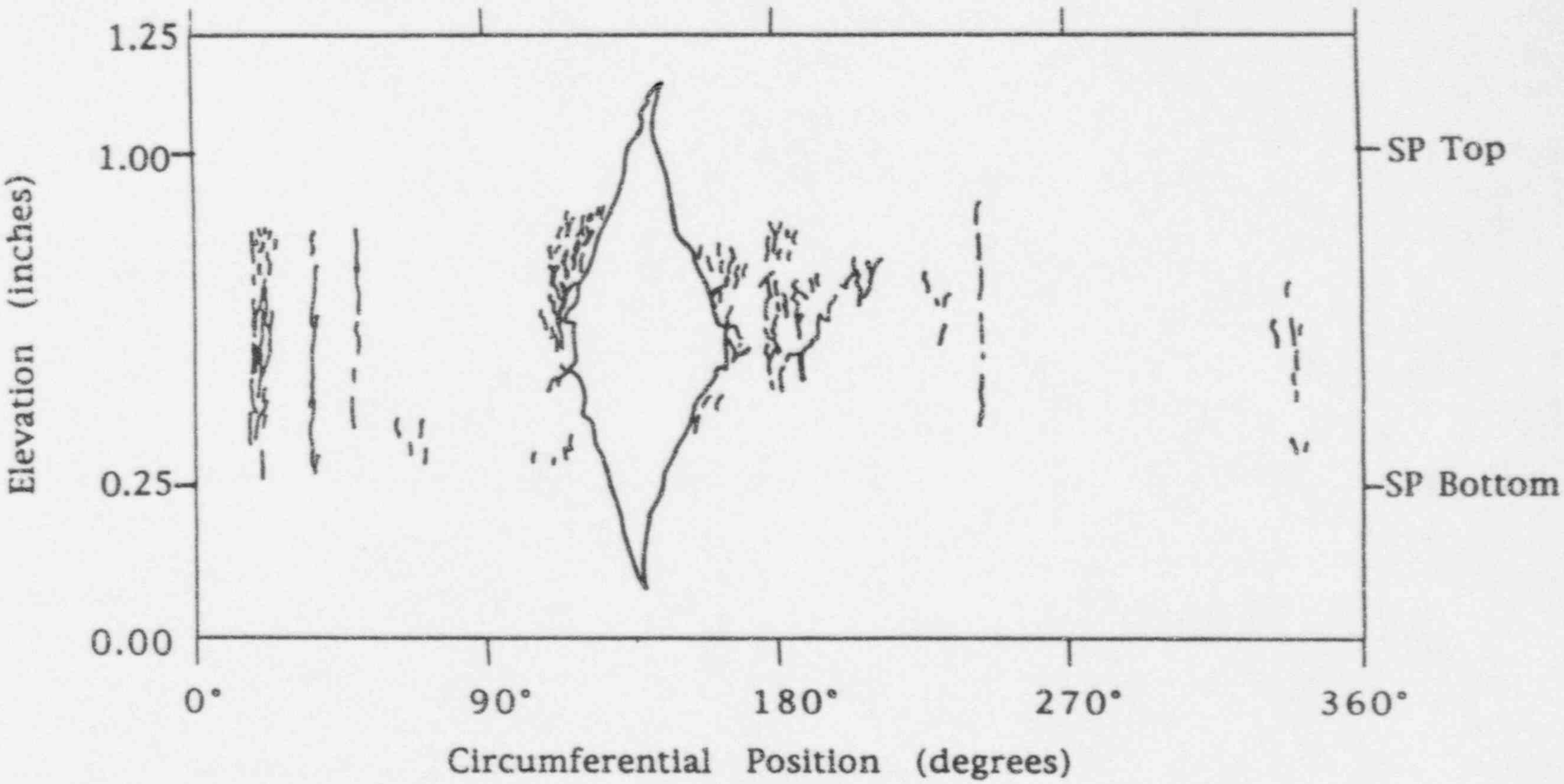


Figure 3-6 Sketch of the OD surface crack distribution found at the seventh tube support plate (TSP7) region of Tube R20-C7. Also shown is the location of the burst fracture opening. The burst opening extended beyond the TSP crevice region, but the corrosion cracking on the burst fracture was confined to the crevice region.

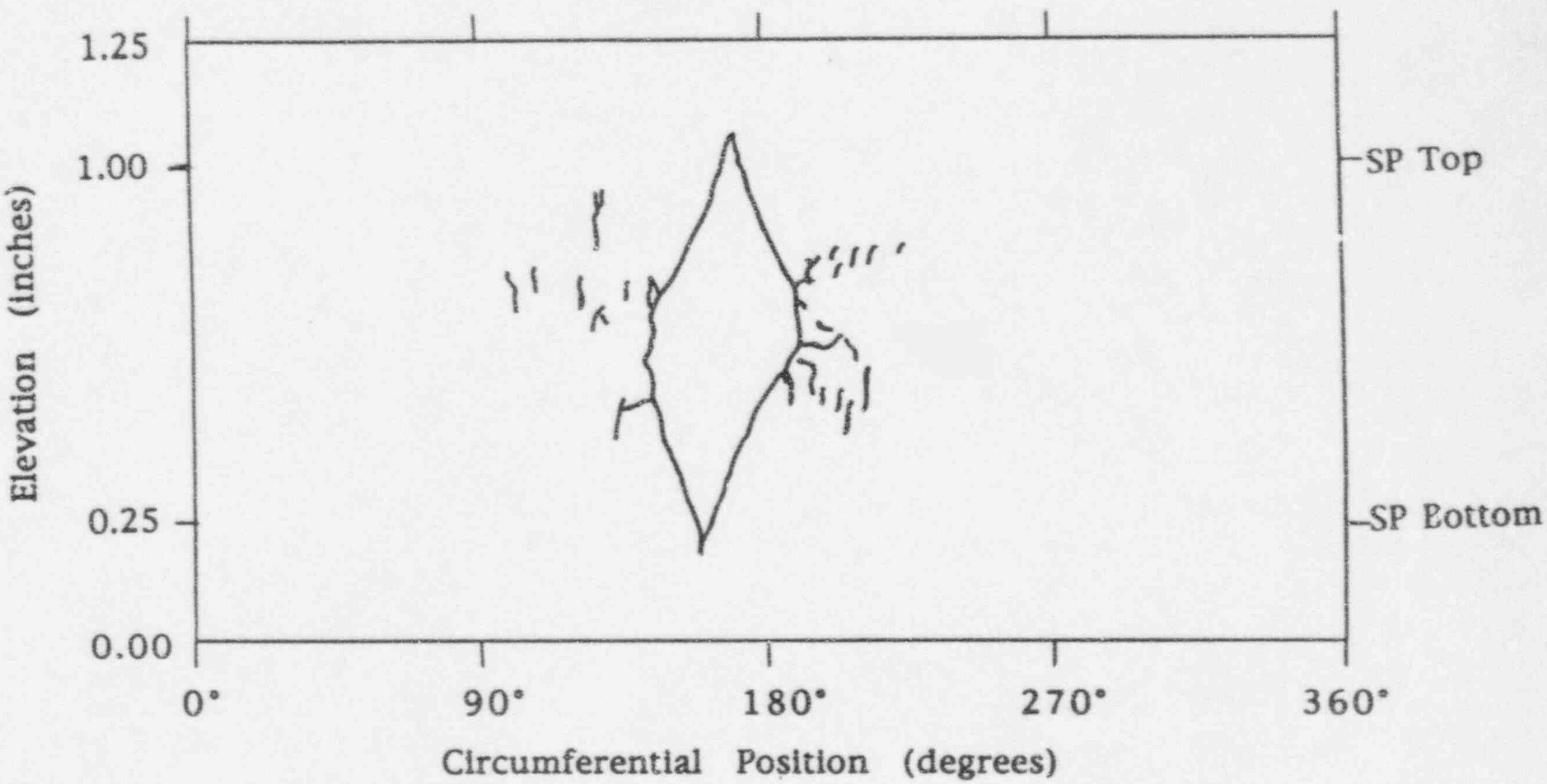


Figure 3-7 Sketch of the OD surface crack distribution found at the third tube support plate (TSP3) region of Tube R20-C!02. Also shown is the location of the burst fracture opening. The burst opening extended beyond the TSP crevice region, but the corrosion cracking on the burst fracture was confined to the crevice region.

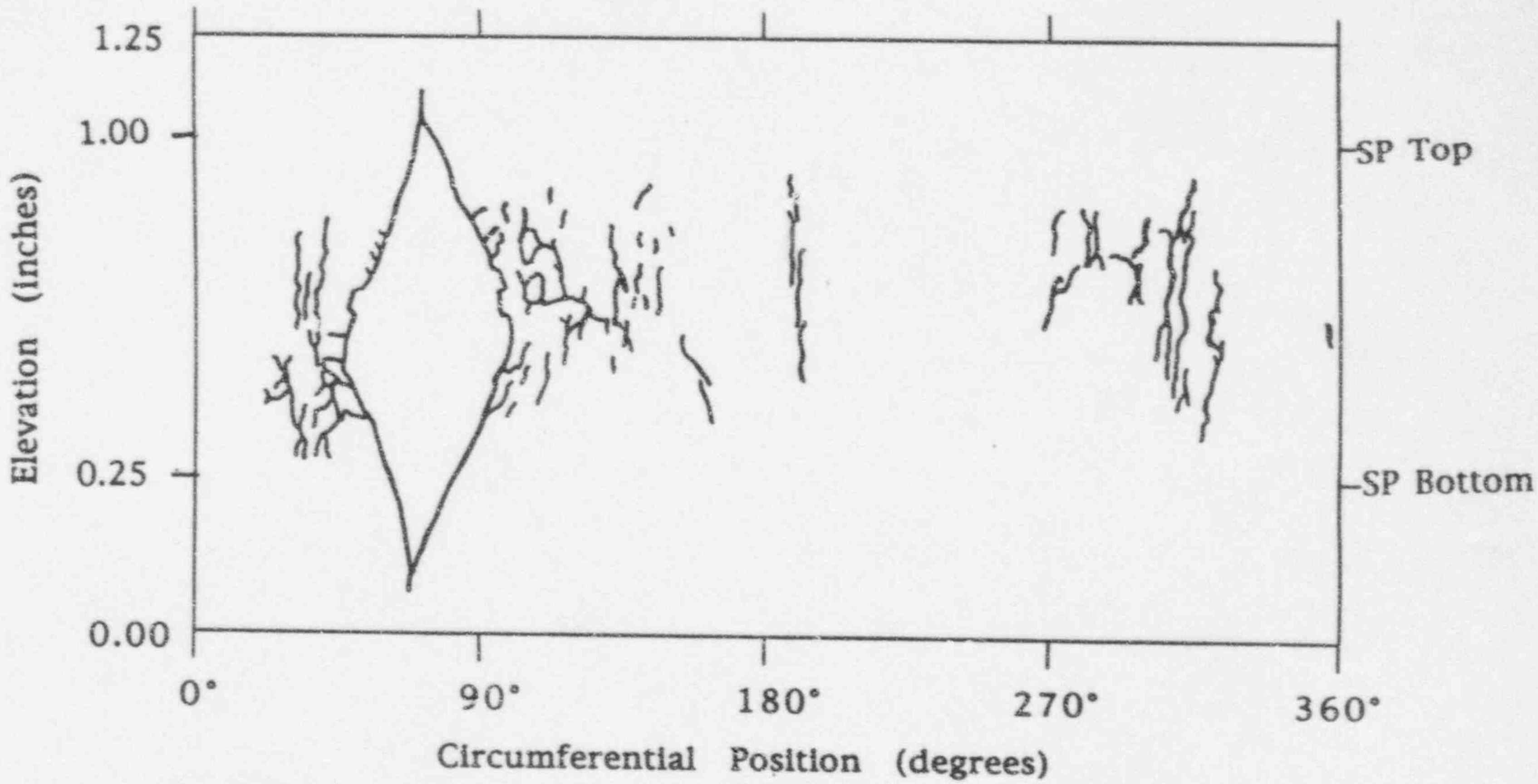


Figure 3-8 Sketch of the OD surface crack distribution found at the fifth tube support plate (TSP5) region of Tube R20-C102. Also shown is the location of the burst fracture opening. The burst opening extended beyond the TSP crevice region, but the corrosion cracking on the burst fracture was confined to the crevice region.

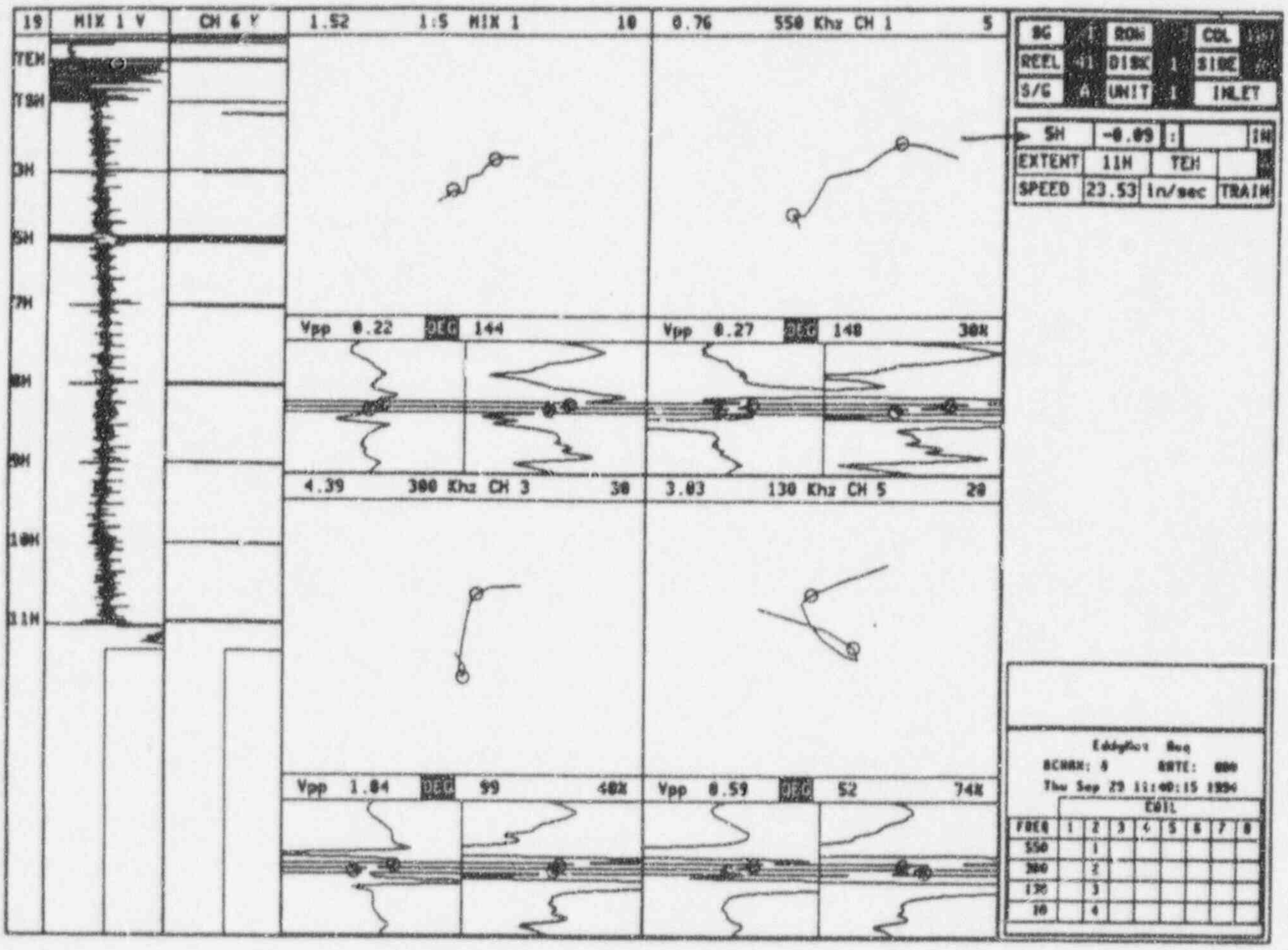


Figure 3-9. Laboratory Reevaluation of Field Bobbin Data for R3C107 5H

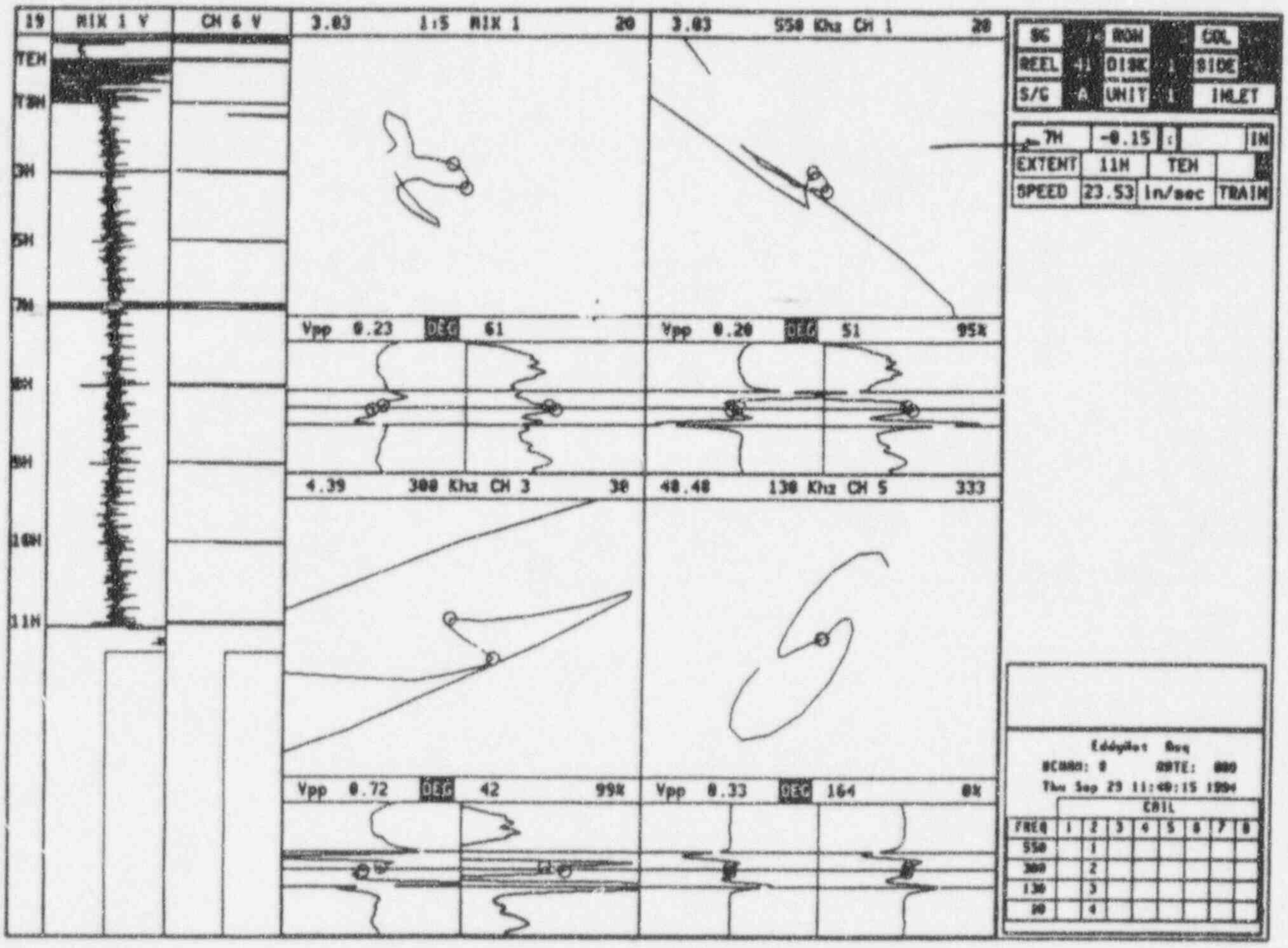


Figure 3-10. Laboratory Reevaluation of Field Bobbin Data for R3C107 7H

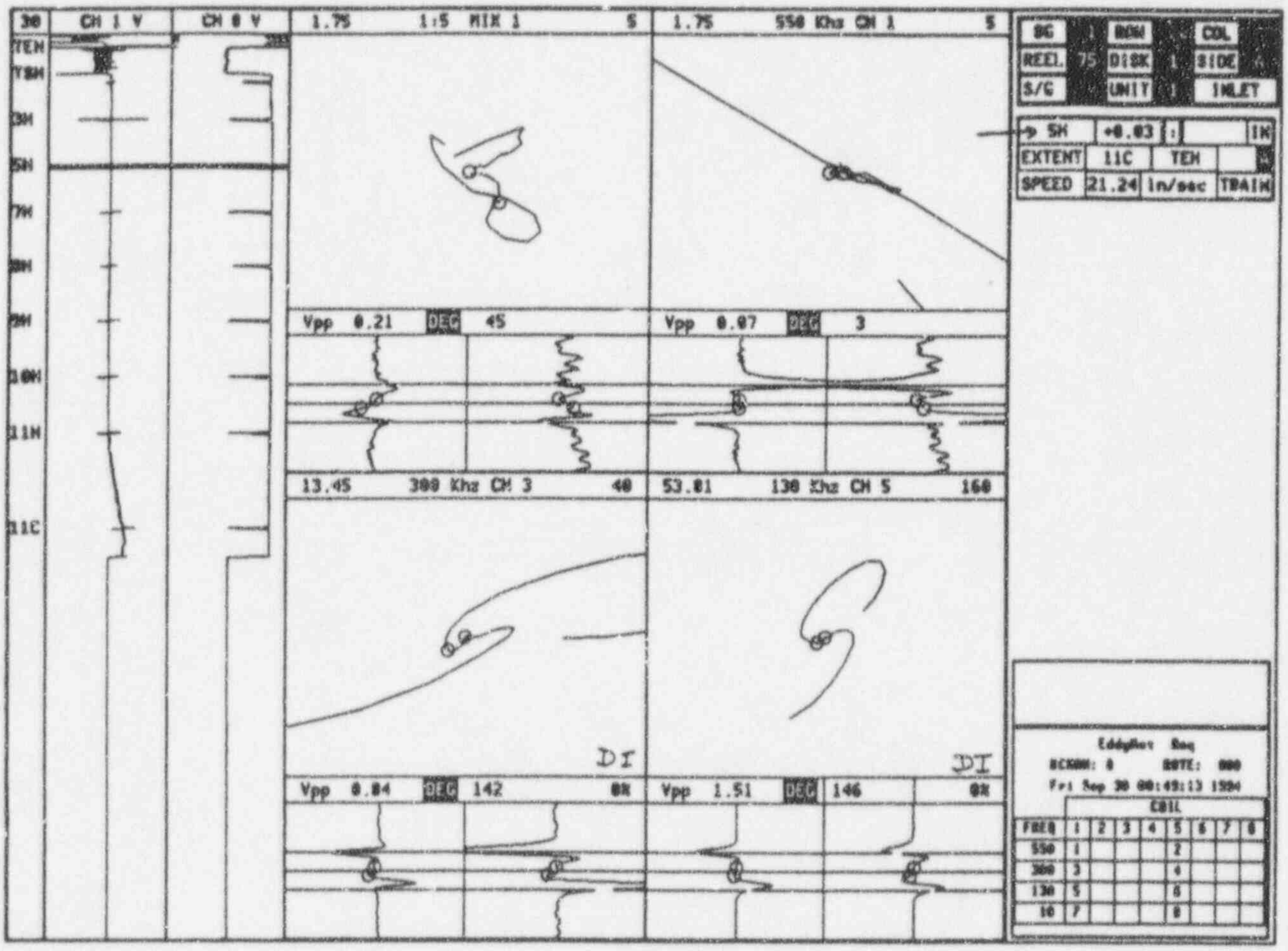


Figure 3-11. Laboratory Reevaluation of Field Bobbin Data for R20C7 5H

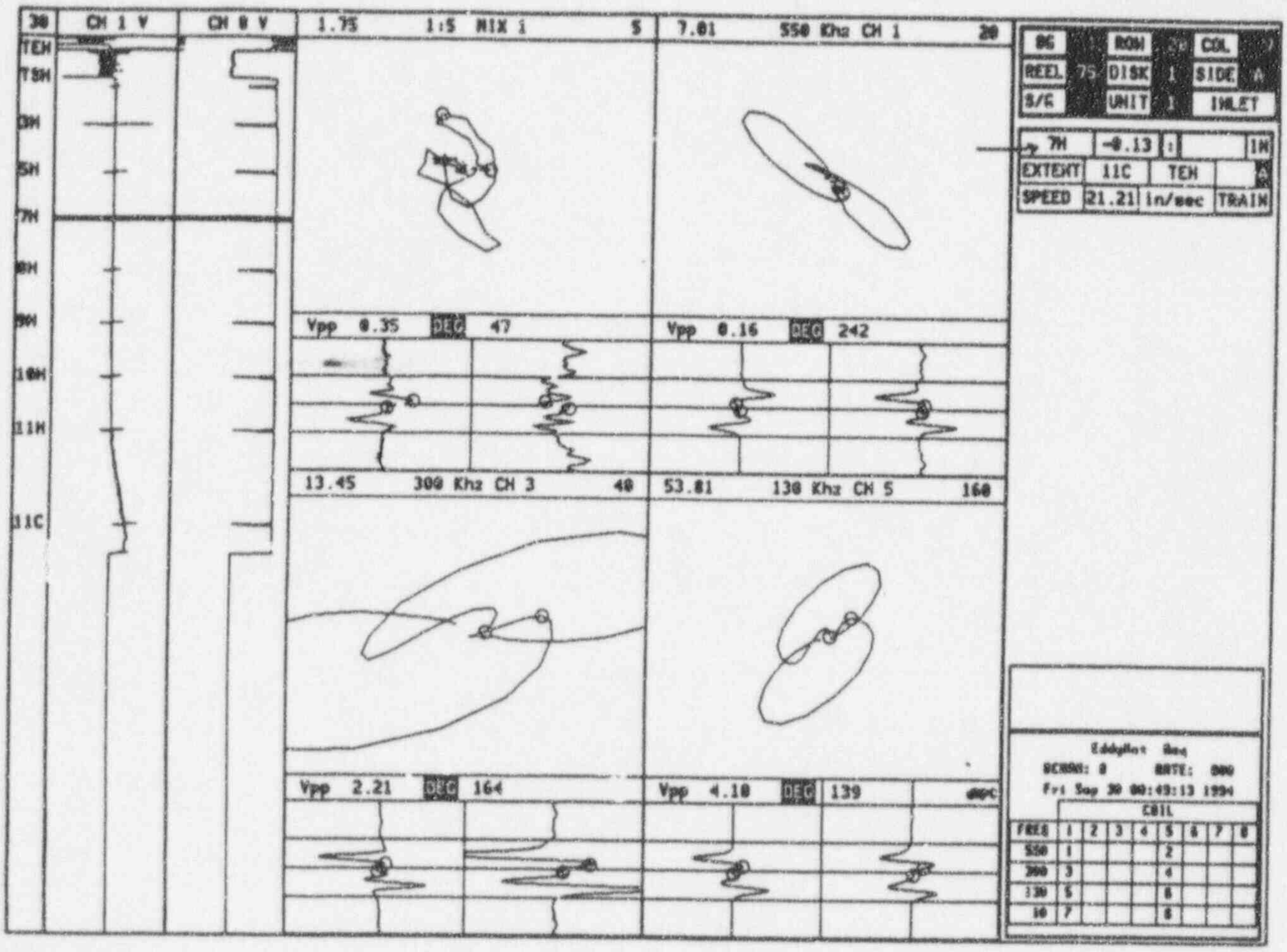


Figure 3-12. Laboratory Reevaluation of Field Bobbin Data for R20C7 7H

Figure 3-13
Comparison of 3/4" Leak Test Data with CRACKFLO Predictions

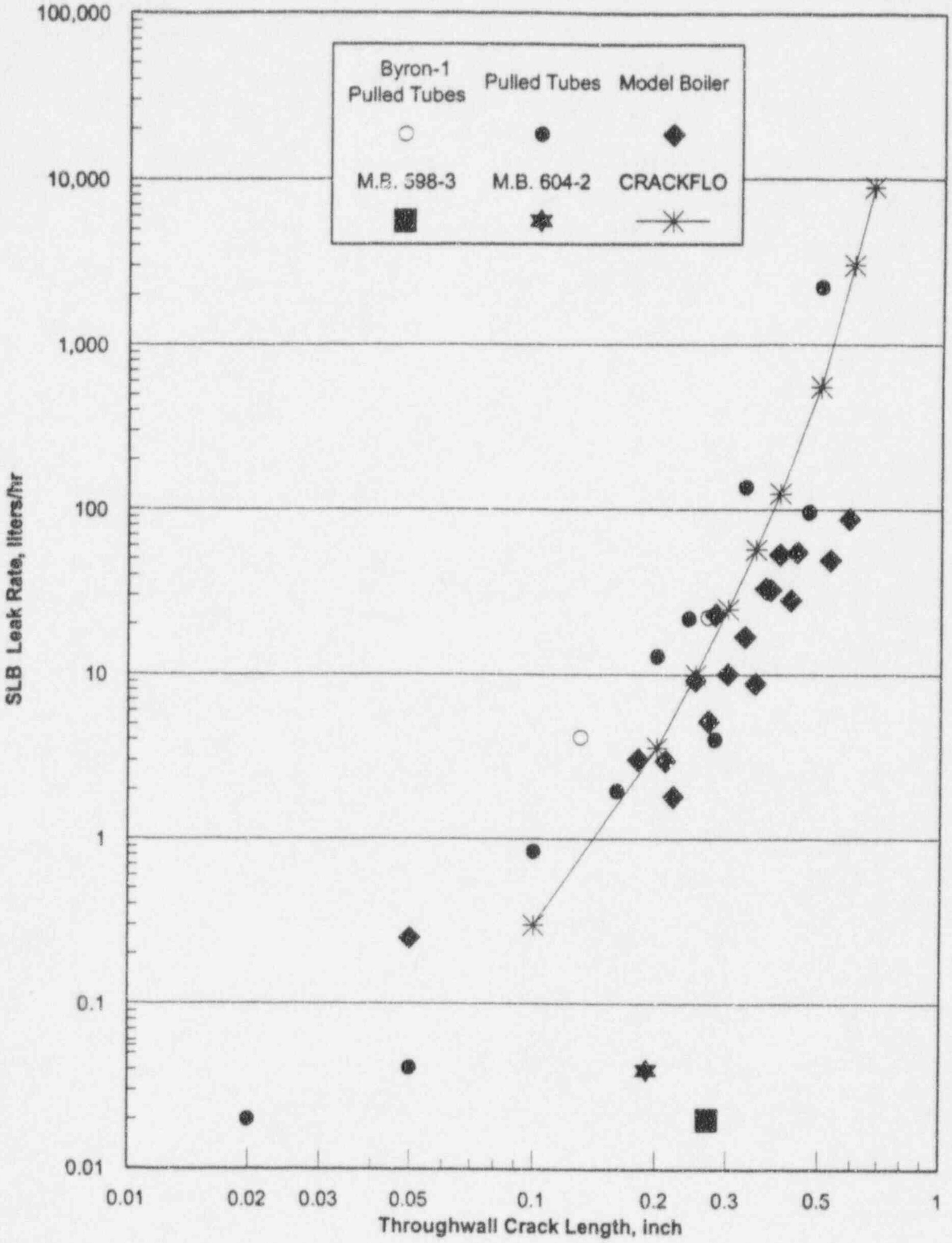


Figure 3-14: Burst Pressure vs Bobbin Amplitude

3/4" x 0.043" Alloy 600 MA SG Tubes (NRC Database @ 650°F)

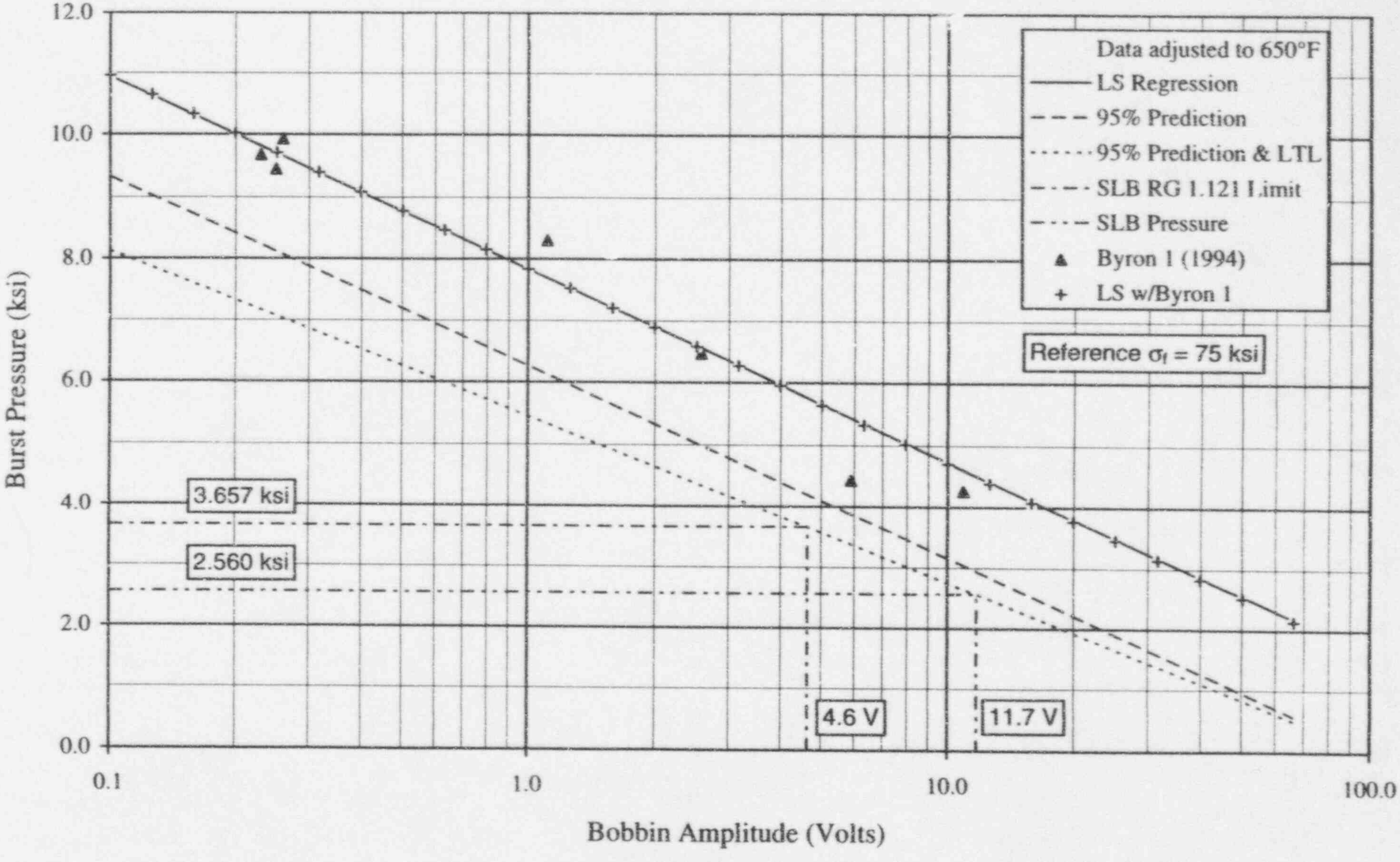
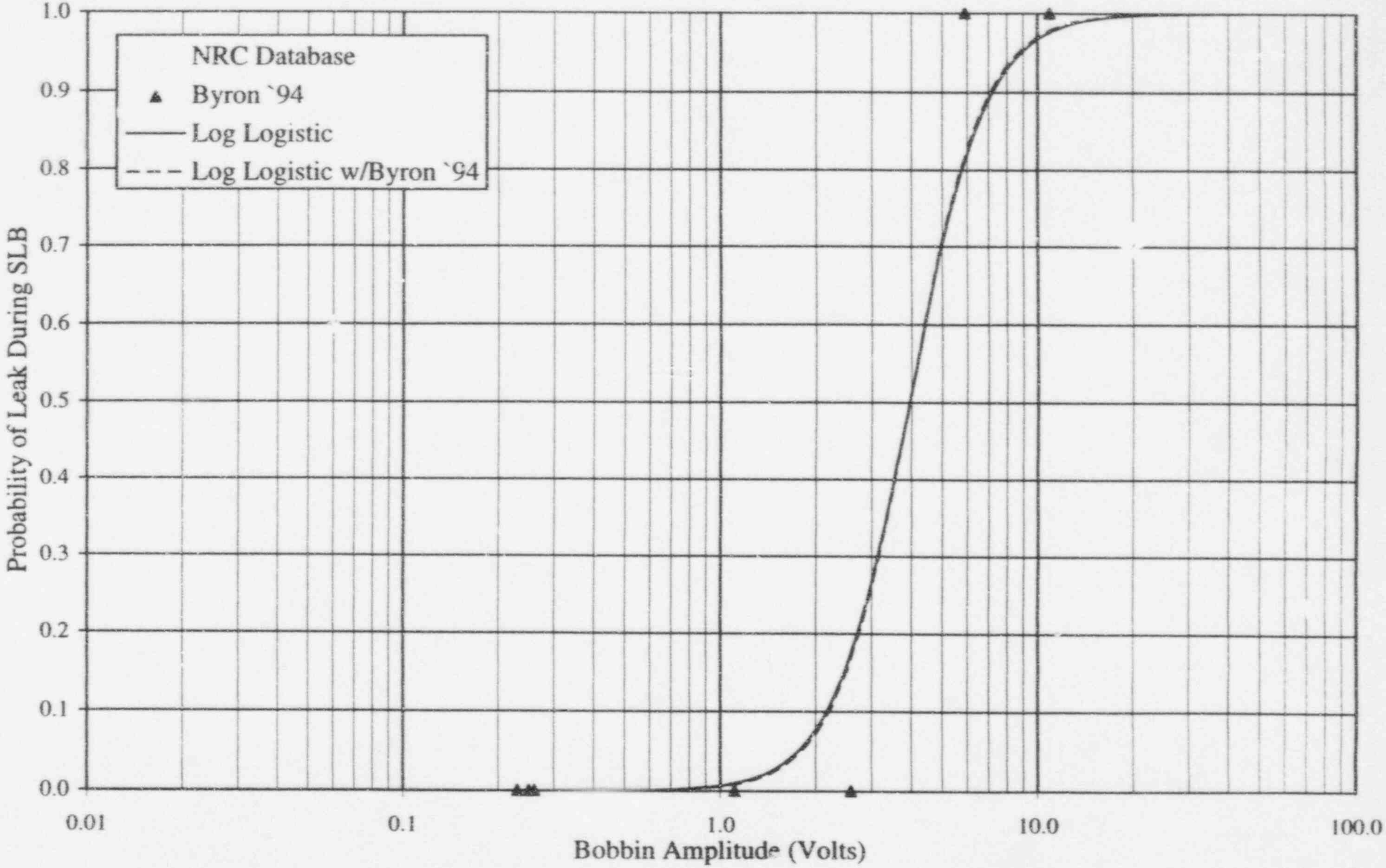


Figure 3-15: Probability of Leak for 3/4" SG Tubes @ 650°F, ΔP = 2560 psi

Comparison of Byron `94 Data with NRC Reference Database



[34PL_CAE.XLS] PoL.CAE

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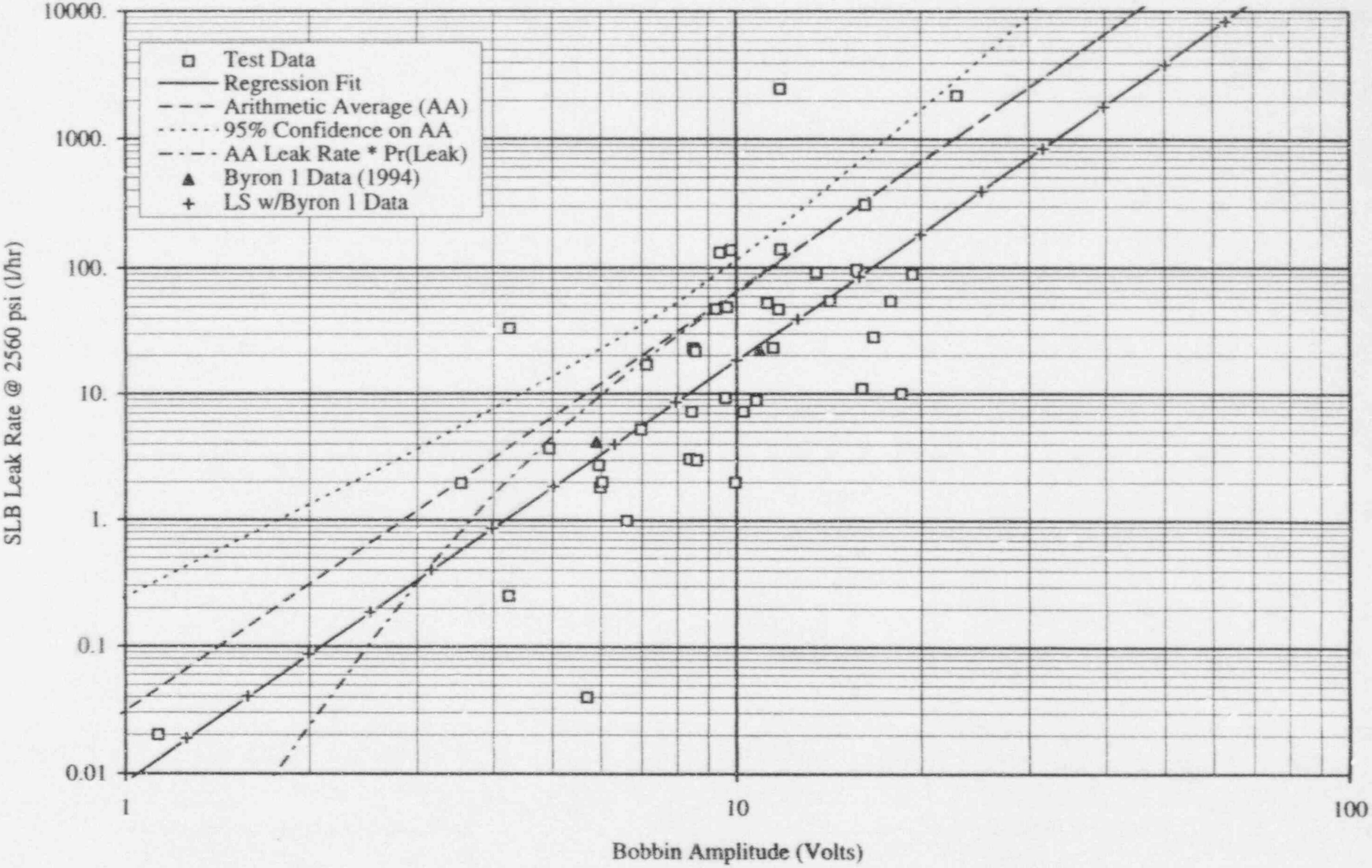
Figure 3-16: SLB Leak Rate vs. Bobbin Amplitude
3/4" x 0.043" Alloy 600 SG Tubes @ 650°F, ΔP = 2560 psi



4.0 EOC-6 INSPECTION RESULTS AND VOLTAGE GROWTH RATES

4.1 EOC-6 Inspection Results

4.1.1 Bobbin Coil Inspection

The Byron-1 EOC-6 inspection was performed in September, 1994, and was the first inspection implementing a 1.0-volt IPC. The prior, non-IPC inspection was performed in February 1993. Under the IPC guidelines for calibration, identification, and measurement of signal amplitudes, 100% of the tubes were inspected full length with bobbin EC probes. RPC examination was performed of all bobbin indications reported with amplitudes >1 volt to identify confirmed indications >1 volt and all indications >2.7 volts for repair. RPC examination was also performed for a significant number of signals less than 1 volt. The EOC-6 bobbin indications were all classified as distorted support indications (DSIs). Reviews were performed during the analysis of all dented TSP intersections (DNIs) to establish if the dented intersections contained flaw-like components. No bobbin or RPC indications were found at dented intersections. Dents are not included in the tabulations of this report. A number of indications reported at the EOC-5 inspection were not observed at EOC-6, and were therefore not included in the EOC-6 results.

The IPC analysis database differed from the final plant database by three small voltage indications. Two SG-C final plant indications were not included in the IPC database: R3C74 5H, a 0.53 volt indication RPC confirmed at 0.41 volts and not plugged; and R21C61 9H, a 0.52 volt signal which was not RPC examined and not plugged. A 0.63 volt indication at SG-C R19C58 9H which was not RPC examined and not plugged was included in the IPC database but should have been deleted. All of these signals are low voltage, and are therefore judged to have negligible effect on the results of the analyses in this report.

The distribution of the bobbin indications versus voltage at Byron-1 is provided in Table 4-1 and EOC-6 voltages are shown in the Figures 4-1a through 4-1e histograms. The bobbin indication voltages above about 3.2 volts are shown as discrete values, to reduce roundoff errors from binning. A total of 3075 ODSCC indications at TSP intersections were reported at EOC-6, of which 802 were in SG-A, 914 in SG-B, 899 in SG-C, and 460 in SG-D. Figure 4-1a shows the total number of bobbin indications for all four SGs, while Figures 4-1b through 4-1e show indications for each SG at EOC-6. SG-C, with 616 indications returned to service at BOC-7, is the limiting SG for SLB leakage analyses, as demonstrated by comparative analysis to SG-A in Section 8. The median voltage bin for SG-C was slightly higher than that of the overall distribution (0.7 volts vs. 0.6 volts).

Table 4-1 also shows the number of repaired indications. A total of 659 indications exceeded the approved 1.0 volt IPC repair limit for this inspection; all of these were RPC inspected and 535 were confirmed and repaired. In addition, 13 RPC NDF (no degradation found) indications above 1 volt (548-535), 113 RPC NDF indications (830-717), and a total of 295 indications (830-535) including RPC confirmed indications less than 1 volt were repaired because of other indications on the same tube requiring repair. Figures 4-2a and 4-2b illustrate the repaired indication distributions for all SGs and for SG-C.

Table 4-2 summarizes the EOC-6 indication bobbin voltages greater than 4.0 volts. RPC inspection results, voltages at the prior inspection and whether or not it is a new indication are also shown. The largest bobbin voltage indications found in 1994 were 10.95 volts in SG-C, 7.64, 7.10 and 5.92 volts in SG-A; 4.56 volts in SG-B; and 4.09 volts in SG-D. The 10.95 and 5.92 volt indications were included among the pulled tubes, and it was shown in Section 3 that the measured burst pressures for these indications exceeded the R.G. 1.121 structural margins. Thus tube integrity requirements were satisfied at EOC-6. None of the largest indications were reported in 1993 per the field analysis guidelines, and all were located at TSP 3H and were RPC confirmed in EOC-6. The largest bobbin indication of 10.95 volts, SG-C R20C7 3H, was RPC confirmed as a 4.59 volt MAI (multiple axial indication). Reanalysis of the EOC-5 EC tapes per the Appendix A analysis guidelines showed this indication as 1.09 volt.

The EC bobbin responses for SG-C R20C7 3H at BOC-6 and EOC-6 are shown in Figure 4-3 and the EOC-6 MRPC (multiple rotating pancake coil) trace is shown in Figure 4-4. The EOC-6 response for 3H in the 300/100 kHz mix channel gives a clear 10.95 volt indication. The MRPC response shows two closely spaced axial indications of comparable amplitude and a smaller amplitude indication. The BOC-6 response for this intersection in the mix channel produces a 1.09 volt indication. (Note: the Figure 4-3 voltage differs slightly from the reported value because of calibration/setup differences.) The '93 indication is distorted by a contribution from the mix residual.

4.1.2 Number of Indications vs. TSP Location

Table 4-3 provides a tabulation of the 3075 TSP ODSCC indications by TSP elevation, and Figure 4-5 provides a histogram displaying this information. For the Byron-1 Model D4 SGs, the 1H level represents the Flow Distribution Baffle (FDB), a plate with oversize tube holes and no flow holes. The interim plugging criteria are not applicable to this location per the draft generic letter guidance. Few indications are expected, and none were found in Byron-1 at EOC-6, at 1H because of the hole geometry. The support levels above the FDB are numbered in the cold leg order, i.e., the next hot leg TSP is 3H since its height corresponds to the 3rd preheater plate. The remaining TSPs are designated 5H, 7H, 8H, 9H, 10H, and 11H. There is an expected decreasing probability of encountering ODSCC signals with increasing hot leg tube support plate elevation, consistent with observations, since both the tube internal temperature and primary-to-secondary differential temperature decrease with higher elevation. 95% of all reported TSP ODSCC flaw indications at Byron-1 were found at the first three hot leg TSPs: 3H, 5H and 7H. No indications were found at cold leg TSPs.

4.1.3 Rotating Pancake Coil (RPC) Inspection

As mentioned above, all indications >1.0 volt in flaw signal amplitude, plus a number of smaller indications, were subjected to 3-coil RPC probe inspection. Consistent with the Appendix A requirements for RPC testing, overall objectives of the RPC testing were to (i) assess the consistency of the underlying tube condition with prior cases of TSP ODSCC, (ii) support the indications as ODSCC with small dents, (iii) identify that the indications were within the TSP, (iv) confirm the absence of circumferential indications, and (v) determine the

extent of the indication with respect to repair criteria. The RPC inspection met these objectives, in that it confirmed that all indications were axial ODSCC located within the TSPs. No indications were found by the RPC inspection of dented TSP intersections. At Byron-1, it is expected that the dent indications are mechanically induced dings rather than corrosion-induced denting.

Table 4-1 includes the distribution of RPC confirmed indications and repaired indications as well as the total bobbin voltage distribution, and Figure 4-6 shows the RPC confirmation rate for each bin as a percentage of indications examined. From Table 4-1 it can be seen that of 967 indications which were RPC tested, 717 were confirmed, a 74% confirmation rate. Above 1.0 volt, 535 of 659 indications or 81% of indications were RPC confirmed, while below 1.0 volt, 182 of 308 or 59% of indications were confirmed. All indications greater than 2.2 volts were RPC confirmed. Previous experience with inspections performed under IPC analysis guidelines show that these are relatively high confirmation rates.

Table 4-4 provides the same bobbin indication and repaired indication listings for EOC-6 as Table 4-1, but is supplemented by two columns which provide the distribution of indications returned to service in BOC-7. The first of these columns shows all indications returned to service, regardless of RPC confirmation. From this table, it can be seen that a 2.1 volt indication in SG-C is the largest indication (RPC NDF) which was returned to service, and that the total number of indications returned to service was 2245 for all SGs, and 616 for SG-C. The next column of Table 4-4 provides the list of RPC confirmed or not RPC inspected indications which were returned to service. This distribution is reduced from that of the prior column, since it excludes RPC NDF indications. All confirmed indications greater than 1.0 volt are repaired, so no indications greater than 1.0 volt are present in this distribution. Since RPC NDF indications are not expected to contribute appreciably to the leak rate or burst probability over the next cycle, this provides the more relevant BOC distribution. Figures 4-7 and 4-8 illustrate the Table 4-4 distributions of indications returned to service for all SGs, and for SG-C, respectively.

4.2 Voltage Growth Rates

The Cycle 6 voltage growth rates were developed from the September, 1994 (EOC-6) field analysis data and by analyst review of the February, 1993 data (EOC-5) for the same indications. The Byron/Braidwood inspection guidelines were enhanced to increase detectability of flaws and reduce voltage variability. These guidelines included cross-calibration of the field ASME standards to the reference laboratory standard. The Byron/Braidwood guidelines were prepared by CECo consistent with Appendix A of V. C. Summer WCAP-13522 with exceptions specified in the Byron IPC submittals and supplemental information. Growth rates were developed for all potential flaws. The growth rate analysis was performed in accordance with guidance of the draft generic letter in that growth rates were not calculated for the 1993 indications which were reanalyzed as NDD. For this reason, the total number of voltage growth values (2851) is smaller than the total number of EOC-6 indications (3075).

Average growth rates were calculated as a percentage of the beginning of cycle voltage for all SGs and also as a composite for Cycle 6, and as a composite for plugged tubes for Cycles 4 and 5. The values are shown in Table 4-5. The Cycle 6 composite value of 67% is similar to the Cycle 4 and 5 values of 80% and 68%, although the Cycle 4 and 5 data are for plugged tubes only and are therefore expected to be higher than for the entire population of Cycle 4 and 5 indications. SG-A experienced the largest growth rates during Cycle 6, an average of 117%, while SG-D, -C and -B values followed at 69%, 66% and 39%, respectively. In all cases, percentage growth rates were significantly lower for BOC voltages above 0.75 volts than for those below 0.75 volts. SG-A indications above 0.75 volts experienced the largest differential voltage growths, averaging 0.58 volts over 58 indications. This value is skewed by three large growth values for SG-A with BOC voltages >0.75 volts, shown in Table 4-6.

Voltage growth distributions, shown in Table 4-7, were developed for each of the four SGs. Figure 4-9 illustrates the cumulative growth distribution for each SG, and Figure 4-10 illustrates the binned growth data by SG. SG-A had the largest average growth rate and the most conservative cumulative probability distribution, except for the upper end of the distribution. SG-C growth was the next higher distribution, but was higher than SG-A at the upper end due to SG-C R20C7 3H, which had the largest Cycle 6 growth value of 9.86 volts. This growth was determined from an EOC-6 voltage of 10.95 volts and BOC voltage of 1.09 volts. This intersection was pulled and metallurgical results were described in Section 3. Three other Table 4-6 growth values, all in SG-A, were larger than 5.0 volts. All of the largest growths were new indications, i.e., not reported at EOC-5. The voltage growth distributions were modified prior to use in the voltage projections in that negative growth rates, i.e., the values in bins less than 0.0 volts, were added to the 0.0 volt bin. In effect, this changed negative growth values into a zero growth value. It can thus be seen in Table 4-7 that the cumulative probability for SG-C voltage growths is 16.3%,

Figure 4-10 provides a histogram of the growth results. The median growth bin was 0.2 volts for all SGs, except for SG-C, where it was 0.3 volts. Cycle 6 was reported to be 466.5 EFPD in length; no cycle length adjustments are made to the growth values reported in this section. Adjustments to the Cycle 6 growth distribution for Cycle 7 length are, however, included in the EOC-7 projections (see Section 8). Figure 4-11 provides a histogram of the voltage growth and a cumulative distribution of voltage growths for all SGs. Figure 4-12 provides the same information for SG-C only.

As mentioned in the discussion of the average growth values in Table 4-5, differential voltage growth rates tend to decrease for higher BOC voltages; Figure 4-13 illustrates this trend for Byron-1 Cycle 6. The negative slope in this BOC voltage versus voltage growth scatter plot provides lower percentage growth rates for indications with higher BOC voltages.

4.3 NDE Uncertainties

The NDE uncertainty was provided in Reference 11.8, EPRI Report TR-100407, Revision 1 (Draft of August 1993), and this EPRI NDE uncertainty is applied for Cycle 6 at Byron-1.

The NDE uncertainty is principally due to probe wear with a standard deviation of approximately 7% about a mean of zero and analyst variability with a standard deviation of 10.3%. These distributions are applied as normal distributions and combined to obtain a net NDE uncertainty of 12.5% for one standard deviation. The upper bound on the probe wear uncertainty is limited to 15% by the Byron-1 IPC requirement to replace the bobbin probes when measurements on the probe wear standard for a worn probe differ from that found for the new probe by 15%. The upper bound on the analyst variability uncertainty would be limited to 20% by the eddy current analysis guidelines which require lead analyst resolution of bobbin voltages (with one or more reported above 1.0 volt) differing between analysts by more than 20%. However, as of the February 3, 1994, NRC/Industry meeting the NRC has not accepted the 20% cutoff on the analyst variability uncertainty. Pending a further resolution of this issue with the NRC, the analyst uncertainty is applied without a cutoff for the EOC voltage projections performed in this report. For EOC voltage projections, separate distributions of 7% with a cutoff at 15% for probe wear and 10.3% with no cutoff for analyst variability are applied in this report. These NDE uncertainty distributions are shown in Figure 4-14. Additional discussion on application of the NDE uncertainty is included in Reference 11.5.

4.4 Distributions Requested by Draft Generic Letter

Paragraph 6.b of Enclosure 1 to Draft Generic Letter 94-XX describes the information to be provided within 90 days of each restart following a steam generator inspection. Among these requirements, the following distributions are requested in both graphical and tabular form:

- (i) EOC voltage distribution - all indications found during the inspection regardless of MRPC confirmation
- (ii) Cycle voltage growth rate distribution (i.e., from BOC to EOC)
- (iii) Voltage distribution for EOC repaired indications - distribution of indications presented in (i) above that were repaired (i.e., plugged or sleeved)
- (iv) Voltage distribution for indications left in service at the beginning of the next operating cycle regardless of MRPC confirmation - obtained from (i) and (iii) above
- (v) Voltage distribution for indications left in service at the beginning of cycle that were confirmed by MRPC to be crack-like or not MRPC inspected
- (vi) non-destructive examination uncertainty distribution used in predicting the EOC (for the next cycle of operation) voltage distribution

Table 4-9 lists these reporting requirements and the corresponding section of this report where the information is located.

Table 4-1. Byron 1 EOC-6 (10/94) Comparison of PIs Found at TSPs, Confirmed by RPC, and Indications Repaired																				
	Steam Generator A				Steam Generator B				Steam Generator C				Steam Generator D				All Steam Generators			
'94 Volts	No. of Bobbin Indications	No. of Indications Examined	No. of Indications Confirmed	No. of Indications Repaired	No. of Bobbin Indications	No. of Indications Examined	No. of Indications Confirmed	No. of Indications Repaired	No. of Bobbin Indications	No. of Indications Examined	No. of Indications Confirmed	No. of Indications Repaired	No. of Bobbin Indications	No. of Indications Examined	No. of Indications Confirmed	No. of Indications Repaired	No. of Bobbin Indications	No. of Indications Examined	No. of Indications Confirmed	No. of Indications Repaired
0.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0.2	4	0	0	0	1	0	0	0	6	0	0	0	4	0	0	0	9	0	0	0
0.3	57	7	3	6	14	1	0	0	13	0	0	0	27	1	0	0	111	9	3	6
0.4	105	16	9	16	49	7	3	6	45	3	1	5	65	3	1	1	264	29	14	28
0.5	105	13	6	10	94	8	2	6	92	4	2	6	82	4	2	4	373	29	12	26
0.6	106	17	7	15	134	11	6	8	95	4	2	7	57	7	5	6	[illegible]	39	20	36
0.7	82	18	14	15	118	20	13	17	130	18	11	25	60	5	4	4	390	61	42	61
0.8	73	14	7	13	121	16	12	15	116	19	12	21	48	3	2	3	358	52	33	52
0.9	66	23	11	10	92	11	8	9	89	9	6	9	28	0	0	0	275	43	25	36
1.0	47	16	13	11	81	10	7	8	92	19	12	17	24	1	1	1	244	46	33	37
1.1	34	34	31	31	68	68	54	56	59	59	47	47	19	19	12	12	180	180	144	146
1.2	31	31	24	25	46	46	36	36	40	40	26	30	13	13	7	7	130	130	93	98
1.3	28	[illegible]	22	23	30	30	25	25	33	33	27	27	12	12	7	7	103	103	81	82
1.4	18	18	15	17	29	29	20	20	26	26	24	24	4	4	4	4	77	77	63	65
1.5	6	6	4	4	12	12	9	9	17	17	16	16	12	12	10	10	47	47	39	39
1.6	6	6	4	5	7	7	7	7	10	10	9	9	0	0	0	0	23	23	[illegible]	21
1.7	4	4	4	4	4	4	4	4	13	13	11	12	2	2	[illegible]	2	23	23	21	22
1.8	4	4	3	4	3	3	3	3	8	8	8	8	1	1	1	1	16	16	15	16
1.9	4	4	4	4	1	1	1	1	4	4	4	4	0	0	0	0	9	9	9	9
2.0	5	5	5	5	1	1	1	1	4	4	4	4	0	0	0	0	10	10	10	10
2.1	2	2	2	2	1	1	1	1	2	2	1	1	0	0	0	0	5	5	4	4
2.2	3	3	3	3	0	0	0	0	1	1	1	1	0	0	0	0	4	4	4	4
2.3	1	1	1	1	2	2	2	2	1	1	1	1	0	0	0	0	4	4	4	4
2.4	2	2	2	2	0	0	0	0	1	1	1	1	0	0	0	0	3	3	3	3
2.5	1	1	1	1	2	2	2	2	2	2	2	2	0	0	0	0	5	5	5	5
2.6	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	3	3	3	3
2.7	0	0	0	0	1	1	1	1	2	2	2	2	0	0	0	0	3	3	3	3
3.1	2	2	2	2	1	1	1	1	0	0	0	0	0	0	0	0	3	3	3	3
3.2	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1
3.37	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1
3.64	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	1	1	1	1
3.80	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	1	1	1	1
3.98	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1
4.09	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1
4.56	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	1	1	1	[illegible]
5.92	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1
7.10	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1
7.64	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1
10.95	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	1	1	1	1
Total	802	281	203	243	914	294	220	240	899	303	234	283	460	89	60	64	3075	967	717	830
Total > 1V	157	157	133	139	210	210	169	171	227	227	188	193	65	65	45	45	659	659	535	548

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Table 4-2

Byron-1: Largest EOC-6 TSP Indication Voltages (Indications >4.0V)

S/G	Row	Column	TSP	EOC-6 Bobbin Volts	EOC-6 RPC Volts	BOC-6 Voltage	New Indication?
C	20	7	03H	10.95	4.59	1.09	Yes
A	3	3	03H	7.64	5.74	0.93	Yes
A	20	7	03H	7.10	3.69	1.14	Yes
A	3	107	03H	5.92	4.03	0.44	Yes
B	20	104	03H	4.56	1.97	0.91	Yes
D	25	38	03H	4.09	3.81	0.35	Yes

Table 4-3

Byron-1: No. of EOC-6 ODSCC Indications vs. TSP Location

TSP	SG-A	SG-B	SG-C	SG-D	Total	% of Total
03H	416	603	605	303	1927	62.7%
05H	219	225	253	113	810	26.3%
07H	96	47	17	28	188	6.1%
08H	42	30	16	3	91	3.0%
09H	23	9	6	7	45	1.5%
10H	6	0	0	3	9	0.3%
11H	0	0	2	3	5	0.2%
Total	802	914	899	460	3075	

Table 4-4. Byron 1 EOC-6 (10/94) Indications Returned to Service: All Indications and RPC Confirmed or Not RPC Inspected Indications

	Steam Generator A				Steam Generator B				Steam Generator C				Steam Generator D				All Steam Generators			
'94 Volts	No. of Bobbin Indications	No. of Indications Repaired	No. of Indications Returned to Service	Confirmed or Not Insp. Indications Ret. to Svc.	No. of Bobbin Indications	No. of Indications Repaired	No. of Indications Returned to Service	Confirmed or Not Insp. Indications Ret. to Svc.	No. of Bobbin Indications	No. of Indications Repaired	No. of Indications Returned to Service	Confirmed or Not Insp. Indications Ret. to Svc.	No. of Bobbin Indications	No. of Indications Repaired	No. of Indications Returned to Service	Confirmed or Not Insp. Indications Ret. to Svc.	No. of Bobbin Indications	No. of Indications Repaired	No. of Indications Returned to Service	Confirmed or Not Insp. Indications Ret. to Svc.
0.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0.2	4	0	4	4	1	0	1	1	0	0	0	0	4	0	4	4	9	0	9	9
0.3	57	6	51	51	14	0	14	13	13	0	13	13	27	0	27	26	111	6	105	103
0.4	105	16	89	88	49	6	43	41	45	5	40	39	65	1	64	62	264	28	236	230
0.5	105	10	95	93	94	6	88	85	92	6	86	85	82	4	78	76	373	26	347	339
0.6	106	15	91	88	134	8	126	124	95	7	88	88	57	6	51	50	392	36	356	350
0.7	82	15	67	66	118	17	101	100	130	25	105	103	60	4	56	55	390	61	329	324
0.8	73	13	60	59	121	15	106	105	116	21	95	94	48	3	45	44	358	52	306	302
0.9	66	18	48	43	92	9	83	81	89	9	80	78	28	0	28	28	275	36	239	230
1.0	47	11	36	34	81	8	73	71	92	17	75	71	24	1	23	23	244	37	207	199
1.1	34	31	3	0	68	56	12	0	59	47	12	0	19	12	7	0	180	146	34	0
1.2	31	25	6	0	46	36	10	0	40	30	10	0	13	7	6	0	130	98	32	0
1.3	28	23	5	0	30	25	5	0	33	27	6	0	12	7	5	0	103	82	21	0
1.4	18	17	1	0	29	20	9	0	26	24	2	0	4	4	0	0	77	65	12	0
1.5	6	4	2	0	12	9	3	0	17	16	1	0	12	10	2	0	47	39	8	0
1.6	6	5	1	0	7	7	0	0	10	9	1	0	0	0	0	0	23	31	2	0
1.7	4	4	0	0	4	4	0	0	13	12	1	0	2	2	0	0	23	22	1	0
1.8	4	4	0	0	3	3	0	0	8	8	0	0	1	1	0	0	16	16	0	0
1.9	4	4	0	0	1	1	0	0	4	4	0	0	0	0	0	0	9	9	0	0
2.0	5	5	0	0	1	1	0	0	4	4	0	0	0	0	0	0	10	10	0	0
2.1	2	2	0	0	1	1	0	0	2	1	1	0	0	0	0	0	5	4	1	0
2.2	3	3	0	0	0	0	0	0	1	1	0	0	0	0	0	0	4	4	0	0
2.3	1	1	0	0	2	2	0	0	1	1	0	0	0	0	0	0	4	4	0	0
2.4	2	2	0	0	0	0	0	0	1	1	0	0	0	0	0	0	3	3	0	0
2.5	1	1	0	0	2	2	0	0	2	2	0	0	0	0	0	0	5	5	0	0
2.6	1	1	0	0	1	1	0	0	1	1	0	0	0	0	0	0	3	3	0	0
2.7	0	0	0	0	1	1	0	0	2	2	0	0	0	0	0	0	3	3	0	0
3.1	2	2	0	0	1	1	0	0	0	0	0	0	0	0	0	0	3	3	0	0
3.2	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	1	1	0	0
3.37	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0
3.64	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	1	1	0	0
3.80	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	1	1	0	0
3.98	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0
4.09	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	1	1	0	0
4.56	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	1	1	0	0
5.92	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0
7.10	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0
7.64	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0
10.95	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	1	1	0	0
Total	802	243	559	526	914	240	674	621	899	283	616	571	460	64	396	368	3075	830	2245	2086
Total > 1V	157	139	18	0	210	171	39	0	227	193	34	0	65	45	20	0	659	548	111	0

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Table 4-5. Average Voltage Growth Per Cycle for Byron-1

Cycle	Total No. of TSP Indications	Average BOC Voltage	Average ΔV per Cycle	Percent Growth per Cycle
Cycles 4 and 5 (Plugged Tubes Only):				
Cycle 4: 1990 to 1991 All Indications	550	0.32	0.26	80%
Cycle 5: 1991 to 1993 All Indications	532	0.46	0.31	68%
Cycle 6: '93-'94				
SG-A All Indications $V_{BOC} <$ 0.75V $V_{BOC} \geq$ 0.75V	 785 727 58	 0.35 0.30 1.03	 0.41 0.40 0.58	 117% 134% 56%
SG-B All Indications $V_{BOC} <$ 0.75V $V_{BOC} \geq$ 0.75V	 777 555 222	 0.59 0.44 0.98	 0.23 0.29 0.09	 39% 65% 9%
SG-C All Indications $V_{BOC} <$ 0.75V $V_{BOC} \geq$ 0.75V	 842 682 160	 0.52 0.41 1.00	 0.34 0.38 0.19	 66% 93% 19%
SG-D All Indications $V_{BOC} <$ 0.75V $V_{BOC} \geq$ 0.75V	 447 413 34	 0.40 0.35 0.98	 0.27 0.29 0.06	 69% 83% 6%
All SGs All Indications $V_{BOC} <$ 0.75V $V_{BOC} \geq$ 0.75V	 2851 2377 474	 0.47 0.37 0.99	 0.32 0.35 0.18	 67% 94% 18%

Table 4-6

Byron-1: Largest Cycle 6 Voltage Growths (Values >2.5V)

SG	Row	Column	TSP	EOC-6 Bobbin Volts	EOC-6 RPC Volts	BOC-6 Voltage	Voltage Growth	New Indication?
C	20	7	03H	10.95	4.59	1.09	9.86	Yes
A	3	3	03H	7.64	5.74	0.93	6.71	Yes
A	20	7	03H	7.10	3.69	1.14	5.96	Yes
A	3	107	03H	5.92	4.03	0.44	5.48	Yes
D	25	38	03H	4.09	3.81	0.35	3.74	Yes
B	20	104	03H	4.56	1.97	0.91	3.65	Yes
C	32	30	03H	3.64	2.32	0.68	2.96	Yes
C	25	13	05H	3.80	2.36	0.93	2.87	Yes
A	16	8	03H	3.98	1.76	1.29	2.69	Yes
B	37	28	05H	2.66	1.66	0.15	2.51	Yes

Table 4-7
Byron-1 Cycle 6 Growth Distribution by SG
(2851 Total Indications)

BIN	SG-A			SG-B			SG-C			SG-D		
	No.	Cum. No.	Cum. %	No.	Cum. No.	Cum. %	No.	Cum. No.	Cum. %	No.	Cum. No.	Cum. %
-0.70	0	0	0.0%	0	0	0.0%	0	0	0.0%	0	0	0.0%
-0.60	1	1	0.1%	0	0	0.0%	0	0	0.0%	0	0	0.0%
-0.50	2	3	0.4%	0	0	0.0%	0	0	0.0%	0	0	0.0%
-0.40	0	3	0.4%	2	2	0.3%	7	7	0.8%	0	0	0.0%
-0.30	4	7	0.9%	20	22	2.8%	11	18	2.1%	5	5	1.1%
-0.20	6	13	1.7%	23	45	5.8%	17	35	4.2%	7	12	2.7%
-0.10	12	25	3.2%	39	84	10.8%	41	76	9.0%	19	31	6.9%
0.00	21	46	5.9%	69	153	19.7%	61	137	16.3%	26	57	12.8%
0.10	73	119	15.2%	123	276	35.5%	101	238	28.3%	74	131	29.3%
0.20	128	247	31.5%	149	425	54.7%	99	337	40.0%	79	210	47.0%
0.30	121	368	46.9%	97	522	67.2%	107	444	52.7%	61	271	60.6%
0.40	112	480	61.1%	86	608	78.2%	99	543	64.5%	73	344	77.0%
0.50	83	563	71.7%	49	657	84.6%	80	623	74.0%	33	377	84.3%
0.60	53	616	78.5%	45	702	90.3%	76	699	83.0%	23	400	89.5%
0.70	47	663	84.5%	33	735	94.6%	36	735	87.3%	11	411	91.9%
0.80	42	705	89.8%	14	749	96.4%	32	767	91.1%	8	419	93.7%
0.90	23	728	92.7%	9	758	97.6%	18	785	93.2%	10	429	96.0%
1.00	18	746	95.0%	6	764	98.3%	14	799	94.9%	11	440	98.4%
1.10	10	756	96.3%	2	766	98.6%	17	816	96.9%	2	442	98.9%
1.20	6	762	97.1%	1	767	98.7%	5	821	97.5%	0	442	98.9%
1.30	4	766	97.6%	2	769	99.0%	5	826	98.1%	2	444	99.3%
1.40	1	767	97.7%	2	771	99.2%	1	827	98.2%	0	444	99.3%
1.50	3	770	98.1%	0	771	99.2%	1	828	98.3%	1	445	99.6%
1.60	2	772	98.3%	1	772	99.4%	1	829	98.5%	0	445	99.6%
1.70	2	774	98.6%	1	773	99.5%	5	834	99.0%	0	445	99.6%
1.80	1	775	98.7%	0	773	99.5%	1	835	99.2%	0	445	99.6%
1.90	3	778	99.1%	1	774	99.6%	1	836	99.3%	0	445	99.6%
2.00	1	779	99.2%	1	775	99.7%	0	836	99.3%	0	445	99.6%
2.10	2	781	99.5%	0	775	99.7%	1	837	99.4%	0	445	99.6%
2.20	0	781	99.5%	0	775	99.7%	2	839	99.6%	0	445	99.6%
2.30	0	781	99.5%	0	775	99.7%	0	839	99.6%	1	446	99.8%
2.40	0	781	99.5%	0	775	99.7%	0	839	99.6%	0	446	99.8%
2.50	0	781	99.5%	0	775	99.7%	0	839	99.6%	0	446	99.8%
2.60	0	781	99.5%	1	776	99.9%	0	839	99.6%	0	446	99.8%
2.70	1	782	99.6%	0	776	99.9%	0	839	99.6%	0	446	99.8%
2.90	0	782	99.6%	0	776	99.9%	1	840	99.8%	0	446	99.8%
3.00	0	782	99.6%	0	776	99.9%	1	841	99.9%	0	446	99.8%
3.70	0	782	99.6%	1	777	100.0%	0	841	99.9%	0	446	99.8%
3.80	0	782	99.6%	0	777	100.0%	0	841	99.9%	1	447	100.0%
5.50	1	783	99.7%	0	777	100.0%	0	841	99.9%	0	447	100.0%
6.00	1	784	99.9%	0	777	100.0%	0	841	99.9%	0	447	100.0%
6.80	1	785	100.0%	0	777	100.0%	0	841	99.9%	0	447	100.0%
9.90	0	785	100.0%	0	777	100.0%	1	842	100.0%	0	447	100.0%

Note: Negative growth rates are included in the Monte Carlo projection growth distribution as zero growth values, i.e., in the 0.0 volt bin.

Table 4-8
Probe Wear and Analyst Variability - Tabulated Values

Analyst Variability Std. Dev = 10.3% Mean = 0.0% No Cutoff	
Value	Cumul. Prob.
-40.0%	0.00005
-38.0%	0.00011
-36.0%	0.00024
-34.0%	0.00048
-32.0%	0.00095
-30.0%	0.00179
-28.0%	0.00328
-26.0%	0.00580
-24.0%	0.00990
-22.0%	0.01634
-20.0%	0.02608
-18.0%	0.04027
-16.0%	0.06016
-14.0%	0.08704
-12.0%	0.12200
-10.0%	0.16581
-8.0%	0.21867
-6.0%	0.28011
-4.0%	0.34888
-2.0%	0.42302
0.0%	0.50000
2.0%	0.57698
4.0%	0.65112
6.0%	0.71989
8.0%	0.78133
10.0%	0.83419
12.0%	0.87800
14.0%	0.91296
16.0%	0.93984
18.0%	0.95973
20.0%	0.97392
22.0%	0.98366
24.0%	0.99010
26.0%	0.99420
28.0%	0.99672
30.0%	0.99821
32.0%	0.99905
34.0%	0.99952
36.0%	0.99976
38.0%	0.99989
40.0%	0.99995

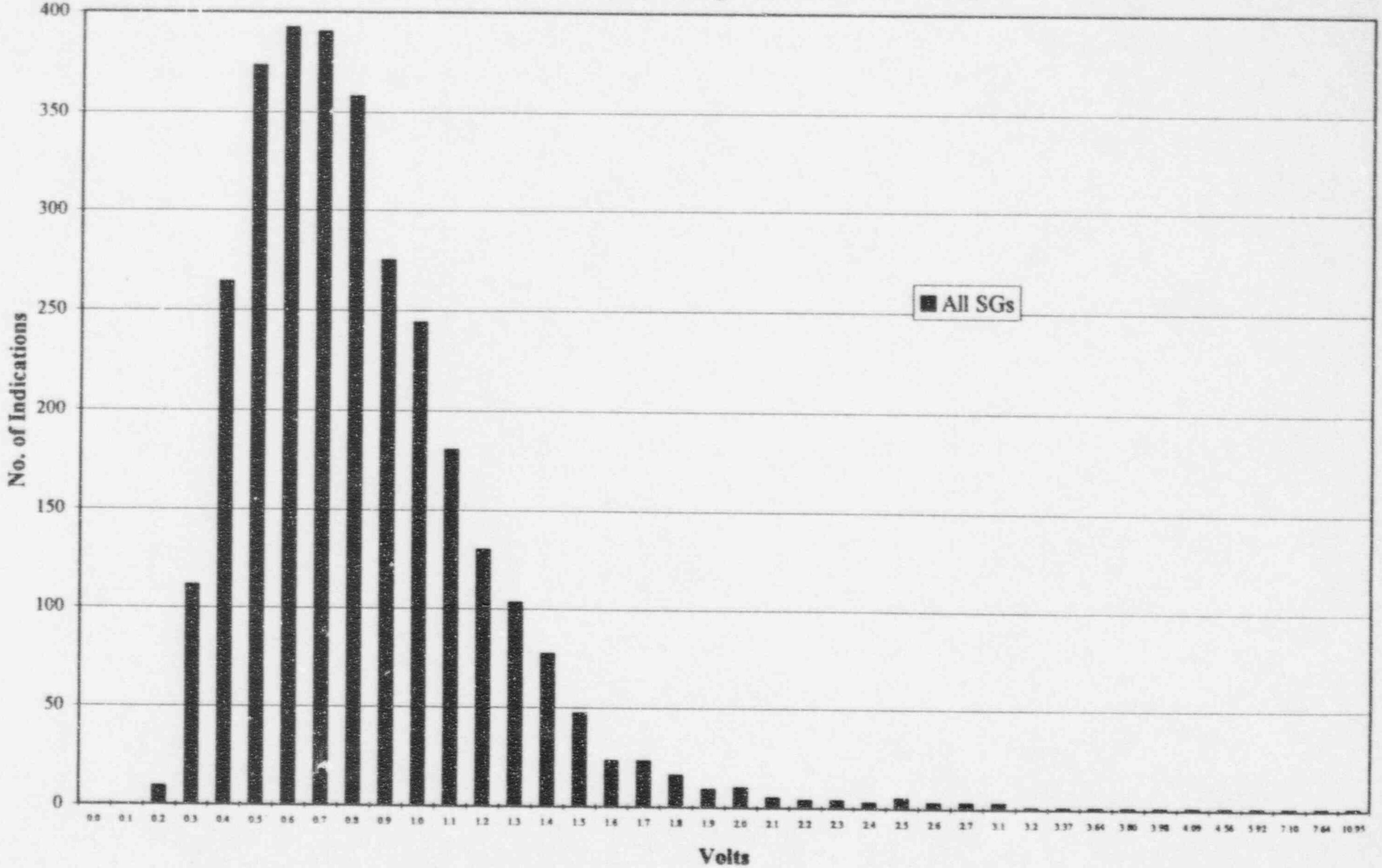
Probe Wear Variability Std. Dev = 7.0% Mean = 0.0% Cutoff at +/- 15%	
Value	Cumul. Prob.
< -15.0%	0.00000
-15.0%	0.01606
-14.0%	0.02275
-13.0%	0.03165
-12.0%	0.04324
-11.0%	0.05804
-10.0%	0.07656
-9.0%	0.09927
-8.0%	0.12655
-7.0%	0.15866
-6.0%	0.19568
-5.0%	0.23753
-4.0%	0.28385
-3.0%	0.33412
-2.0%	0.38755
-1.0%	0.44320
0.0%	0.50000
1.0%	0.55680
2.0%	0.61245
3.0%	0.66588
4.0%	0.71615
5.0%	0.76247
6.0%	0.80432
7.0%	0.84134
8.0%	0.87345
9.0%	0.90073
10.0%	0.92344
11.0%	0.94196
12.0%	0.95676
13.0%	0.96835
14.0%	0.97725
15.0%	0.98394
> 15.0%	1.00000

Table 4-9

Correspondence Between Generic Letter Requirements and Report Contents

Generic Letter Enclosure 1 Para. 6b(b)	Subject	Section	Table	Figure
(i)	EOC-6 voltage distribution - all bobbin ind.	4.1	4-1	4-1a-e
(ii)	Cycle 6 growth distribution	4.2	4-7	4-11, 4-12
(iii)	EOC-6 voltage distribution - repaired indications	4.1	4-1	4-2a,b
(iv)	BOC-7 indications left in service - all indications	4.1	4-4	4-7, 4-8
(v)	BOC-7 indications left in service - RPC confirmed plus not RPC inspected indications	4.1	4-4	4-7, 4-8
(vi)	NDE uncertainty distribution used in predicting EOC voltage distribution	4.3	4-8	4-14

Figure 4-1a
Byron-1 EOC-6 Bobbin Voltage Distribution for All SGs



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1/17/95

Figure 4-1b
Byron-1 EOC-6 Bobbin Voltage Distribution for SG-A

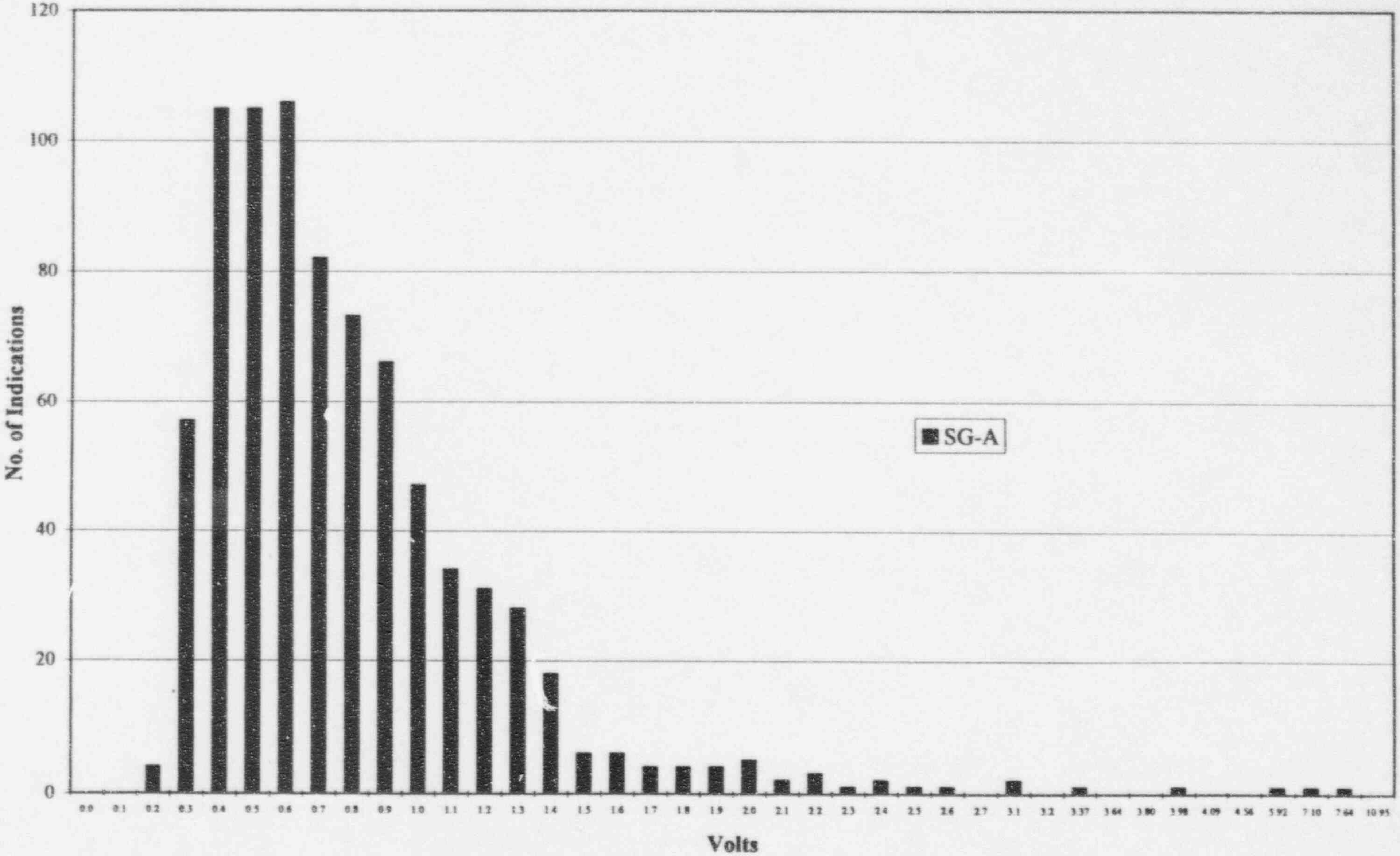


Figure 4-1c
Byron-1 EOC-6 Bobbin Voltage Distribution for SG-B

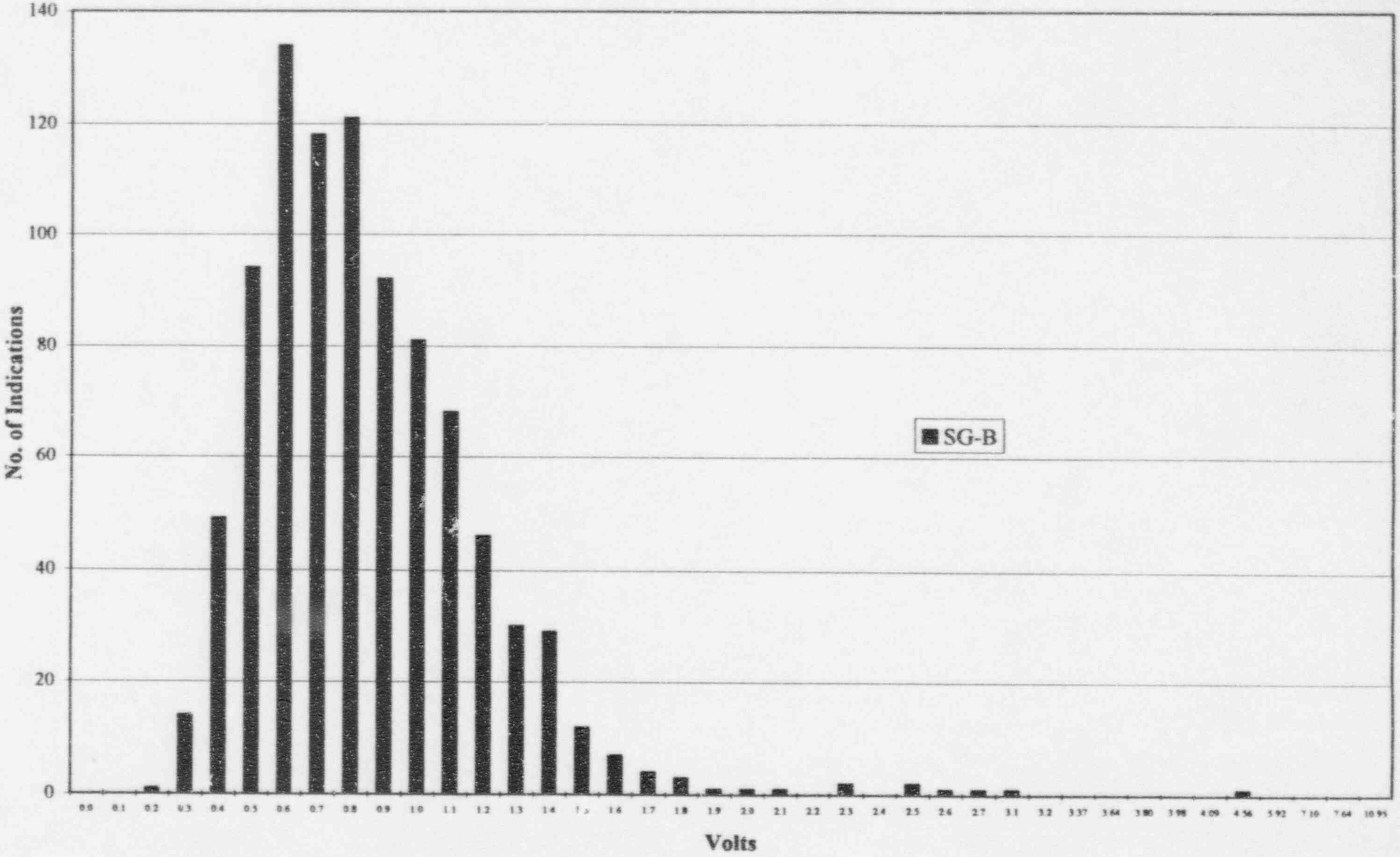


Figure 4-1d
Byron-1 EOC-6 Bobbin Voltage Distribution for SG-C

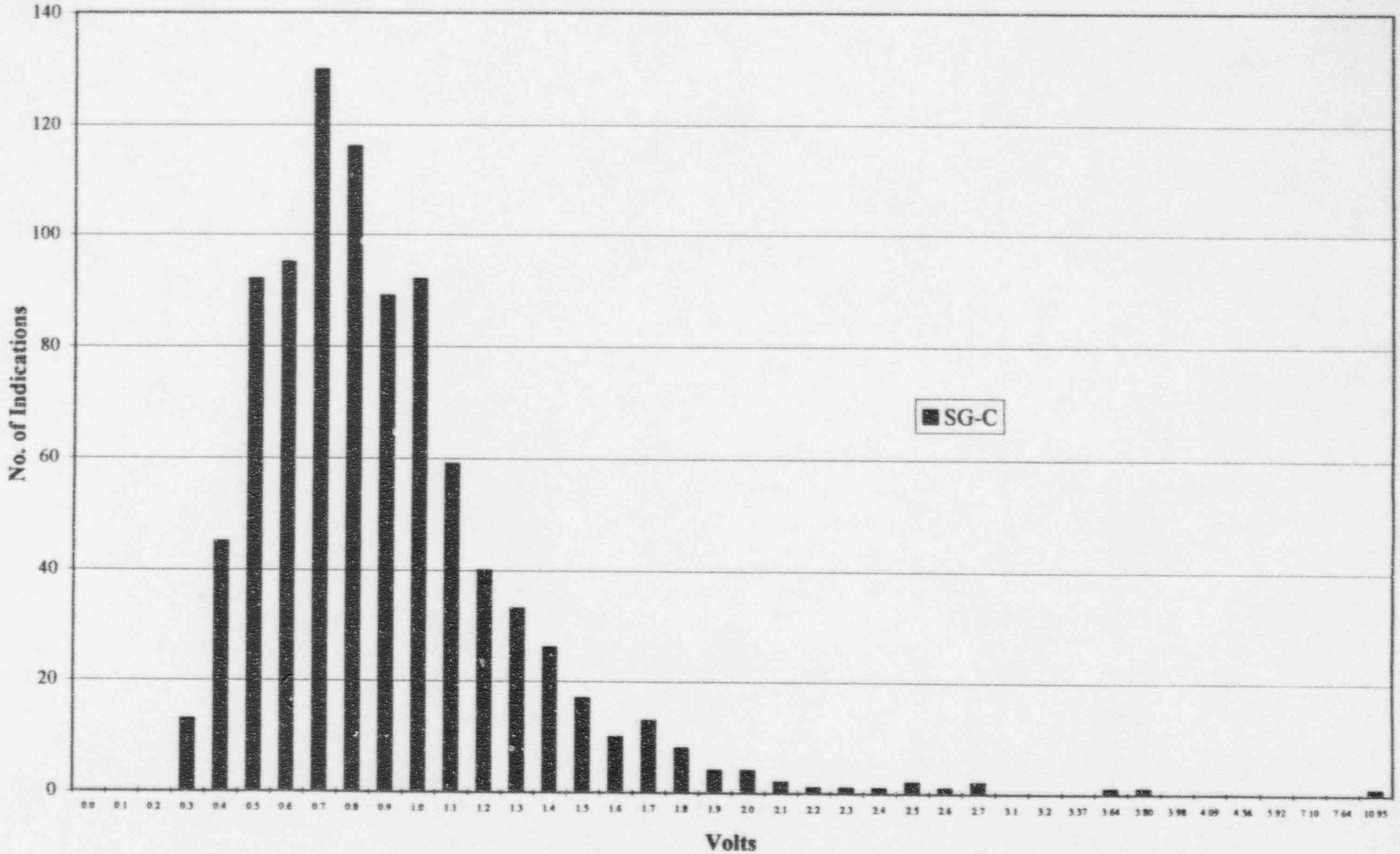
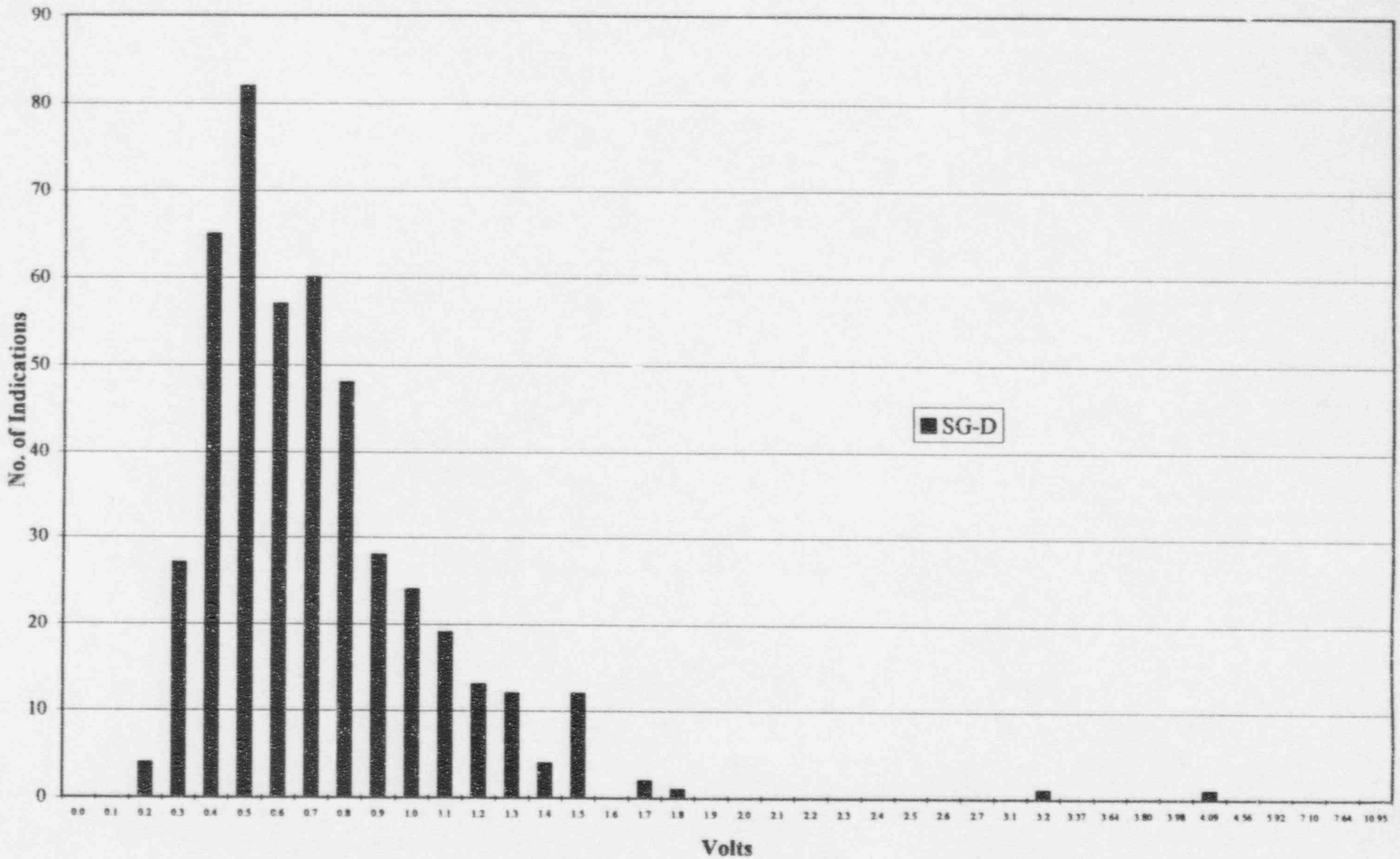


Figure 4-1e
Byron-1 EOC-6 Bobbin Voltage Distribution for SG-D



C:\APC\BYRONAPC\REPORT* Fig 4-1a-e Chart 7

Figure 4-2a
Byron-1 EOC-6 Repaired Indications for All SGs

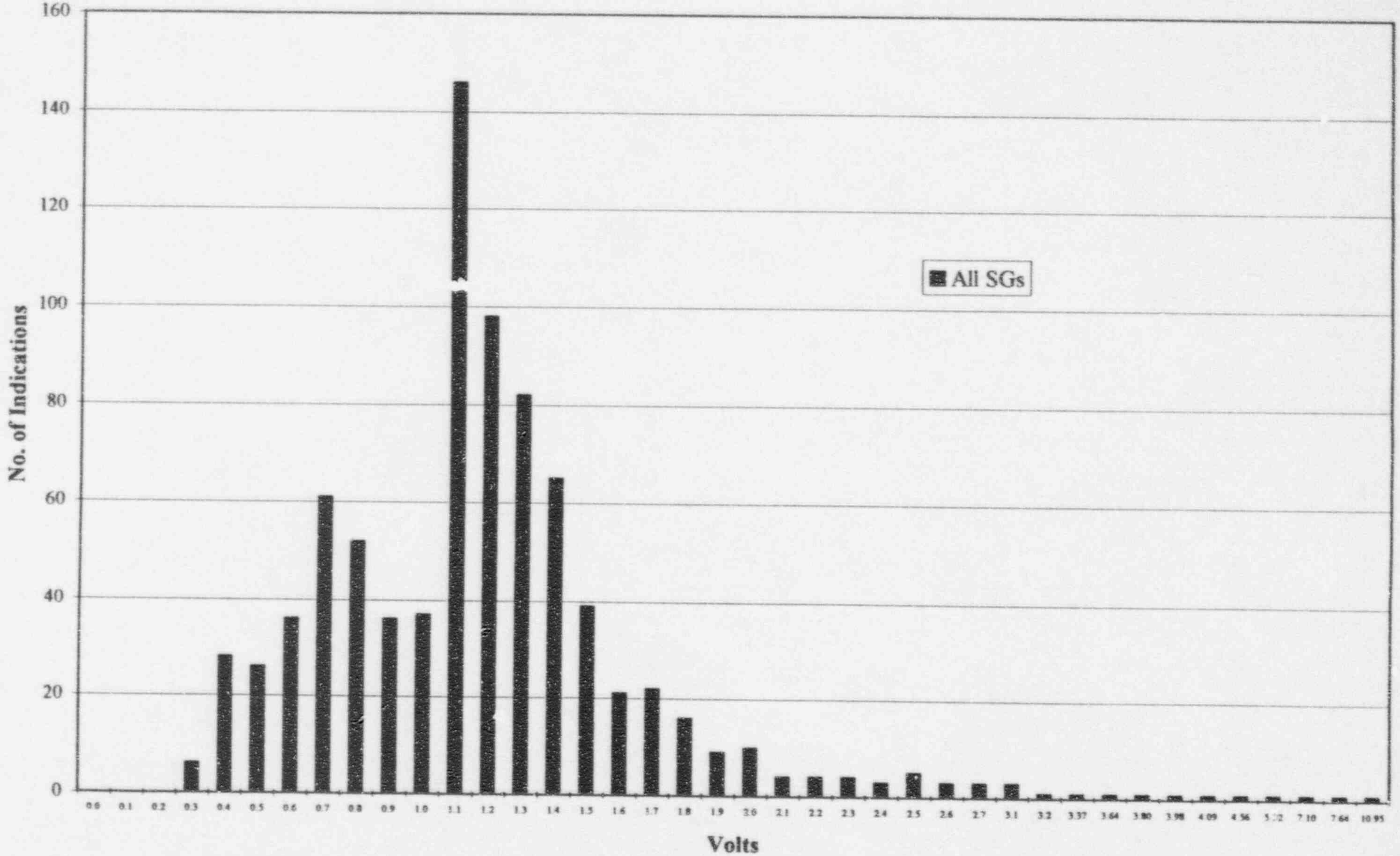
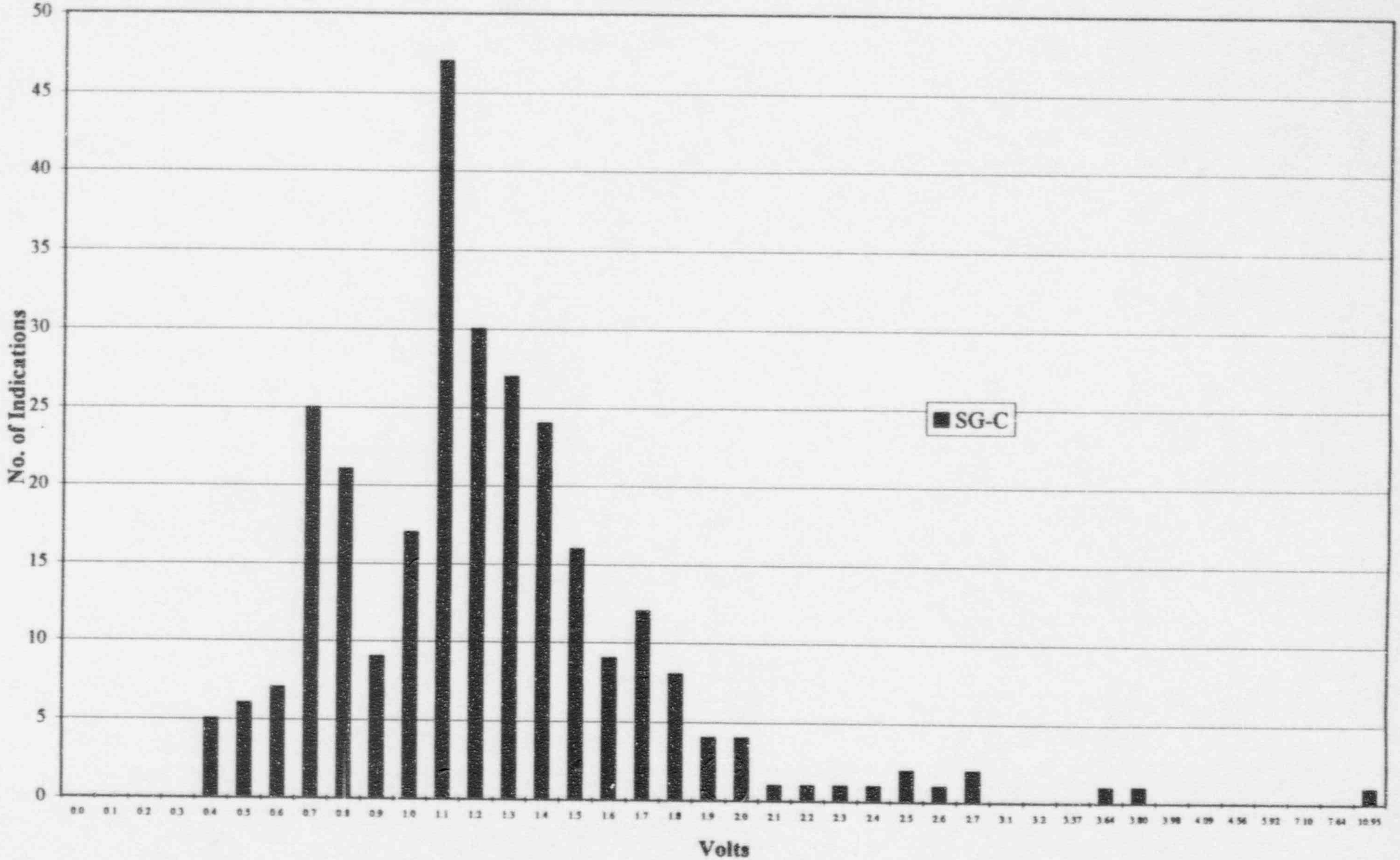
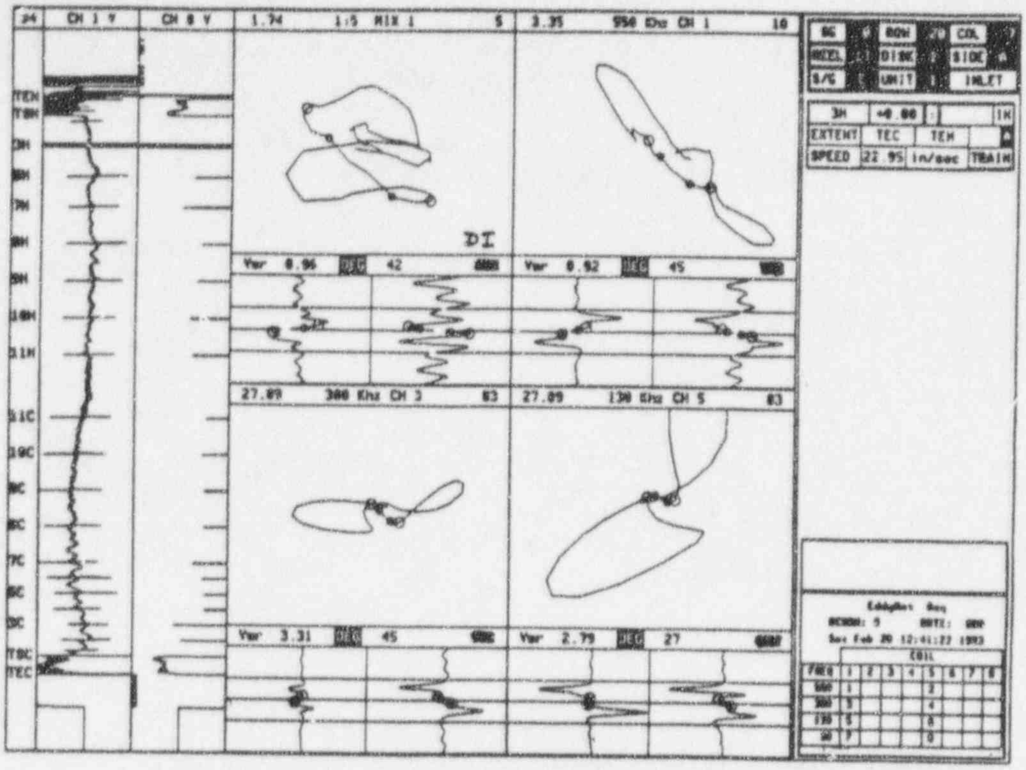


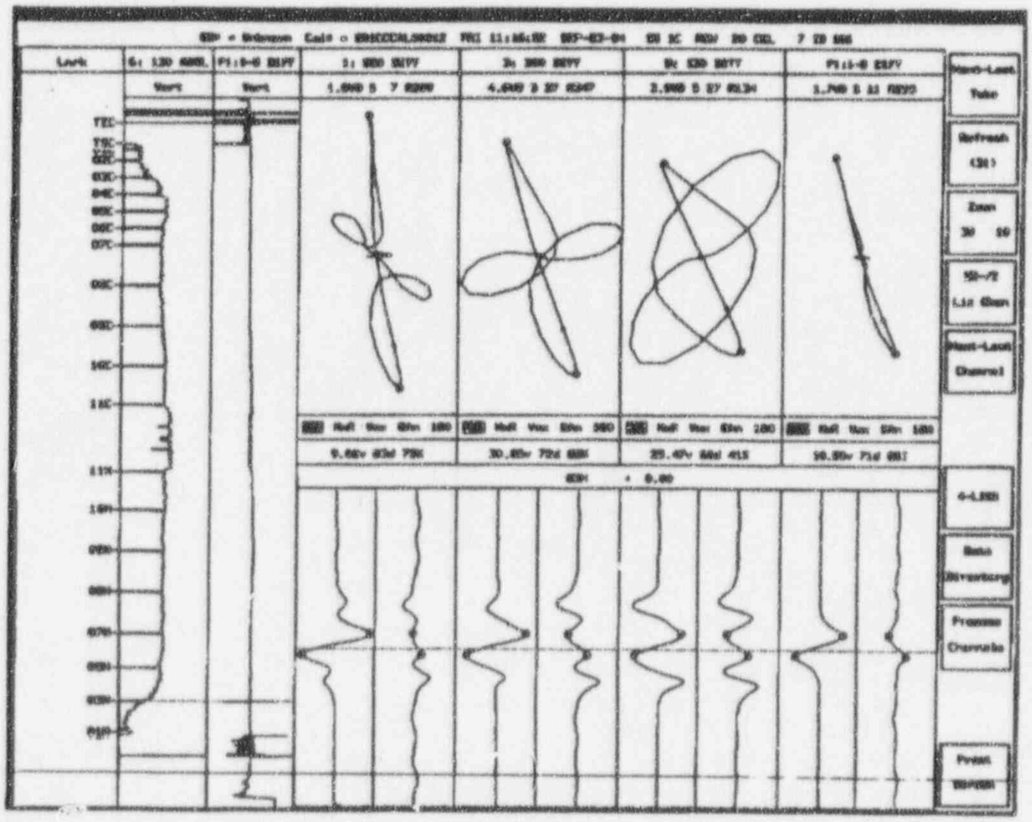
Figure 4-2b

Byron-1 EOC-6 Repaired Indications for SG-C





BOC-6 EC Response



EOC-6 EC Response

Figure 4-3. Bobbin Coil EC Responses for SG-C R20C7 3H at BOC-7 and EOC-7

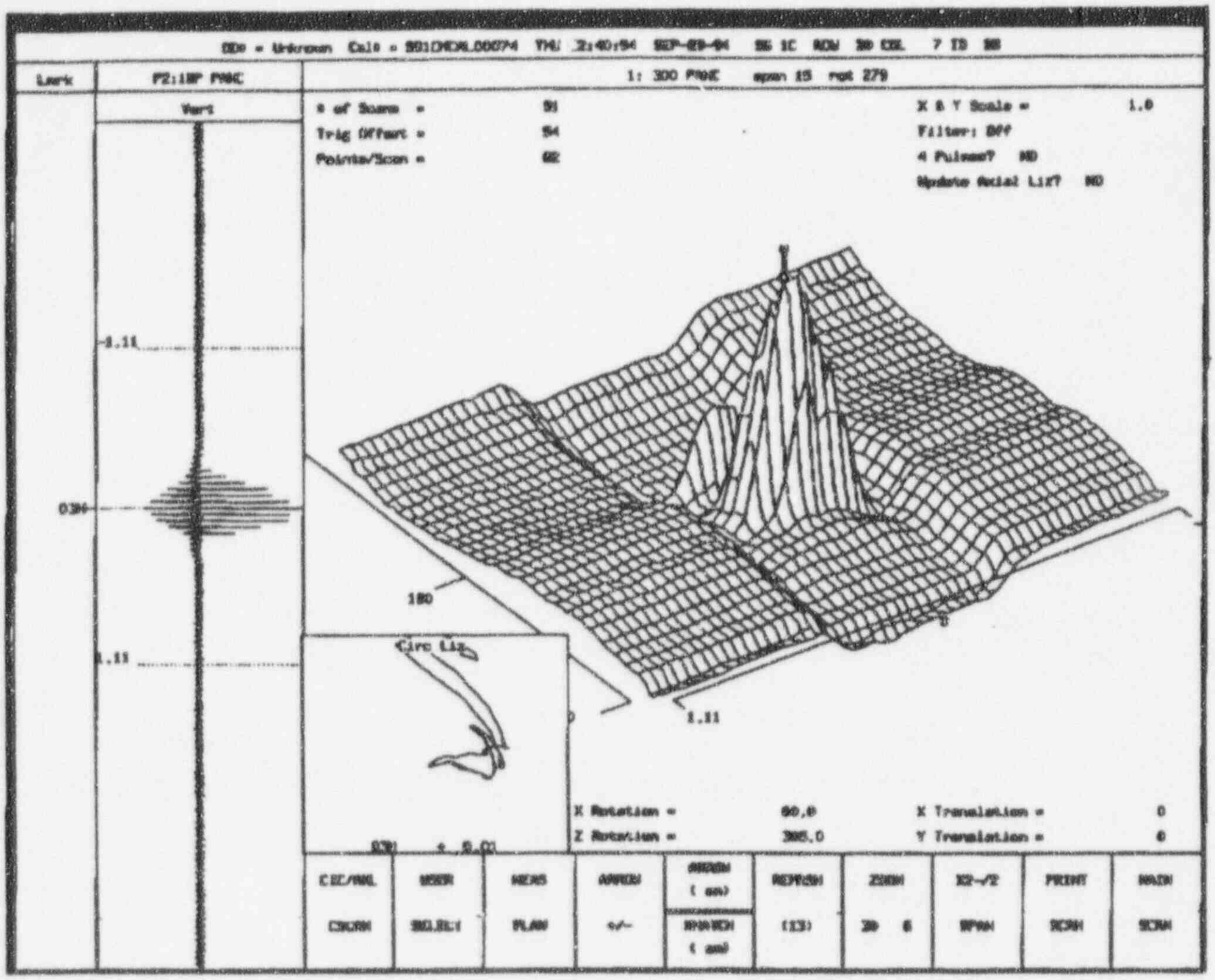


Figure 4-4. MRPC Response for SG-C R20C7 3H at EOC-6

Figure 4-5
Byron-1: EOC-6 ODSCC Indications vs. TSP Number

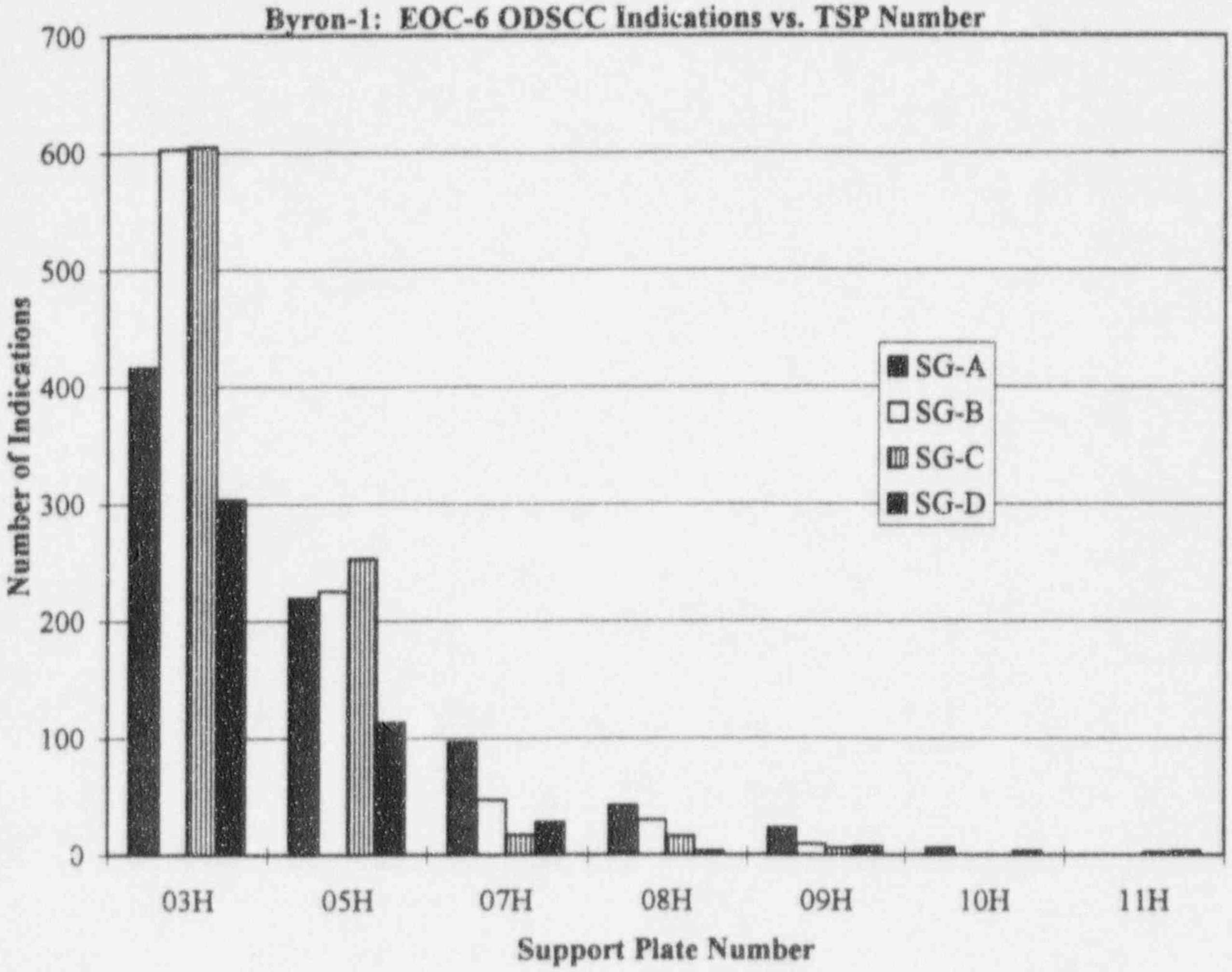


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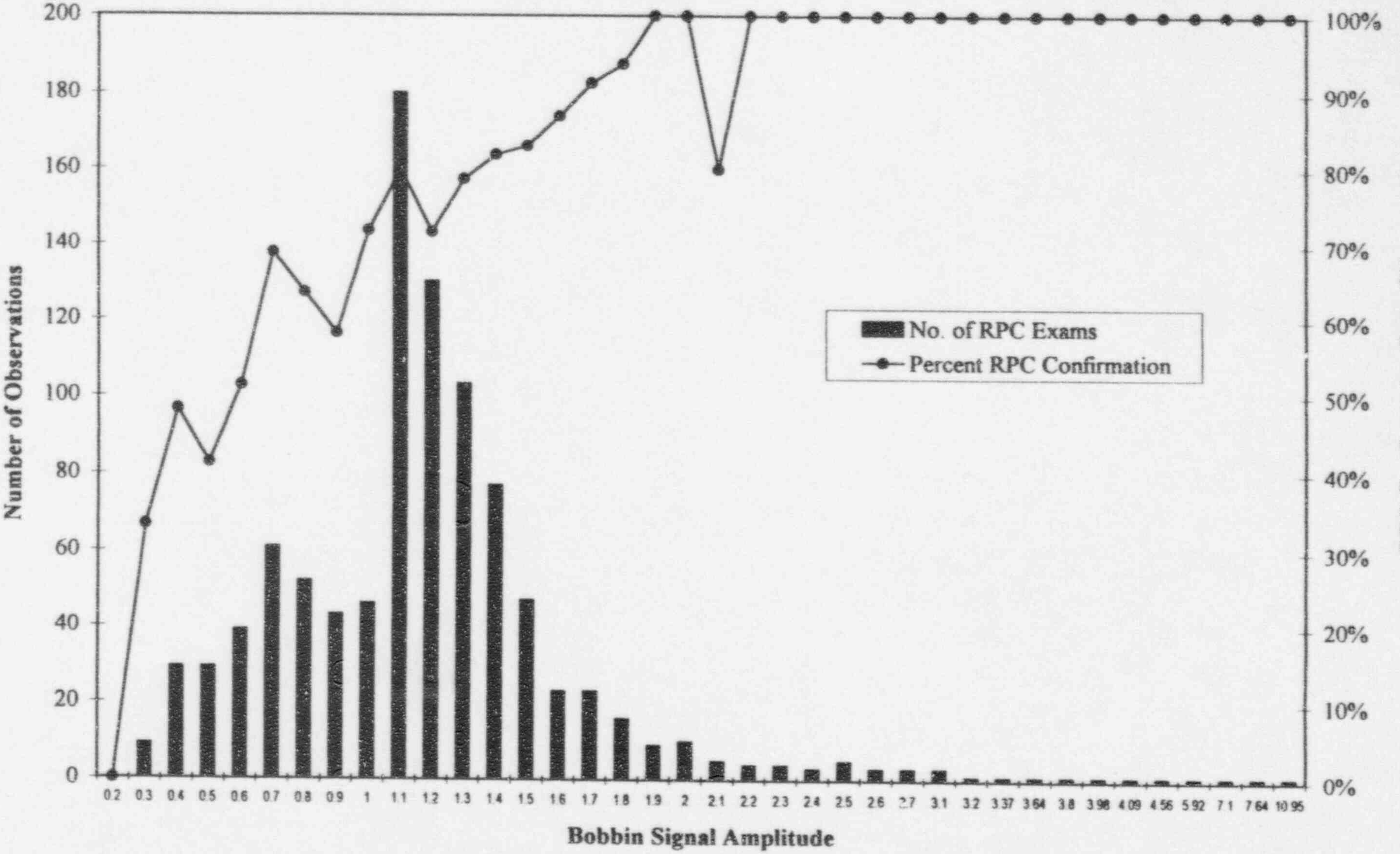
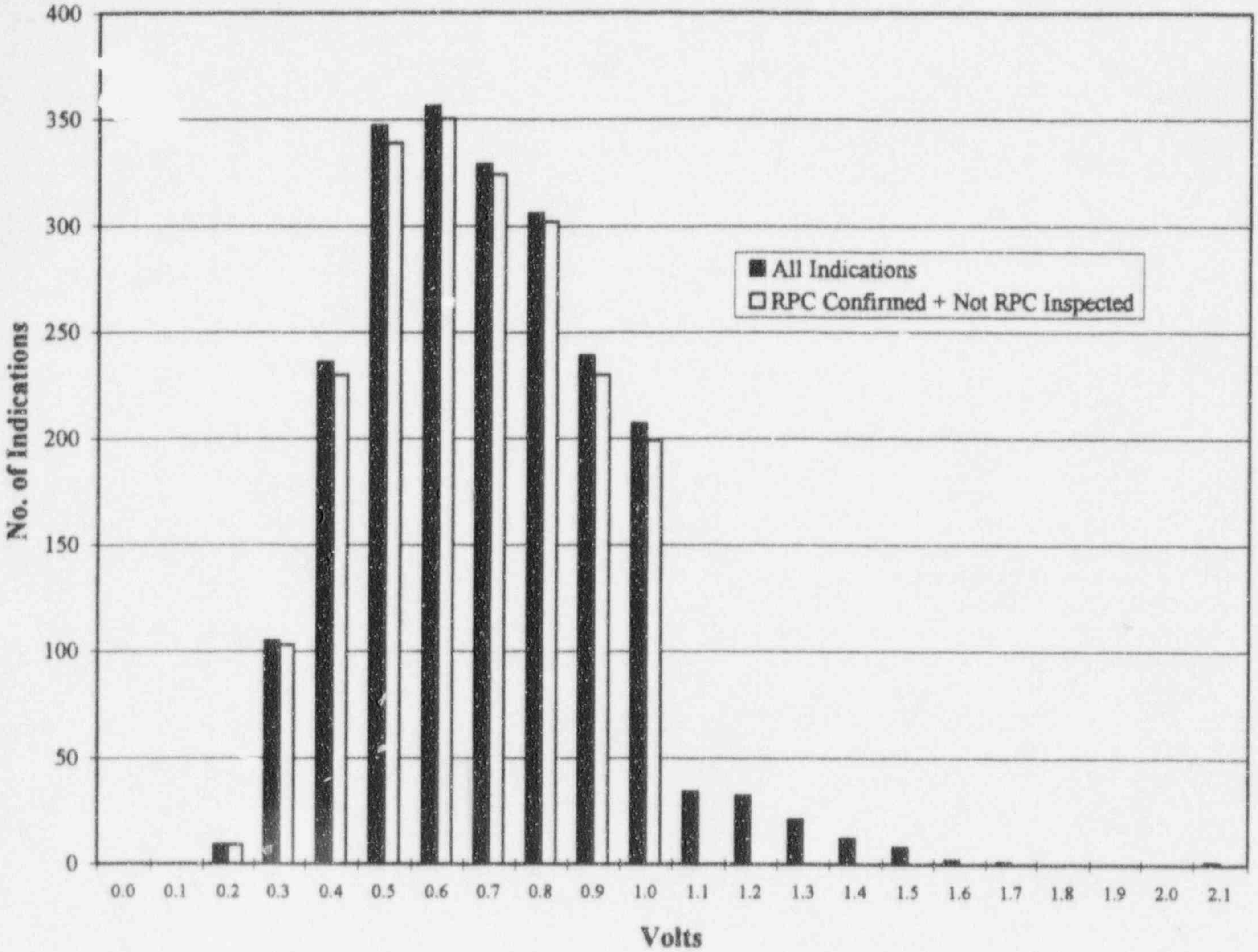
Figure 4-6
Byron-1 EOC-6 RPC Inspection Statistics (All SGs)



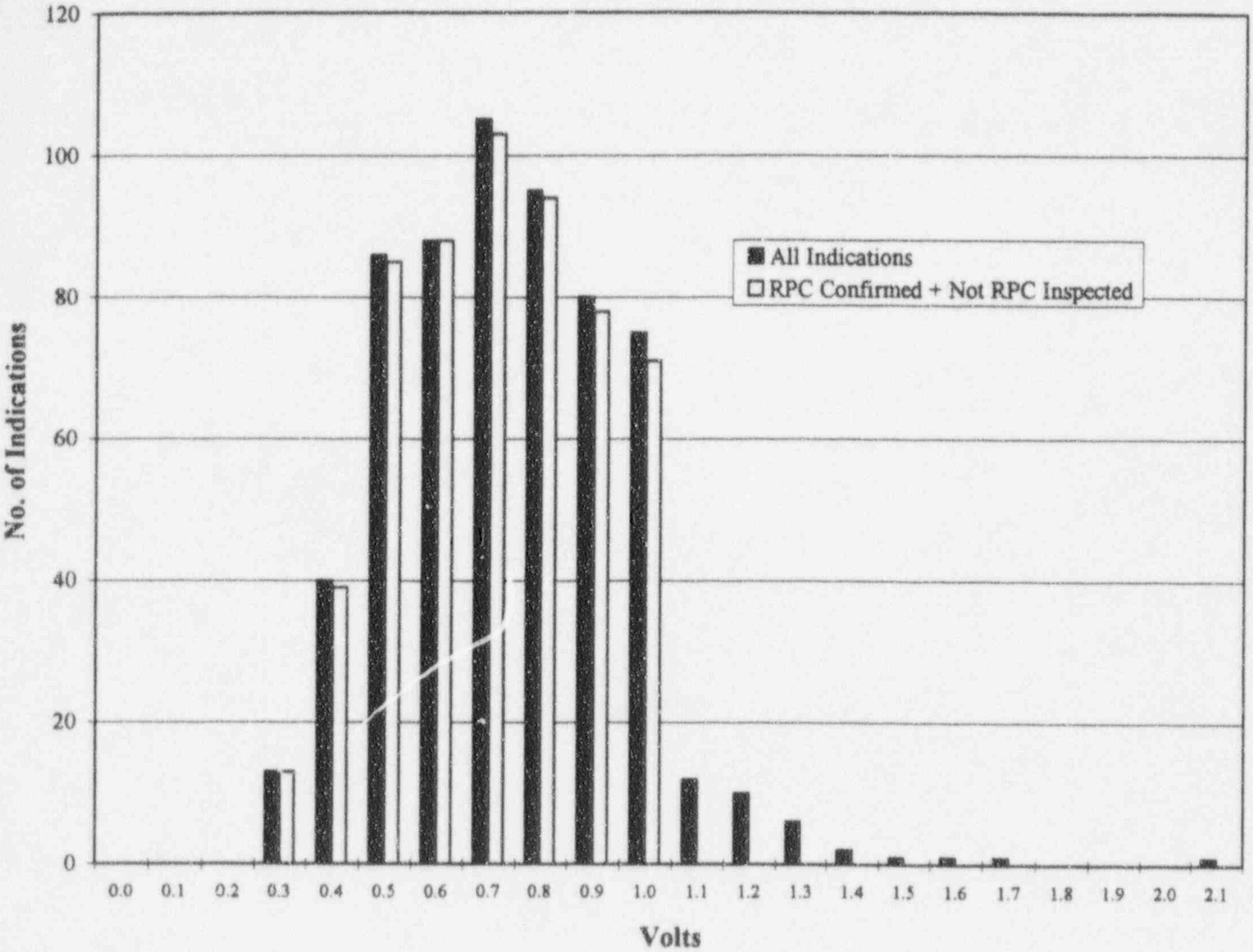
c:\apc\byronapc\report\CAE94RPT.XLS Fig 4_6

Figure 4-7
Byron-1 BOC-7 Bobbin Voltages for All SGs
All Indications vs. RPC Confirmed Plus Not RPC Inspected



C:\APC\BYRONAPC\REPORT* Fig 4-7,8 Chart 1

Figure 4-8
Byron-1 BOC-7 Bobbin Voltages for SG-C
All Indications vs. RPC Confirmed Plus Not RPC Inspected



C:\APC\BYRONAPC\REPORT* Fig 4-7,8 Chart 5

Figure 4-9
Byron-1 Cycle 6 Cumulative Growth Distribution by SG
(2851 Total Growth Values)

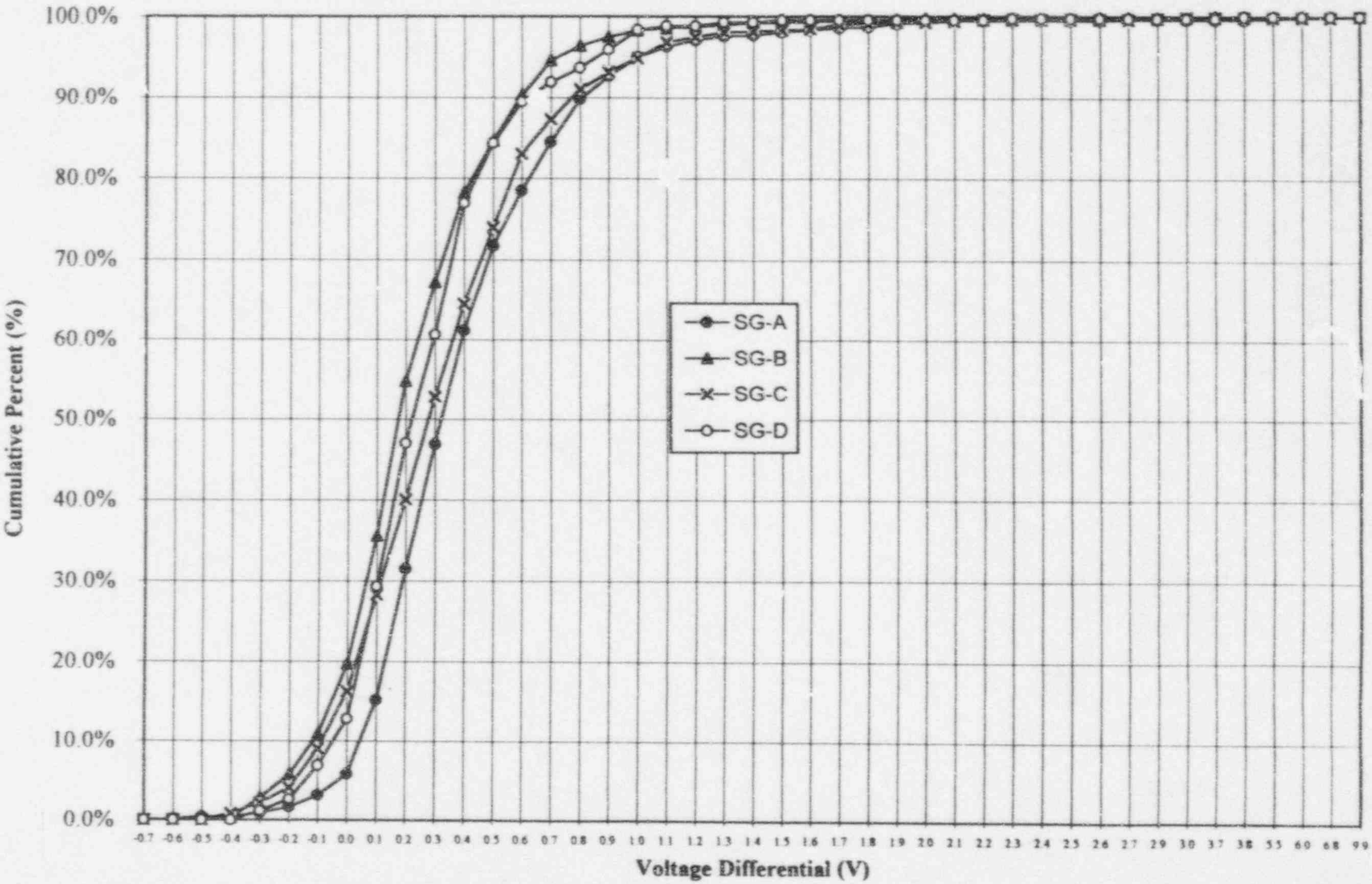


Figure 4-10
Byron-1 Cycle 6 Voltage Growths (by SG)

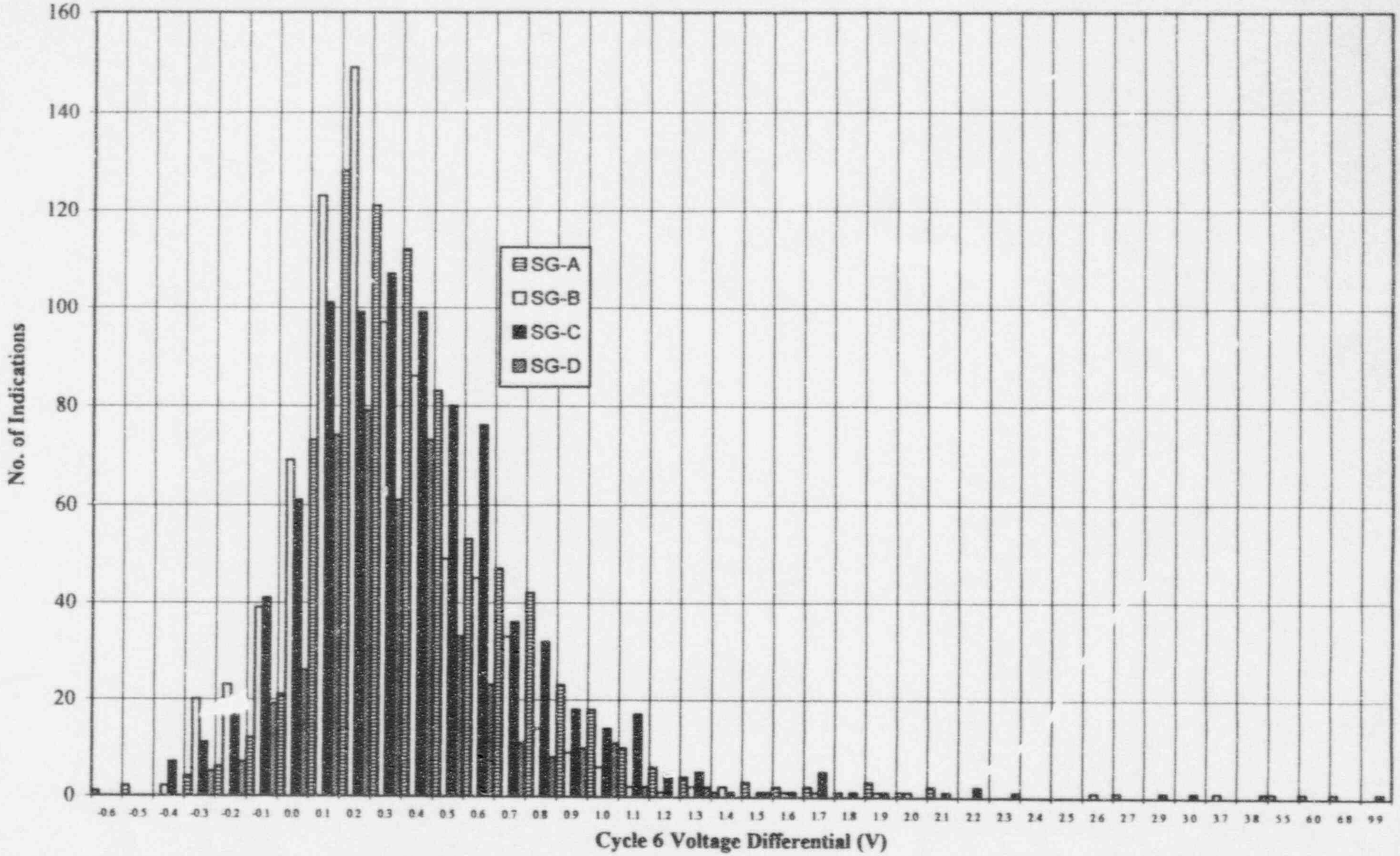


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Figure 4-11. Byron-1 Cycle 6 Growth Distribution for All SGs (2851 Growth Values; Includes Negative Growths in 0.0 Volt Bin)

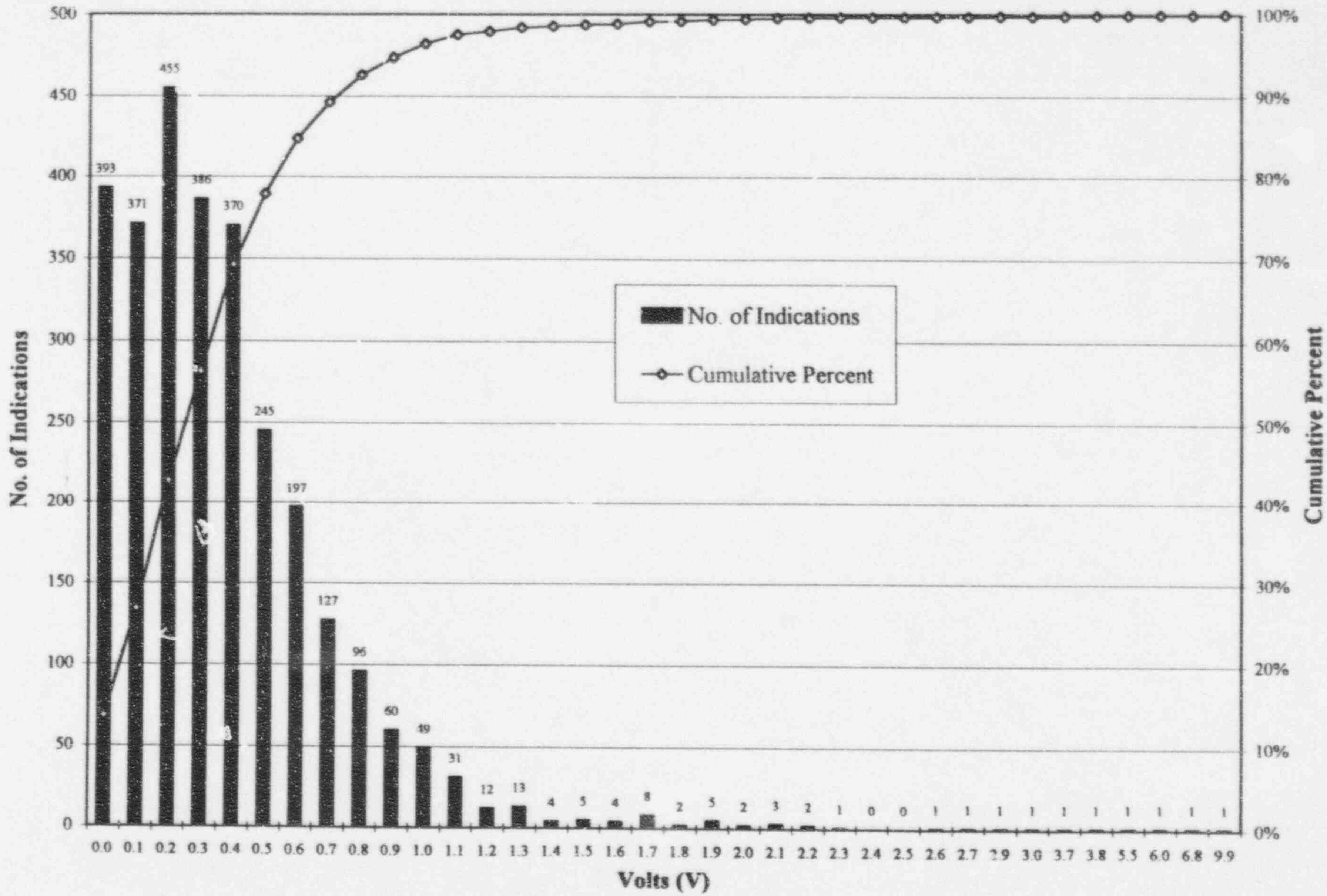

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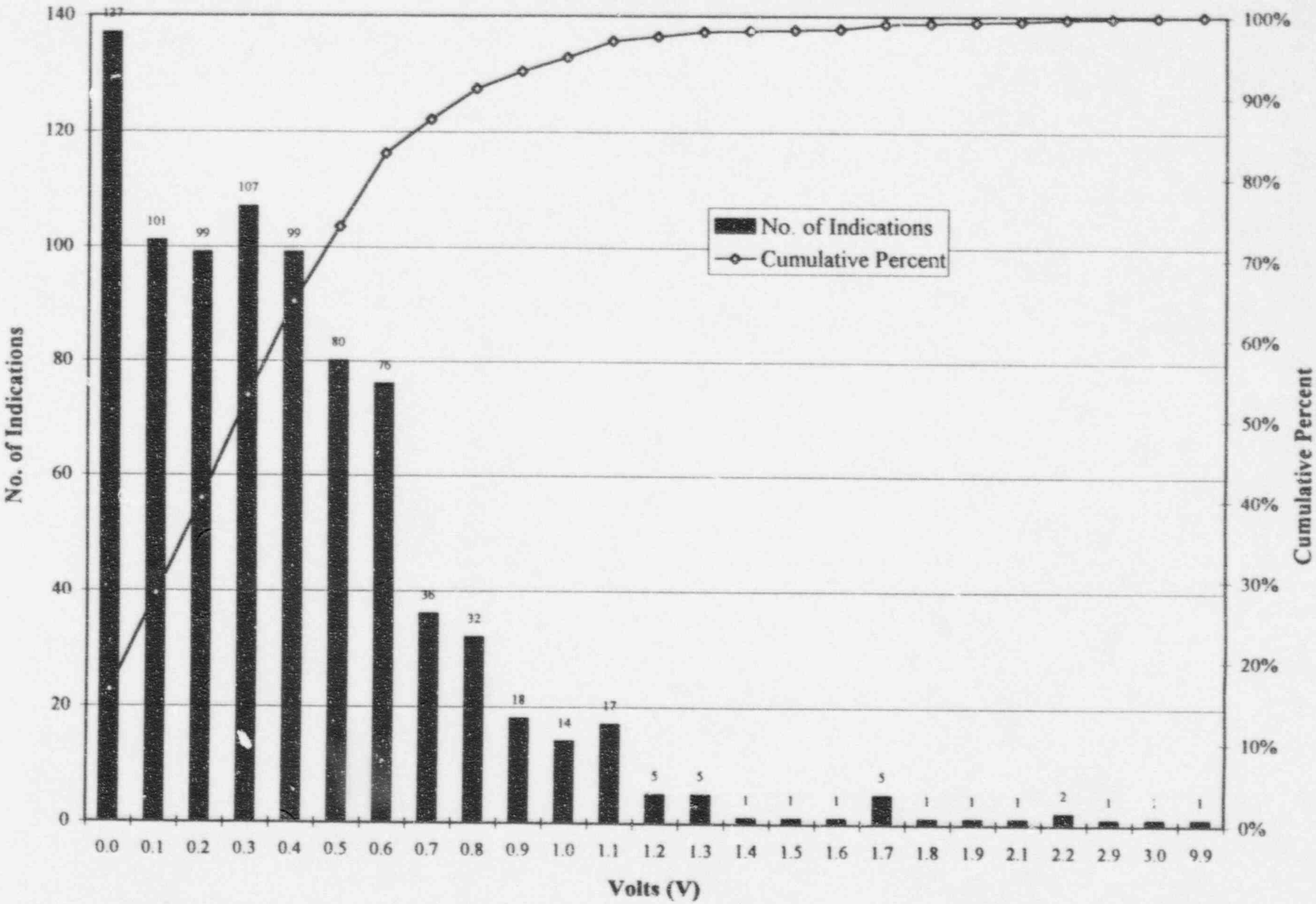
Figure 4-12. Byron-1 Cycle 6 SG-C Growth Distribution
(842 Growth Values; Includes Negative Growths in 0.0 Volt Bin)



C:\APC\BYRONAPC\REPORT* Fig 4-12 Chart 2

Figure 4-13. Byron-1 Cycle 6 Voltage Growth vs. BOC-6 Voltage

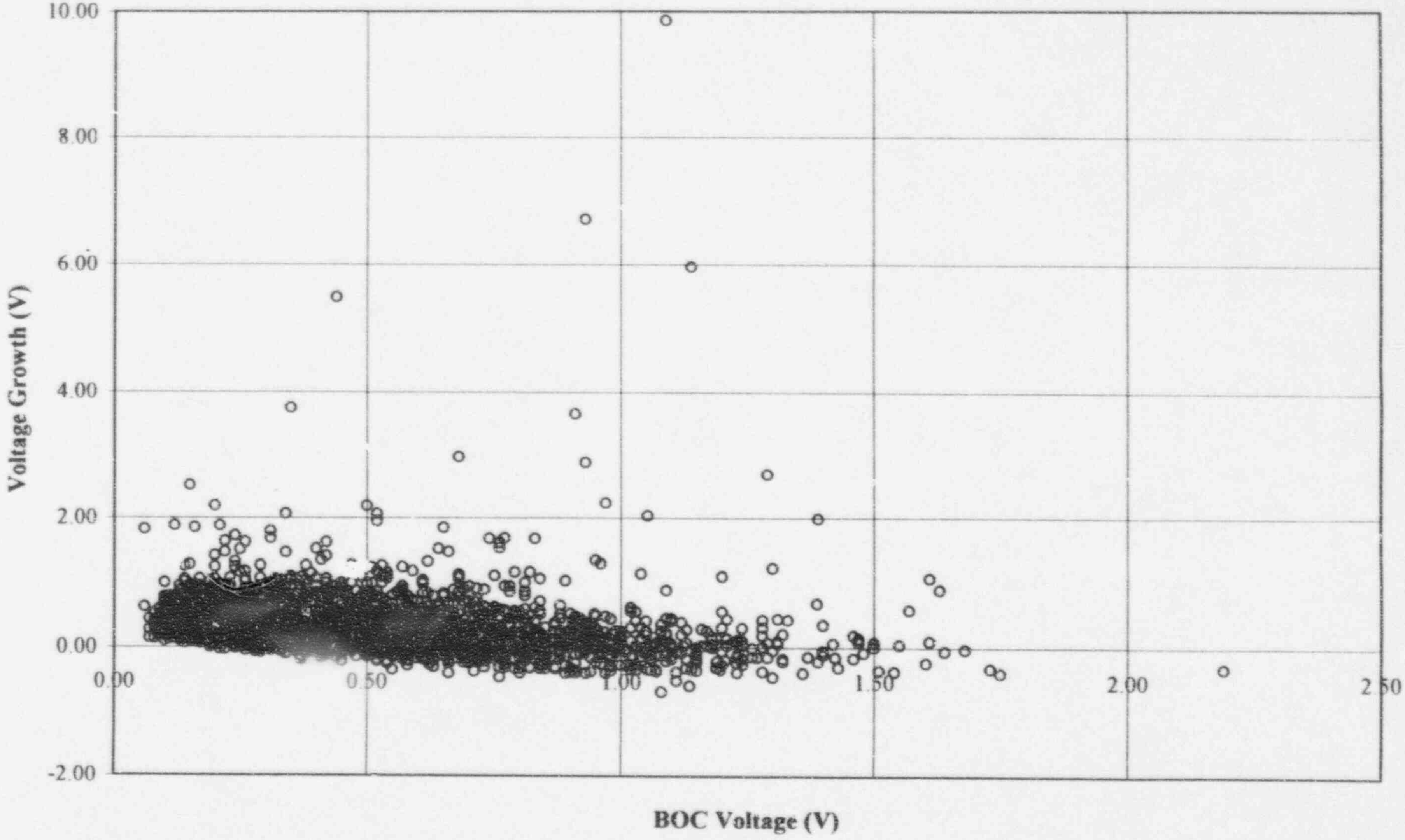


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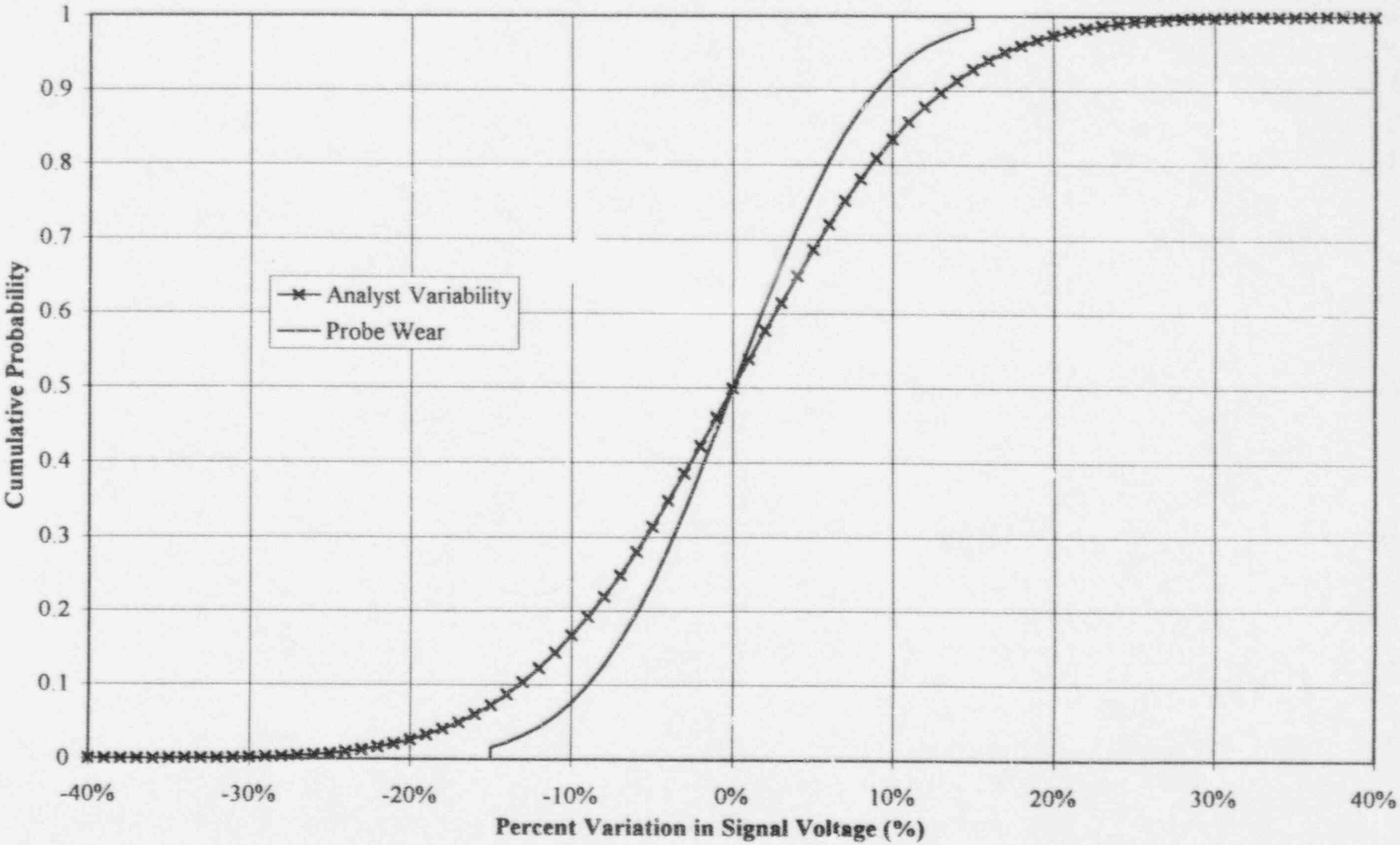
Figure 4-14
NDE Uncertainty Distributions



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5.0 DATABASE APPLIED FOR IPC CORRELATIONS

The available database for 3/4" diameter tubing IPC applications has been described in Reference 11.6, Braidwood-1 IPC WCAP-14046 Rev. 1. This report includes results for the Braidwood-1 tubes pulled in March, 1994. Per NRC telecon request in support of the Byron-1 IPC, the Braidwood-1 data is to be included for the Byron-1 IPC assessment. The Braidwood-1 data given in Table 3-7 of the referenced WCAP has been included in the correlations for Byron-1. If the EPRI data exclusion criteria were applied to the Braidwood-1 pulled tubes, the 0.28 volt indication at R16C42, TSP 5 would be excluded from the database. However, per the NRC telecon, this data point has been included in the correlations for Byron-1. The database applied to the Byron-1 analyses is called the NRC database to contrast it from the EPRI recommended database.

Per the guidance of the Braidwood-1 SER and the NRC telecon, the NRC database includes additional differences from the EPRI database. For the tube burst correlation, the NRC database includes model boiler specimen 598-1, which would not be included in the EPRI database. For the leak rate correlation, the NRC database includes model boiler specimens 598-1 and 598-3, and includes Plant S tube R28C41 at a leak rate of 2496 liter/hr as contrasted to the EPRI recommended value of 125 liter/hr.

6.0 ANALYSIS METHODS FOR VOLTAGE PROJECTIONS, LEAK RATES, AND BURST PROBABILITY

The SLB leak rate and tube burst probability analyses reported herein are based on full Monte Carlo analyses that account for parameter uncertainty per the methods described for leak rate analyses in Reference 11.6, WCAP-14046 Rev. 1. Monte Carlo methods are used to develop an EOC voltage distribution and Monte Carlo techniques are applied to the EOC voltage distribution to obtain the SLB leak rates and tube burst probabilities. To demonstrate compliance of the Westinghouse analysis methodology with the NRC requirements of the draft generic letter and to simplify NRC review, Westinghouse has prepared a methods report (Reference 11.5). This report provides the relevant information on analysis methods for voltage projections, leak rates, and burst probability.

Of note to this analysis is that, for the tube burst probability analyses, the editing elements of the Monte Carlo analyses were revised to separate single tube and multiple tube ruptures. Monte Carlo analyses previously reported by Westinghouse, including the Braidwood-1 IPC evaluation, have computed the total tube burst probability which is the sum of single and multiple ruptures (i.e., the sum of 1, 2, 3, etc. ruptures). The revised editing separately computes the probability of one, two, three or more tube ruptures in addition to the total burst probability. The Monte Carlo process involves sampling all indications in the SG to obtain the number of burst pressure samples with burst pressures less than the SLB value of 2560 psid. In a given SG sample, the number of occurrences of burst pressures less than the SLB value might be one, two, three or a fraction. When fractions of bursts (0.7, 1.3) less than the SLB value occur in a SG sample, such as resulting from applications of a POD, the whole number of the fraction results in an occurrence of the whole number of bursts and the fraction is added to the burst probability of the next largest integer number of bursts. For example, an occurrence of 0.7 results in adding 0.7 occurrence to the one tube rupture frequency and an occurrence of 1.3 adds one occurrence to the one tube rupture frequency and 0.3 occurrence to the two tube rupture frequency. The SG sampling process is then repeated N times. Without adjustments for confidence level, the single and multiple tube burst probabilities are the number of occurrences (frequency) of one, two, etc. pressures less than the SLB value, as summed over all SG samples, divided by N. The burst probabilities reported herein are 95% confidence values which include adjustments for the number N of SG samples.

7.0 ALTERNATE POD DISTRIBUTIONS

The draft NRC generic letter requires the application of POD = 0.6 to define the BOC distribution for the EOC voltage projections unless an alternate POD is approved by the NRC. To provide sensitivity analyses in support of obtaining approval of an alternate POD in the near future, potentially as part of resolution of industry comments on the draft generic letter, alternate PODs are included in the SLB leak and burst analyses. To bound the influence of POD on the analyses, an ideal POD = 1.0 (assumes all indications are detected) is included in the analyses. Industry recommendations on a voltage-dependent POD will be provided as part of the comment resolutions for the draft generic letter.

For the sensitivity analyses of this report, two available variations of a voltage-dependent POD are applied. Figure 7-1 shows the first. These voltage-dependent POD results were originally obtained as part of the EPRI Qualified Data Analyst testing program, and have previously been presented to the NRC. To develop the EPRI data of Figure 7-1, a panel of experts reviewed field and pulled tube eddy current data to identify ODSCC indications. The analysts being tested were evaluated based on the fraction of indications reported versus the panel of experts' flaw identification. Figure 7-1 includes an added, judgemental linearly segmented fit to the data (identified as "EPRI Fit") which has been used as POD1(EPRI) in the sensitivity analyses of this report.

An additional voltage-dependent POD is also presented in Figure 7-1. Although not used in the present analysis, this POD vs. voltage correlation (also approximated and linearized) was recently developed by Commonwealth Edison, Duke Power, and EPRI for Byron, Braidwood, and Catawba 3/4" tubing. Data were selected only from the above units and, as much as possible, indications were established through RPC examination. All indications identified during the program by any of the twelve analysts were examined by a peer review group to determine if a call was "valid". The database consisted of 818 tubes: 50 of these had no detectable degradation, and the remainder had a total of 872 RPC confirmed indications. Added to the database were 222 indications identified in the field but NDD by RPC. Also added were 251 indications identified during the POD program but not called in the field. Figure 7-1 indicates that POD1 and consequently POD2 are both more conservative relative to the ComEd/Duke/EPRI values, particularly at higher voltage levels. Low detectability values (less than 0.6) were found in the ComEd/Duke/EPRI study for voltages less than 0.5 volt. Additional information on this study is expected to be presented during review of draft generic letter comments.

Figure 7-2 shows POD data obtained as part of IPC evaluations for four plants which had implemented an IPC in the prior outage. These data are based on defining POD as the fraction of RPC confirmed indications found in the latest inspection that were reported as bobbin indications in the prior inspection. To account for tube plugging in this definition, indications RPC confirmed and plugged in the prior inspection are considered as also confirmed in the latest inspection in applying the POD definition. This definition of a POD has been labeled probability of prior cycle detection (POPCD). This can also be shown as:

$$\text{POPCD} = \frac{\text{Prior Cycle Reported Ind. Confirmed by RPC: Confirmed in Latest Inspection Plus Confirmed and Repaired in Prior Inspection}}{\text{Numerator Plus New Ind. RPC Confirmed in Latest Inspection}}$$

The logic for defining POPCD is that the EOC indications that are important to SLB leakage and burst probability are the RPC confirmed indications. RPC NDF indications, if a real indication exists, are too small to contribute to leakage or burst since RPC detectability data show that essentially all indications greater than about 65% depth are confirmed by RPC inspection as flaw indications. Indications not RPC inspected are <1.0 volt and would not contribute significantly to leakage or burst. Thus RPC confirmed indications are an appropriate basis for defining a POD for IPC applications. For an IPC, an appropriate POD is then the fraction of EOC RPC indications that were detected at the prior inspection. Since some prior cycle indications were RPC confirmed and plugged, it can be assumed that these indications would have been confirmed at EOC if not plugged and it is appropriate to include the prior inspection RPC confirmed and repaired indications in the definition of POPCD. This POD definition is based on field inspection results that influence IPC analyses and supplements the EPRI POD evaluations based on peer review of field data.

The individual plant data used for the averages of Figure 7-2 were reported at an EPRI NDE meeting in July, 1994. To provide a voltage-dependent POD that differs significantly from the EPRI POD1, a simple linear, lower bound fit to the data was applied as POD2 (POPCD). The resulting four PODs used in the analyses of this report are shown in Figure 7-3.

Figure 7-1
Comparison of ODSCC Detection: EPRI Data and Fit at 90% Conf. Level vs. ComEd/Duke/EPRI Data Fit (approximated) at 95% Conf. Level

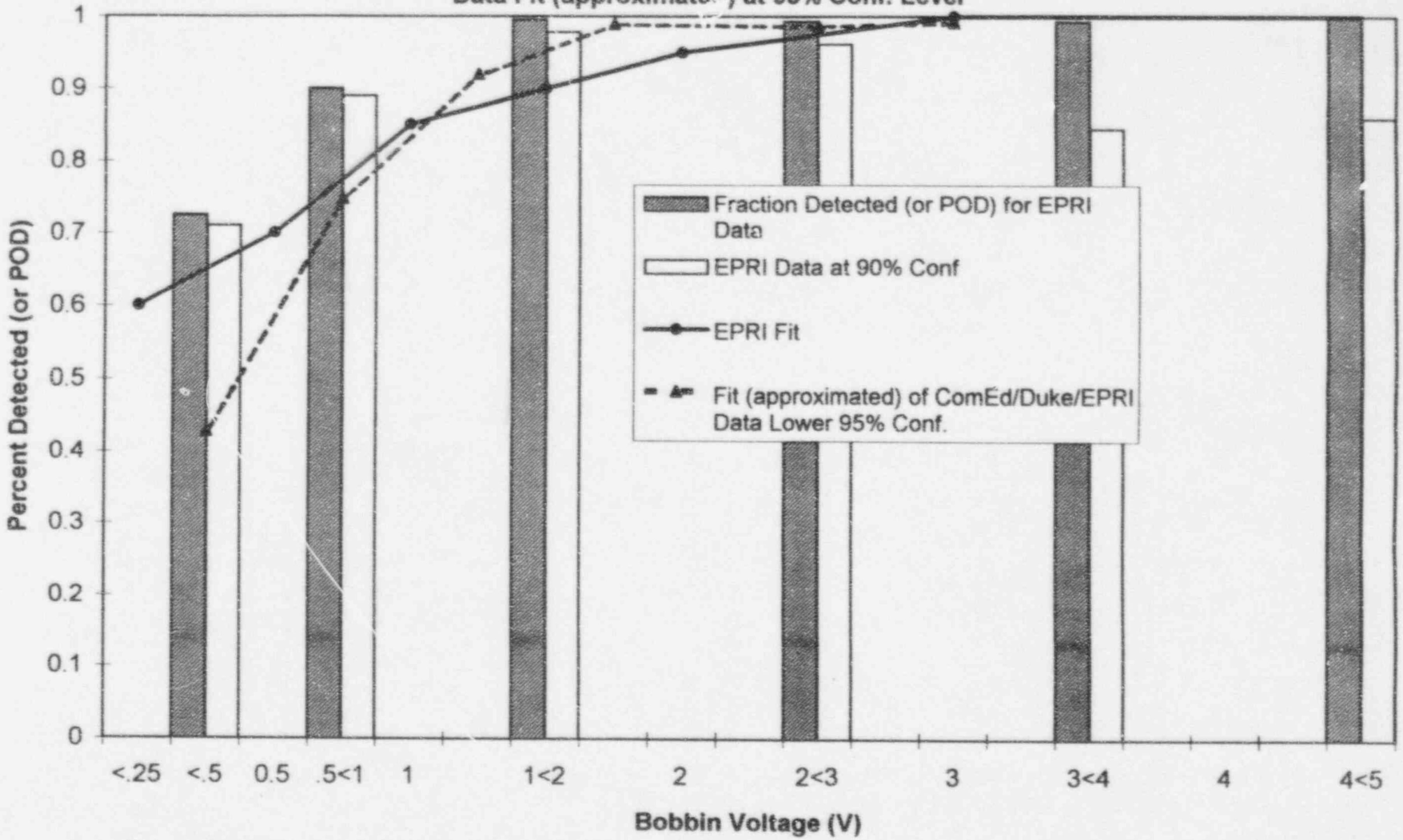

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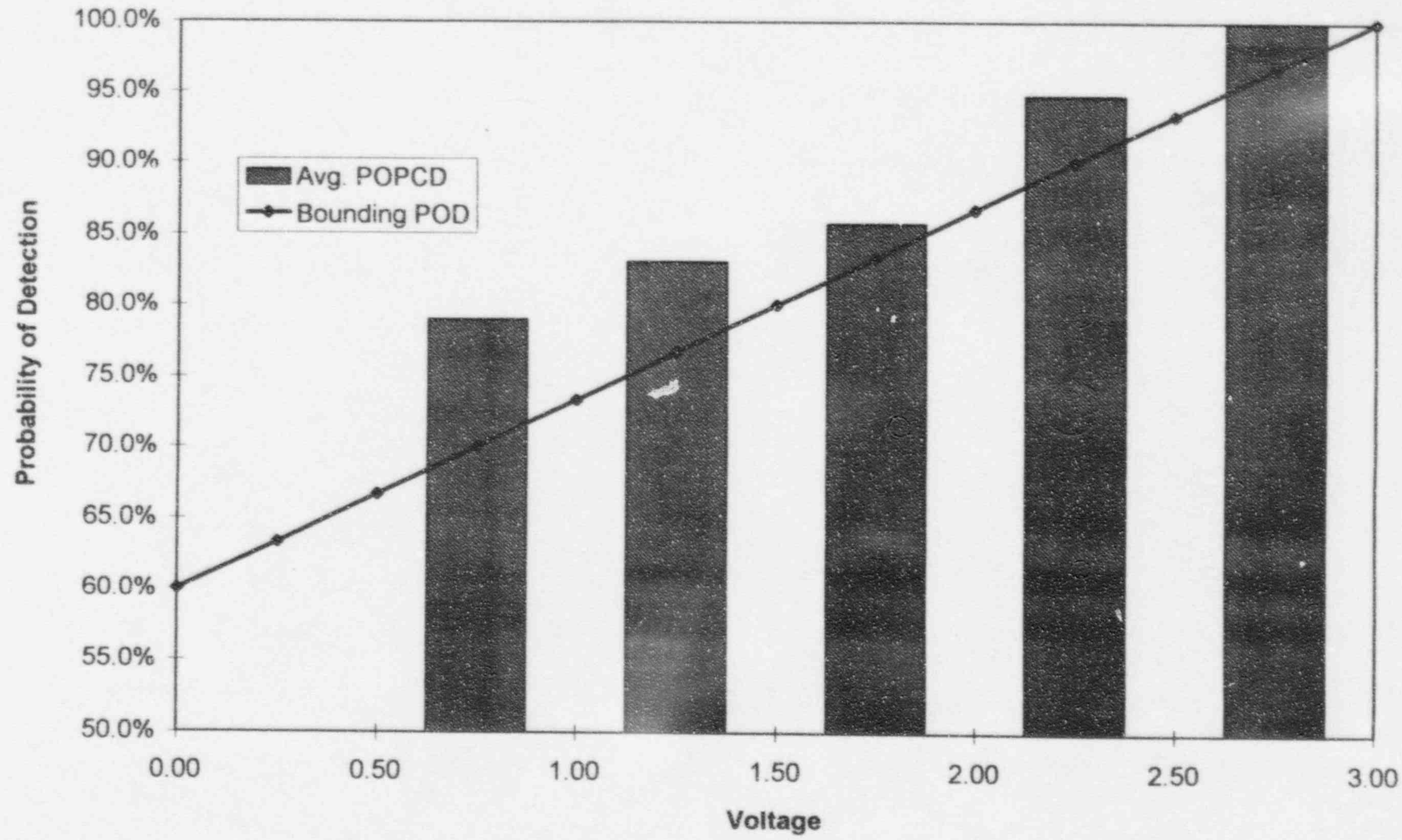
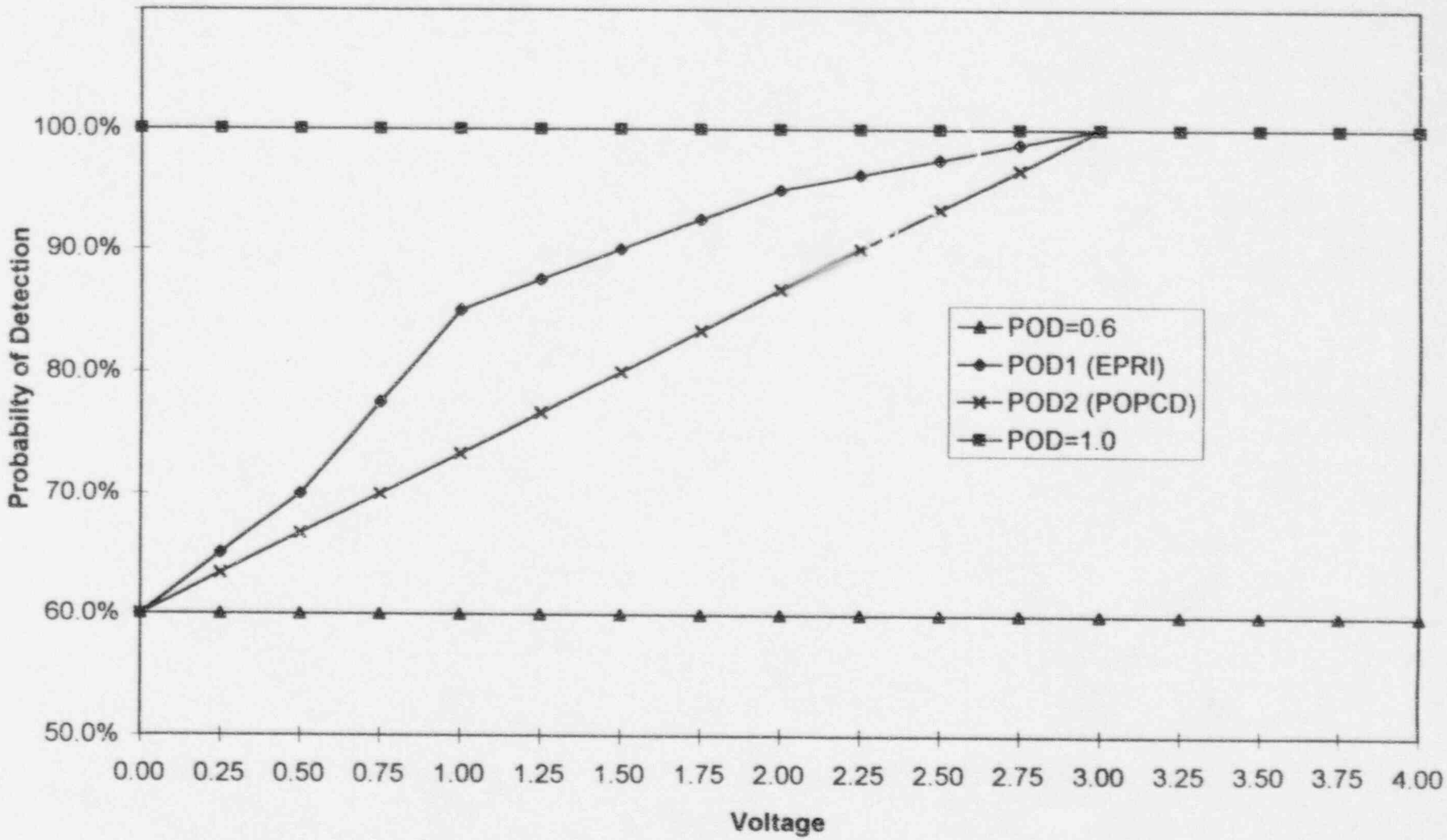
Figure 7-2
Average POPCD for 4 Plants vs. Linearized Bounding POD



c:\apc\byronapc\popcd.xls* 0.6-1 POD Chart 2-1

Figure 7-3
Comparison of Probability of Detection Models



c:\apc\byronapc\ * Fig 7-3 4 PODs Chart 1

8.0 PROJECTED CYCLE 7 VOLTAGE DISTRIBUTIONS

Consistent with the draft generic letter (Ref. 11.2) methodology, Monte Carlo analyses were applied to develop projected EOC distributions from the BOC distributions. The BOC voltages are increased by allowances for NDE uncertainties (from Section 4.3) and voltage growth (from Section 4.2) to obtain the EOC values. In the Monte Carlo analyses, each voltage bin of the BOC voltage distributions is increased by a random sample of the NDE uncertainty and growth distributions to obtain an EOC voltage sample. Each sample is weighted by the number of indications in the bin. The sampling process is repeated for each BOC voltage bin and then repeated for a large number of samples across the BOC distribution.

8.1 Limiting SG Evaluation

Of the four Byron-1 SGs, SG-A and SG-C were judged to be more limiting for leak rate and burst probability analysis, because of their larger amplitude (> 4.0V) indications. To determine the more limiting of these SGs, leak rates and burst probabilities were determined for the actual EOC-6 and projected EOC-7 (using POD=0.6) voltage distributions of both SGs. Cycle lengths were based on the reported Cycle 6 length of 466.5 EFPD, a projected mid-cycle 7 length of 298.5 EFPD, and a projected EOC-7 of 474.5 days. Standard Monte Carlo methods to account for NDE uncertainty were used along with the voltage growth distributions and a POD=0.6 to develop projected EOC-7 voltage distributions. The SG-A and C growth distributions were each applied for their respective analyses. Use of the individual SG growth rates in the EOC voltage projections maintains the correct frequency of large voltage indications in the tail of the cumulative probability distribution, which is important for the SLB leak rate and burst probability analyses. Each Byron-1 SG has a sufficiently large number (>200 indications) to adequately define a SG-dependent growth rate. Combining SGs to obtain the cumulative growth distributions could result in non-conservative or overly conservative distributions depending on the SGs selected for the combination.

The results for SG-C are presented in sections 8.3 and 8.4, below. The SG-A BOC-7 distribution used to determine the EOC-7 distribution, and the EOC-7 distribution determined using the Table 4-7 voltage growths are shown in Table 8-1 and plotted in Figure 8-1. The SG-A EOC-6 leak rate of 2.0 gpm (based on the actual EOC-6 voltage distribution) and projected EOC-7 leak rate of 4.6 gpm were both lower than the SG-C values of 2.3 gpm and 5.1 gpm, respectively. Likewise, the SG-A EOC-6 burst probability of 1.26×10^{-2} and projected EOC-7 burst probability of 2.94×10^{-2} were also lower than the SG-C values of 1.90×10^{-2} and 3.29×10^{-2}, respectively. SG-C was therefore determined to be the limiting SG for leak and burst considerations, and was the focus of further analysis.

8.2 Input Distributions

Tables 4-1 and 4-4 provided the final EOC-6 voltage distribution and the repaired indication distribution for SG-C, defining the actual BOC-7 distribution. Each of these distributions was developed according to the descriptions provided in section 7 of alternate POD methods, and is shown in Table 8-2 and Figure 8-2. Comparing the total number of indications for each

BOC distribution in Table 8-2, the POD of 0.6 provides about twice as many indications as the POD of 1.0, and includes 0.7 BOC indications for each repaired indication above 3.0 volt. POD1 (EPRI) and POD2 (POPCD) provide intermediate BOC distributions to the 0.6 and 1.0 PODs, with POD2 being slightly more conservative in the total number of indications and largest indications.

8.3 Projected MOC-7 Voltage Distribution

The projected mid-cycle 7 (MOC-7) bobbin voltage distributions are shown in Table 8-3 and Figure 8-3 for each of the PODs applied to the SG-C BOC-7 voltages. The Reference 11.3 method for determining the largest EOC voltage with Monte Carlo analysis was used. The maximum projected EOC-7 voltage is therefore a fractional 0.3 indications, for the POD = 0.6 adjusted distribution, at 11.5 volts. The largest MOC-7 voltage for the distribution of all indications without POD adjustment (POD = 1.0) is 6.5 volts. The more significant factor in determining the largest projected voltage for POD1, POD2, and POD=1.0, which all employ a POD=1.0 above 3.0 volts, is the growth distribution. Therefore, the maximum voltages for each of these three PODs are relatively close at 6.7, 6.8, and 6.5 volts, respectively. The total number of MOC indications for each POD applied in Table 8-3 is essentially the same as the number of total indications in the BOC distribution of Table 8-2, with slight variation due to roundoff.

8.4 Projected EOC-7 Voltage Distribution

The projected end-of-cycle 7 (EOC-7) bobbin voltage distributions are shown in Table 8-4 and Figure 8-4 for each of the PODs applied to the SG-C BOC-7 voltages. The maximum projected EOC-7 voltage (a fractional 0.3 indications) for the POD = 0.6 adjusted distribution is 11.7 volts, higher by 0.2 volts than the MOC-7 projection. The proximity of these values is due to the presence of the assumed 0.7 indications of 10.95 volts in the tail of the POD=0.6 BOC distribution. Application of the growth distribution for the full cycle as compared to a partial cycle increases the number, but not the magnitude, of the largest indications for POD=0.6. The largest EOC-7 voltage for the distribution of all indications without POD adjustment (POD = 1.0) is 9.8 volts. Again, for POD1, POD2, and POD=1.0, the maximum voltages are relatively close at 10.2, 10.2, and 9.8 volts, respectively. Figures 8-5 and 8-6 shown the EOC-7 and MOC-7 projected distributions for POD=0.6 versus the BOC-7 distribution, respectively.

Table 8-1
Byron 1 SG-A EOC-7 Projected Voltages (Limiting SG Analysis)

'94 Volts	EOC-6 Indications	EOC-6 Repaired	BOC-7 POD=0.6	EOC-7 Projected
0.2	4	0	6.7	0.0
0.3	57	6	89.0	5.0
0.4	105	16	159.0	18.0
0.5	105	10	165.0	41.0
0.6	106	15	161.7	65.0
0.7	82	15	121.7	86.0
0.8	73	13	108.7	101.0
0.9	66	18	92.0	105.0
1.0	47	11	67.3	103.0
1.1	34	31	25.7	98.0
1.2	31	25	26.7	88.0
1.3	28	23	23.7	76.0
1.4	18	17	13.0	64.0
1.5	6	4	6.0	52.0
1.6	6	5	5.0	40.0
1.7	4	4	2.7	32.0
1.8	4	4	2.7	24.0
1.9	4	4	2.7	18.0
2.0	5	5	3.3	14.0
2.1	2	2	1.3	10.0
2.2	3	3	2.0	9.0
2.3	1	1	0.7	7.0
2.4	2	2	1.3	6.0
2.5	1	1	0.7	5.0
2.6	1	1	0.7	4.0
2.7	0	0	0.0	3.0
2.8	0	0	0.0	2.0
2.9	0	0	0.0	3.0
3.0	0	0	0.0	1.0
3.1	2	2	1.3	1.0
3.2	0	0	0.0	1.0
3.3	0	0	0.0	1.0
3.4	1	1	0.7	1.0
3.6	0	0	0.0	1.0
3.8	0	0	0.0	1.0
4.0	1	1	0.7	0.0
4.2	0	0	0.0	1.0
5.0	0	0	0.0	1.0
6.0	1	1	0.7	0.0
6.1	0	0	0.0	1.0
6.4	0	0	0.0	1.0
6.7	0	0	0.0	1.0
7.0	0	0	0.0	1.0
7.1	1	1	0.7	0.0
7.5	0	0	0.0	1.0
7.7	1	1	0.7	0.0
8.1	0	0	0.0	0.7
8.7	0	0	0.0	0.3
Total	802	243	1093.7	1094.0
Total > 1V	157	139	122.7	570.0

Table 8-2
BOC-7 Voltage Distributions for Byron-1 SG-C

'94 Volts	No. of Bobbin Indications	No. of Indications Repaired	BOC Distributions			
			POD=0.6	POD1 (EPRI)	POD2 (POPCD)	POD=1.0
0.3	13	0	21.7	19.7	20.3	13.0
0.4	45	5	70.0	61.2	63.9	40.0
0.5	92	6	147.3	125.4	132.0	86.0
0.6	95	7	151.3	123.1	132.7	88.0
0.7	130	25	191.7	146.1	162.5	105.0
0.8	116	21	172.3	125.8	143.2	95.0
0.9	89	9	139.3	99.5	114.6	80.0
1.0	92	17	136.3	91.2	108.5	75.0
1.1	59	47	51.3	21.6	32.0	12.0
1.2	40	30	36.7	16.0	22.6	10.0
1.3	33	27	28.0	10.5	15.7	6.0
1.4	26	24	19.3	5.2	9.1	2.0
1.5	17	16	12.3	2.9	5.3	1.0
1.6	10	9	7.7	2.0	3.3	1.0
1.7	13	12	9.7	2.1	3.7	1.0
1.8	8	8	5.3	0.6	1.5	0.0
1.9	4	4	2.7	0.3	0.7	0.0
2.0	4	4	2.7	0.2	0.6	0.0
2.1	2	1	2.3	1.1	1.3	1.0
2.2	1	1	0.7	0.0	0.1	0.0
2.3	1	1	0.7	0.0	0.1	0.0
2.4	1	1	0.7	0.0	0.1	0.0
2.5	2	2	1.3	0.1	0.1	0.0
2.6	1	1	0.7	0.0	0.1	0.0
2.7	2	2	1.3	0.0	0.1	0.0
3.64	1	1	0.7	0.0	0.0	0.0
3.80	1	1	0.7	0.0	0.0	0.0
10.95	1	1	0.7	0.0	0.0	0.0
Total	899	283	1215.3	854.8	973.9	616.0
Total > 1V	227	193	185.3	62.7	96.3	34.0

Table 8-3
Projected MOC-7 Voltage Distributions for Byron-1 SG-C

'94 Volts	POD Applied			
	POD=0.6	POD1 (EPRI)	POD2 (POPCD)	POD=1.0
0.3	2.0	2.0	2.0	1.0
0.4	14.0	12.0	12.0	8.0
0.5	38.0	33.0	35.0	22.0
0.6	68.0	57.0	61.0	40.0
0.7	101.0	83.0	89.0	58.0
0.8	124.0	98.0	107.0	70.0
0.9	140.0	109.0	120.0	79.0
1.0	140.0	104.0	117.0	78.0
1.1	127.0	91.0	104.0	68.0
1.2	110.0	76.0	89.0	57.0
1.3	88.0	57.0	68.0	43.0
1.4	67.0	42.0	50.0	30.0
1.5	50.0	28.0	35.0	21.0
1.6	36.0	19.0	25.0	13.0
1.7	27.0	13.0	17.0	8.0
1.8	19.0	8.0	12.0	6.0
1.9	15.0	6.0	8.0	4.0
2.0	11.0	5.0	6.0	2.0
2.1	8.0	3.0	4.0	2.0
2.2	6.0	2.0	3.0	1.0
2.3	5.0	1.0	3.0	1.0
2.4	3.0	2.0	2.0	1.0
2.5	3.0	1.0	1.0	1.0
2.6	2.0	0.0	1.0	0.0
2.7	2.0	1.0	1.0	0.0
2.8	2.0	0.0	1.0	1.0
2.9	1.0	1.0	1.0	0.0
3.0	1.0	0.0	0.0	0.0
3.2	1.0	0.0	1.0	0.0
3.6	1.0	0.0	0.0	0.0
4.3	1.0	0.0	0.0	0.0
5.5	0.0	1.0	0.0	0.0
5.7	0.0	0.0	1.0	0.7
5.8	1.0	0.0	0.0	0.0
6.1	0.0	0.7	0.0	0.0
6.3	0.0	0.0	0.7	0.0
6.5	0.0	0.0	0.0	0.3
6.7	0.0	0.3	0.0	0.0
6.8	0.0	0.0	0.3	0.0
9.4	0.7	0.0	0.0	0.0
11.5	0.3	0.0	0.0	0.0
Total	1215.0	856.0	977.0	616.0
Total > 1V	588.0	358.0	434.0	260.0

Table 8-4
Projected EOC-7 Voltage Distributions for Byron-1 SG-C

	POD Applied			
'94 Volts	POD=0.6	POD1 (EPRI)	POD2 (POPCD)	POD=1.0
0.3	2.0	2.0	2.0	1.0
0.4	11.0	10.0	10.0	7.0
0.5	30.0	26.0	28.0	17.0
0.6	53.0	44.0	47.0	31.0
0.7	74.0	60.0	64.0	42.0
0.8	95.0	76.0	83.0	54.0
0.9	108.0	84.0	92.0	61.0
1.0	119.0	90.0	101.0	66.0
1.1	115.0	85.0	95.0	63.0
1.2	105.0	75.0	86.0	55.0
1.3	96.0	66.0	77.0	50.0
1.4	84.0	57.0	66.0	41.0
1.5	67.0	43.0	52.0	32.0
1.6	55.0	34.0	41.0	24.0
1.7	44.0	26.0	32.0	19.0
1.8	34.0	19.0	23.0	13.0
1.9	26.0	13.0	18.0	10.0
2.0	20.0	11.0	13.0	7.0
2.1	15.0	7.0	9.0	5.0
2.2	12.0	5.0	8.0	3.0
2.3	9.0	5.0	5.0	3.0
2.4	7.0	3.0	4.0	2.0
2.5	6.0	2.0	4.0	2.0
2.6	5.0	2.0	3.0	1.0
2.7	3.0	2.0	2.0	1.0
2.8	3.0	1.0	2.0	1.0
2.9	3.0	2.0	1.0	1.0
3.0	2.0	0.0	1.0	0.0
3.1	1.0	1.0	1.0	1.0
3.2	2.0	0.0	1.0	0.0
3.3	1.0	1.0	1.0	0.0
3.4	1.0	0.0	0.0	1.0
3.5	0.0	1.0	1.0	0.0
3.6	1.0	0.0	0.0	0.0
3.7	1.0	0.0	1.0	0.0
3.8	0.0	1.0	0.0	1.0
3.9	1.0	0.0	0.0	0.0
4.0	0.0	0.0	1.0	0.0
4.1	1.0	0.0	0.0	0.0
4.6	1.0	0.0	0.0	0.0
8.3	0.0	1.0	0.0	0.0
8.6	0.0	0.0	1.0	0.7
8.7	1.0	0.0	0.0	0.0
9.3	0.0	0.7	0.0	0.0
9.5	0.0	0.0	0.7	0.0
9.8	0.0	0.0	0.0	0.3
10.2	0.0	0.3	0.3	0.0
10.7	0.7	0.0	0.0	0.0
11.7	0.3	0.0	0.0	0.0
Total	1215.0	856.0	977.0	616.0
Total > 1V	723.0	464.0	550.0	337.0

Figure 8-1. BOC-7 and Projected EOC-7 Voltage Distribution for Byron-1 SG-A

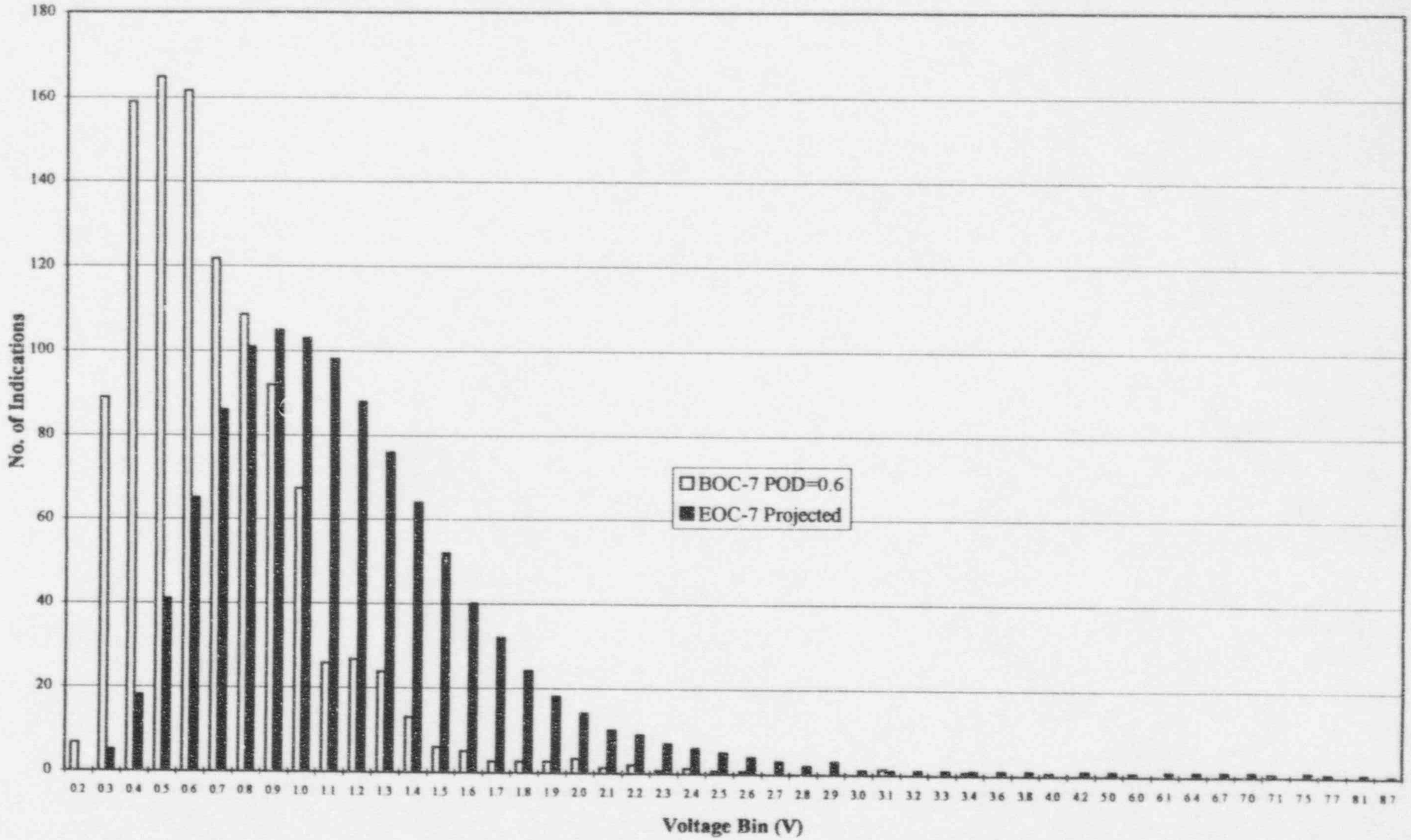


Figure 8-2. SG-C BOC-7 Voltage Distributions for Various PODs

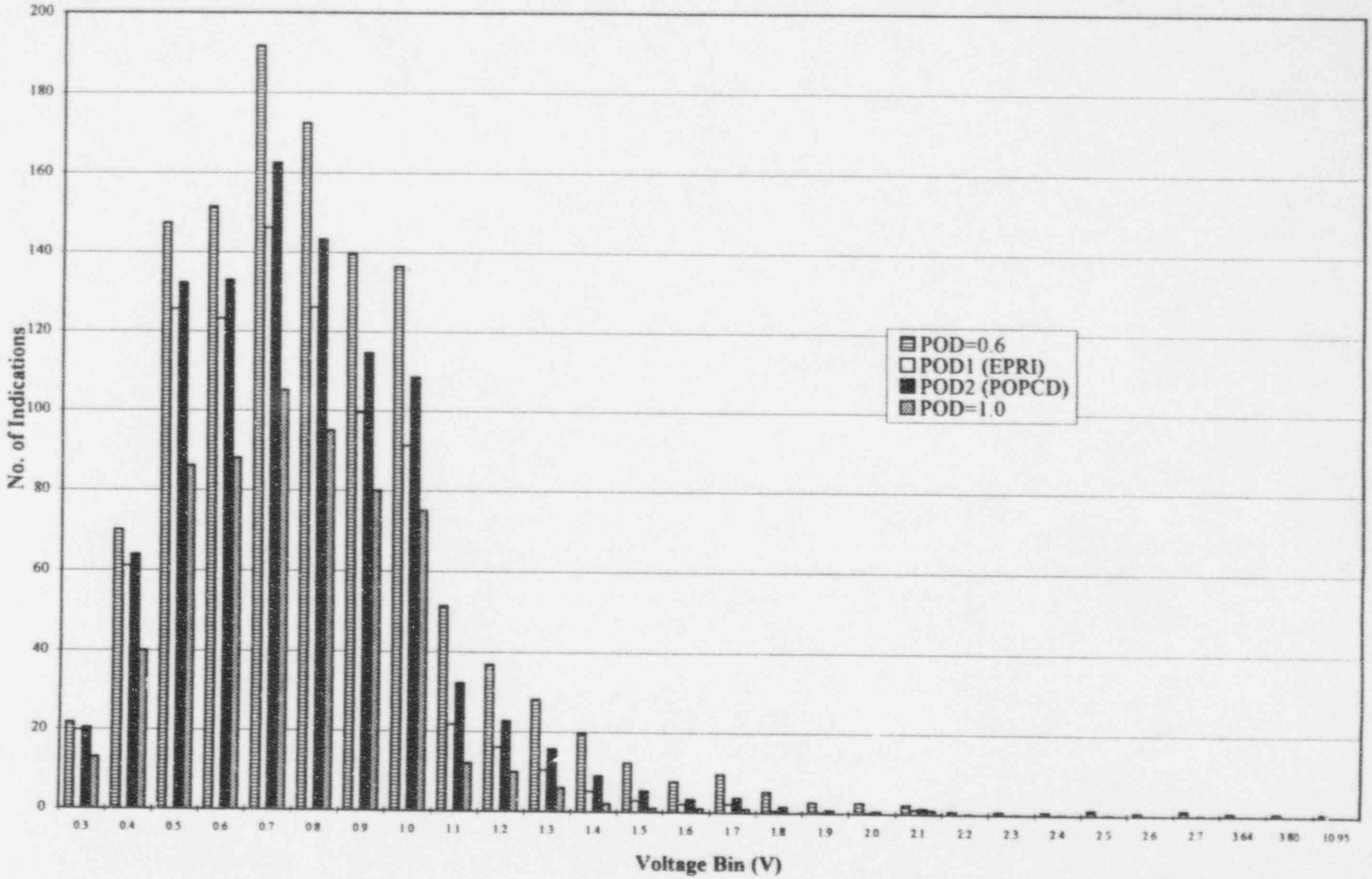


Figure 8-3. SG-C MOC-7 Projected Voltage Distributions for Various PODs

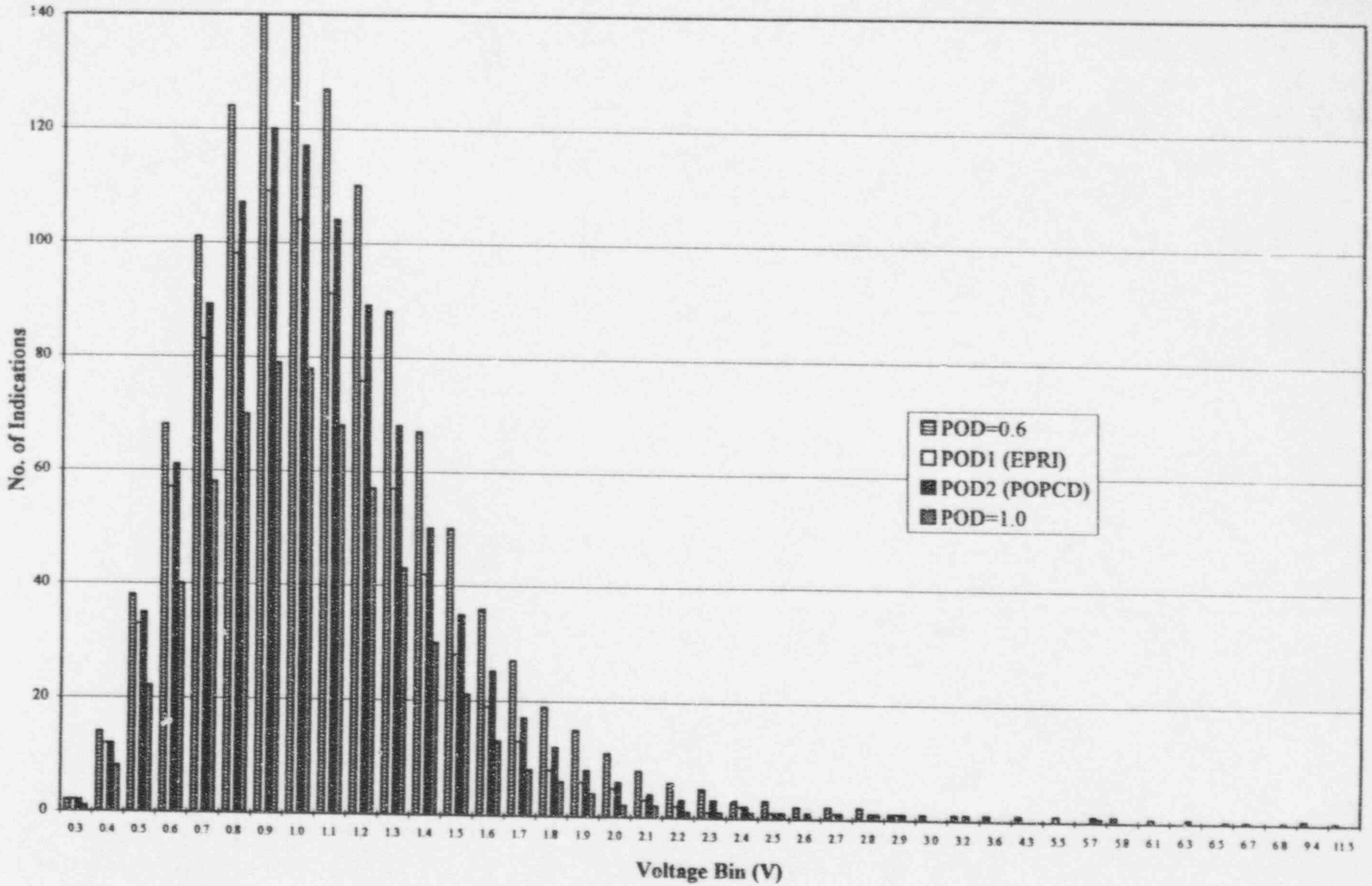


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Figure 8-4. SG-C EOC-7 Projected Voltage Distributions for Various PODs

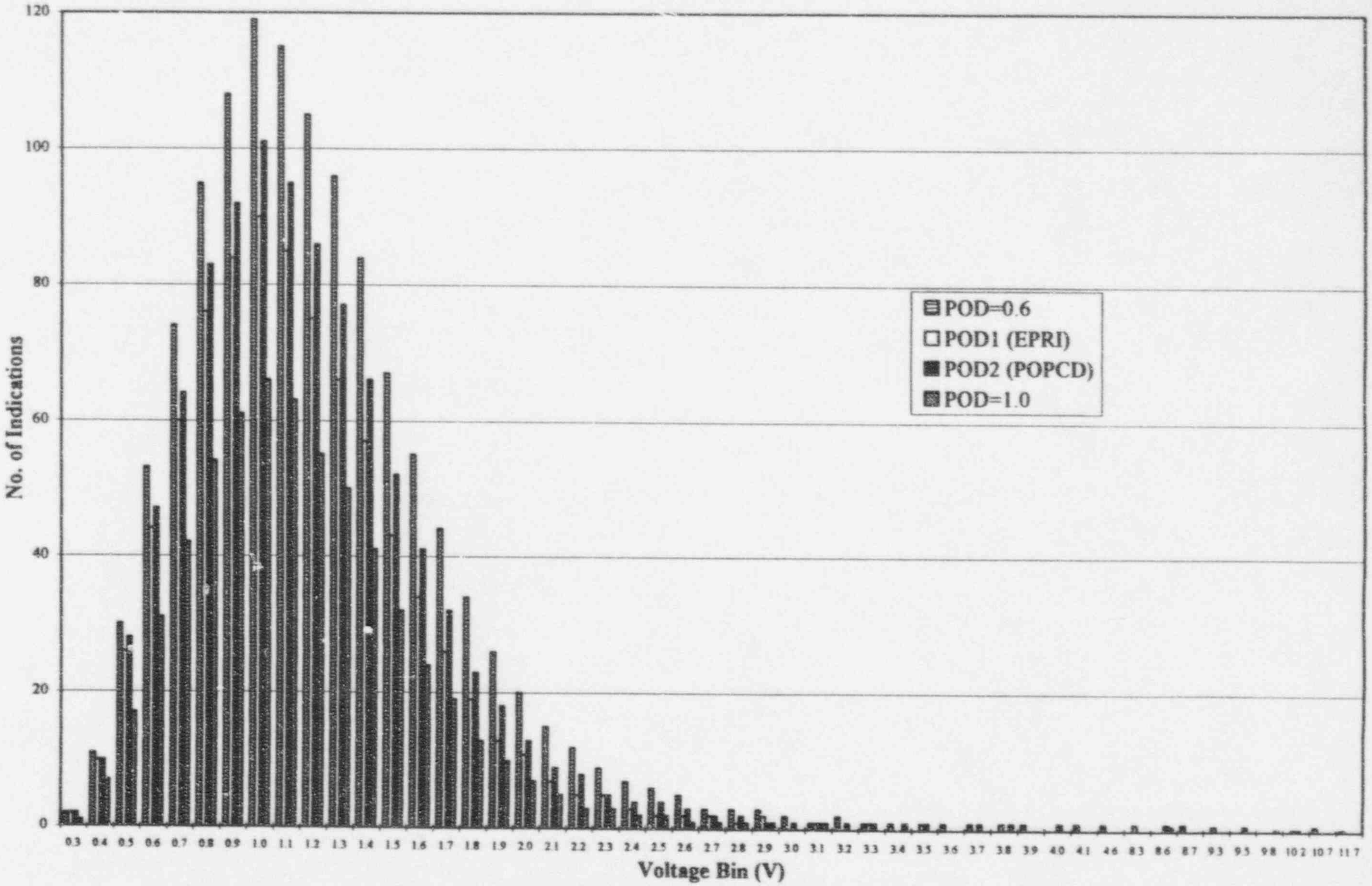

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Figure 8-5: Byron-1, SG-C Projected EOC-7 Voltage Distribution vs. BOC-7 Distribution Adjusted by PoD=0.6

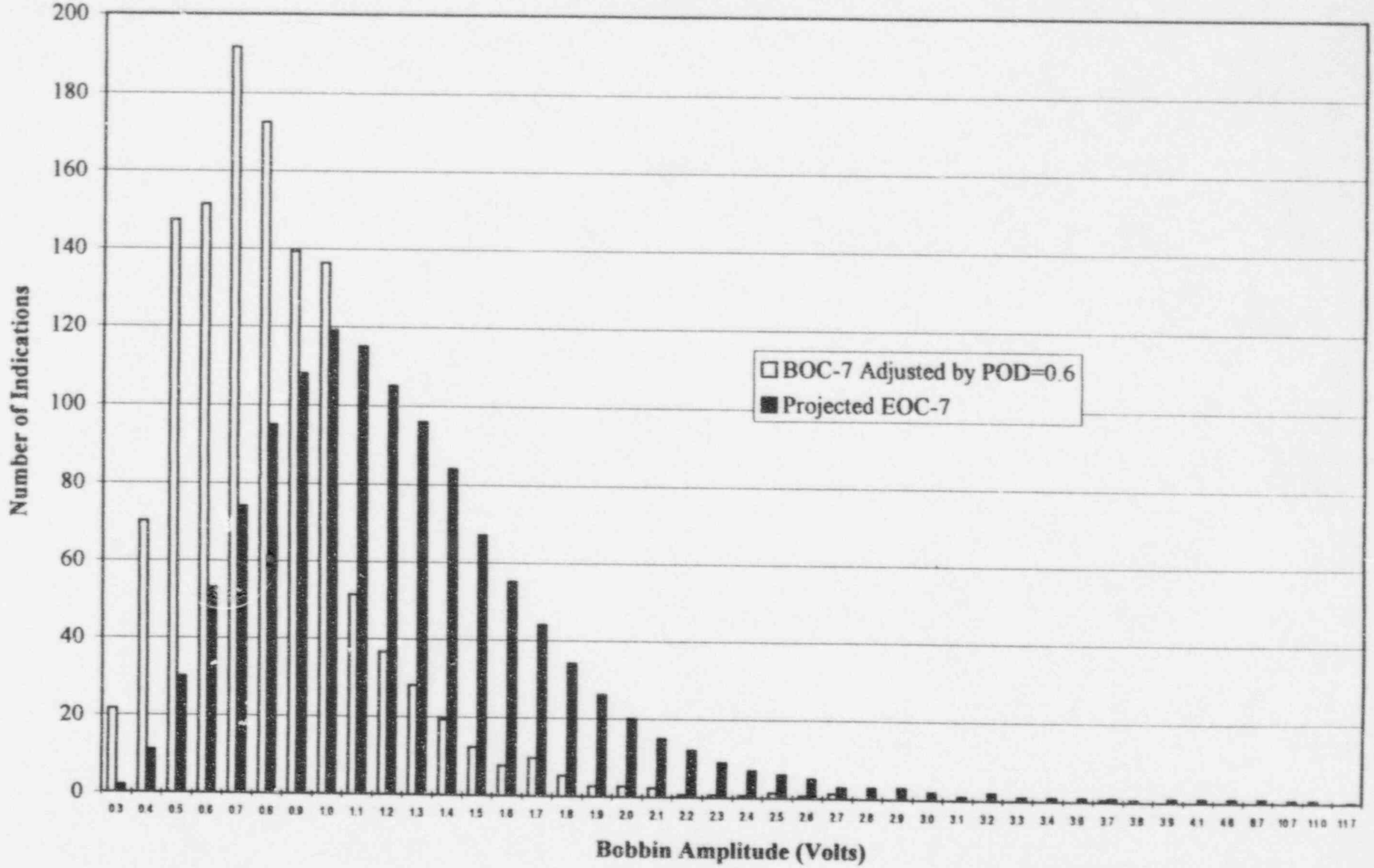
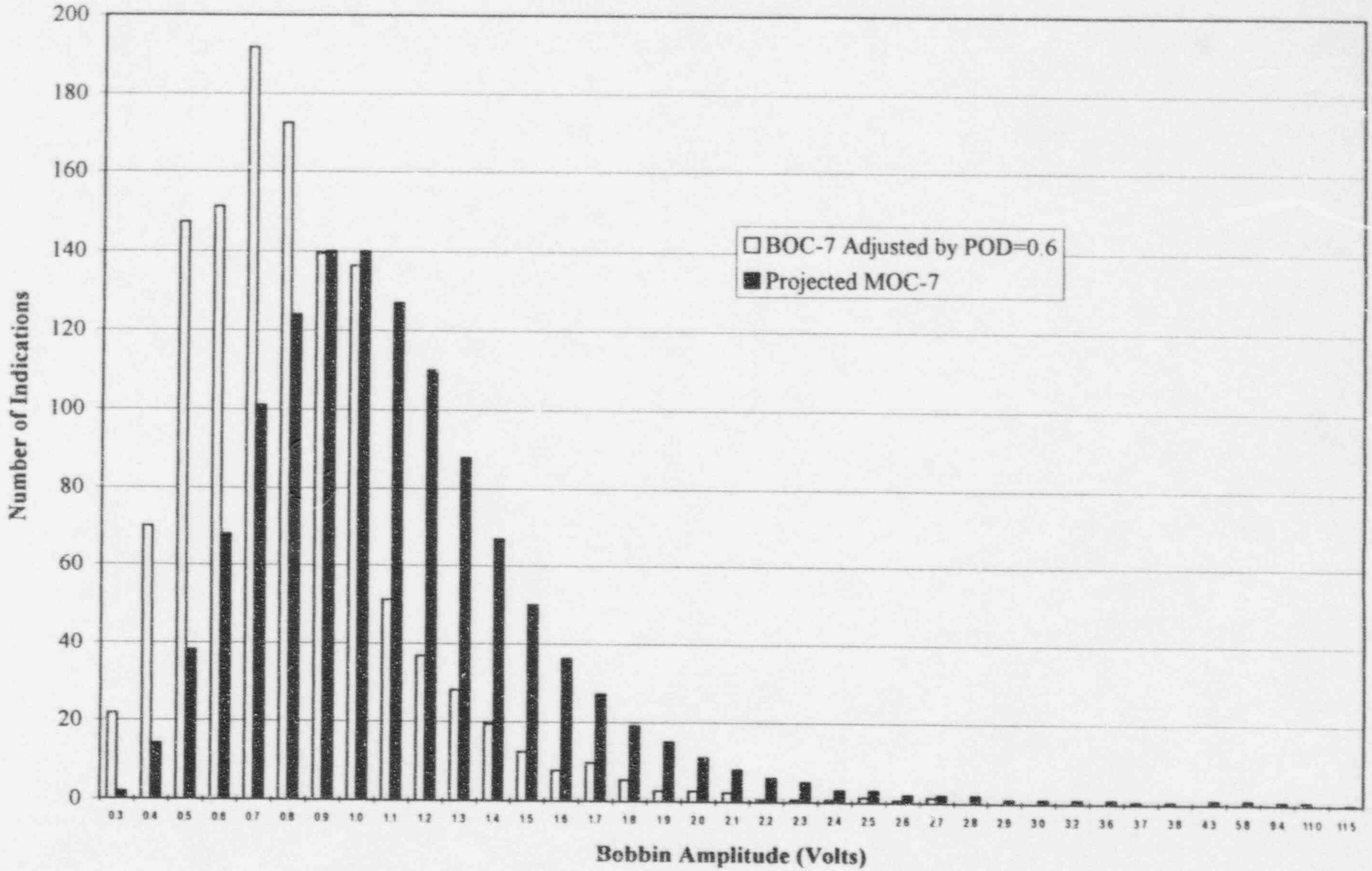


Figure 8-6: Byron-1, SG-C Projected MOC-7 Voltage Distribution vs. BOC-7 Distribution Adjusted by PoD=0.6



9.0 SLB LEAK RATE ANALYSIS RESULTS

9.1 SLB Leak Rates for EOC-6 Actual and BOC-7 Distribution

A SLB leak rate was calculated for the actual SG-C EOC-6 voltage distribution of 899 indications (i.e., regardless of RPC confirmation) shown in Table 4-1. The largest indications in this distribution were 10.95, 3.80, and 3.64 volts; remaining voltages were less than 2.7 volts. The results of the SLB leak rate analyses are given in Table 9-1. SLB leak rates were determined by averaging the results of Monte Carlo simulations for runs of 50,000 samples; 20 runs in all gave results for a total of one million simulations. The leak rate of 2.3 gpm is a 95% cumulative probability value. The allowable leak rate for the faulted SG, as discussed in the Byron-1 SER (Ref. 11.1), is 12.5 gpm, so significant margin was present at EOC-6.

The BOC-7 SLB leak rates were also calculated for each of the four POD-dependent SG-C voltage distributions described in Table 8-2. The respective SLB leak rates and number of Monte Carlo simulations are given in Table 9-1. A factor of 60 difference is observed between a POD of 0.6 compared to POD=1.0. This large difference is due to the large fractional numbers of indications in the upper voltage range for the POD=0.6 distribution. The leak rates for POD1 and POD2 are, as expected, both much closer to the POD=1.0 estimate than the 0.6 estimate, since they both employ a POD of 1.0 above 3.0 volts.

9.2 Projected SLB Leak Rates for Potential Mid-Cycle Voltage Distribution

The mid-cycle 7 SLB leak rates were calculated for each of the four projected SG-C MOC-7 voltage distributions described in Table 8-3. These SLB leak rates are given in Table 9-1. A factor of 5 difference is observed between a POD of 0.6 compared to POD=1.0, since a number of larger voltage indications have entered the MOC-7 voltage distribution. The POD1 and POD2 distributions again provide leak rates intermediate to the POD=0.6 and =1.0 distributions, with POD2 being slightly more conservative than POD1.

9.3 Projected SLB Leak Rates for EOC-7 Voltage Distribution

The projected EOC-7 leak rate for SG-C with a POD = 0.6 (NRC draft generic letter) is 5.1 gpm. This leak rate is less than the allowable SLB leak rate for Byron-1 and thus is acceptable to the guidelines of the NRC draft generic letter.

Table 9-1 also includes the calculated SLB leak rate for the projected EOC-7 distribution based on the alternate POD distributions described in Section 7. It is seen that the more realistic, voltage-dependent POD1 and POD2 analyses result in SLB leak rates of 3.1 and 3.5 gpm which approach the ideal POD = 1.0 result of 1.7 gpm. This results as all of the largest 29 bobbin indications (29 >1.8 volts including 3 above 3.6 volts) were plugged at EOC-6. The POD = 0.6 results in 0.67 indications left in service for each plugged indication while the voltage-dependent PODs result in smaller fractional indications left in service below 3.0 volts and no indications left in service above 3.0 volts.

For Byron-1, the influence of POD on the SLB leak rates is significantly offset by the larger growth rate effect for the EOC-7 projections. With the larger growth rates, the EOC distribution includes comparable maximum voltages with or without a POD correction although the higher PODs result in fewer high voltage indications. The larger difference between POD = 0.6 and 1.0 is more apparent in the BOC-7 analyses in Table 9-1 with leak rates of 1.8 and 0.03, respectively.

Table 9-1
Byron-1, S/G C: Summary of SLB Monte Carlo Analysis Results[1]

Analysis Basis	SLB Leak Rate (gpm)	Tube Burst Probability Analyses				
		No. Monte Carlo S/G Samples	Total Burst Prob.	Single Tube Burst Prob.	Two Tube Burst Prob.	Three Tube Burst Prob.
EOC-6 Actual Voltage Distribution						
Actual Volts	2.3	1000K	1.90×10^{-2}	1.90×10^{-2}	4.74×10^{-6}	3.00×10^{-6}(2)
BOC-7(3)						
POD = 0.6	1.8	500K	1.36×10^{-2}	1.36×10^{-2}	3.05×10^{-5}	8.39×10^{-6}(2)
POD1(EPRI)	0.04	500K	2.19×10^{-4}	2.19×10^{-4}	5.99×10^{-6}(2)	5.99×10^{-6}(2)
POD2(POPCD)	0.06	500K	3.28×10^{-4}	3.27×10^{-4}	7.19×10^{-6}(2)	5.99×10^{-6}(2)
POD = 1.0	0.03	500K	1.53×10^{-4}	1.53×10^{-4}	5.99×10^{-6}(2)	5.99×10^{-6}(2)
Projected Mid-Cycle 7						
POD = 0.6	2.5	1000K	1.92×10^{-2}	1.91×10^{-2}	1.66×10^{-4}	7.84×10^{-6}
POD1(EPRI)	1.0	200K	5.18×10^{-3}	5.17×10^{-3}	1.95×10^{-5}	1.50×10^{-5}(2)
POD2(POPCD)	1.2	750K	5.91×10^{-3}	5.91×10^{-3}	5.19×10^{-6}	3.99×10^{-6}(2)
POD = 1.0	0.52	500K	3.36×10^{-3}	3.26×10^{-3}	1.20×10^{-4}	5.99×10^{-6}(2)
Projected EOC-7 Voltage Distribution						
POD = 0.6	5.1	1000K	3.29×10^{-2}	3.15×10^{-2}	1.46×10^{-3}	3.00×10^{-6}(2)
POD1(EPRI)	3.1	1000K	2.29×10^{-2}	2.28×10^{-2}	1.39×10^{-4}	3.00×10^{-6}(2)
POD2(POPCD)	3.5	350K	2.53×10^{-2}	2.49×10^{-2}	4.86×10^{-4}	8.56×10^{-6}(2)
POD = 1.0	1.7	400K	1.22×10^{-2}	1.21×10^{-2}	1.11×10^{-4}	7.49×10^{-6}(2)

Notes:
1. Monte Carlo analyses at 95% confidence based on NRC database.
2. No occurrences of multiple tube bursts were found in Monte Carlo analyses. Burst probabilities given represent upper 95% confidence based on no occurrences in stated number of Monte Carlo samples.
3. These calculations were performed with a later version of the Monte Carlo code. The code differences do not significantly affect EOC calculations.

10.0 SLB TUBE BURST PROBABILITY ANALYSIS RESULTS

Limited TSP displacement burst probabilities are more representative of expected Byron-1 conditions than the free span burst probability analysis required by the draft generic letter. The limited TSP displacement burst probabilities of Reference 11.7 are summarized in Section 10.1 to represent the expected Byron-1 tube burst probabilities. However, the NRC draft generic letter and the Byron-1 SER require SLB burst probabilities to be conservatively calculated as free span indications. These required, more conservative burst probabilities are given in Sections 10.2 to 10.5.

10.1 SLB Burst Probability Based on Byron-1 Limited TSP Displacements

The study performed in Ref. 11.7 provides the basis for burst probability calculations for Byron-1 based on the limited tube/TSP displacement during SLB. A bounding estimate of the probability of burst of one or more tubes in a SG during a postulated SLB was made by assuming every tube to have a throughwall crack equal to the thickness of the TSP at every TSP intersection. Thus, during a postulated SLB, each intersection was very conservatively postulated to have a throughwall crack exposed by the magnitude of the displacement at that intersection. The probability of burst of one or more tubes is then calculated as the sum of the probabilities of burst of each indication.

The analysis was performed for the actual EOC-6 TSP indications at Byron 1, of which SG-C was the more limiting. The results are shown in Table 10-1. None of the large voltage (> 2.0 volts in this case) indications occurred at tube locations with significant SLB TSP displacements. The indications at R5C1 (1.19 volt), R1C3 (1.74 volt), R3C1 (0.94 volt) and R3C114 (0.51 volt) occur at tube locations with significant TSP displacements of 0.492 to 0.522 inch and dominate the contribution to the limited TSP displacement burst probability of 1.1×10^{-5}. For the indications given in Table 10-1, the free span burst probability is 3.0×10^{-2}.

The results of Table 10-1 show the effectiveness of limited TSP displacements in reducing the tube burst probability to small values and also show that Byron-1 had an acceptably low burst probability at EOC-6. The application of the actual indication distributions reduces the burst probability by more than two orders of magnitude (from 2.9×10^{-3} to 1.1×10^{-5}) compared to the bounding assumption of throughwall indications at all hot leg TSP intersections. The benefits of limited TSP displacement are also seen by the reduction of about three orders of magnitude (3.0×10^{-2} to 1.1×10^{-5}) in the tube burst probabilities compared to the free span IPC analyses.

10.2 Free Span SLB Burst Probability for EOC-6 Actual Distribution

Calculations were performed to determine the free span probability of tube burst using the actual EOC-6 voltage distribution for SG-C, without modifications for repairs or POD considerations. One million Monte Carlo simulations were performed, applying the actual voltage distribution to the leak rate vs. volts correlation with NDE and voltage uncertainties. The calculated total burst probability was 1.90×10^{-2}, which included a negligible contribution for two-tube ruptures and no three-tube ruptures. This exceeds the threshold value of 1.0×10^{-2} established in the SER (Ref. 11.1 Sec 3.0 Item g.4), which requires an assessment of the

safety signficance of this condition.

Assessing this condition, it is noted that the burst probability is dominated by the single large indication of 10.95 volts at R20C7 3H in SG-C. This indication is located fully within the tube support plate thickness, and is in a location of limited (less than 0.15") displacement under SLB conditions, with uncertainty factors included. Thus the larger voltage indications found at EOC-6 would not burst due to the TSP constraint. Moreover, the 10.95 volt indication was pulled and burst tested in the laboratory. The measured burst pressure of 4500 psi is higher than the R.G. 1.121 structural margin requirement of $1.43\Delta P_{SLB}$ = 3660 psi. Thus this indication would not have a significant contribution to the burst probability at EOC-6. Similarly, all other Byron-1 pulled tubes (Section 3) had high burst pressures. Thus the Byron-1 EOC-6 burst probability, as based on pulled tube test results, would be much less than 10^{-2} and the calculated value of 1.90×10^{-2} has negligible safety significance. Since both the Byron-1 and Braidwood-1 (including 5.0 and 10.3 volt indications) pulled tubes had burst pressures well above R.G. 1.121 burst margin guidelines, it can be expected that EOC-7 burst probabilities would also be significantly lower than obtained from the free span burst analyses. Thus both the pulled tube measurements and the limited TSP displacement support low burst probabilities, and significantly lower than the free span analyses.

10.3 Projected Free Span SLB Burst Probability for Potential Mid-Cycle Voltage Distribution

For POD = 0.6, the tube burst probability is not significantly affected by the potential mid-cycle inspection since there is only a factor of two difference between the BOC-7 and EOC-7 results. For POD = 1.0, the mid-cycle burst probability of 3.38×10^{-3} is less than the NRC draft generic letter guideline of 1.0×10^{-2} for reporting to the NRC and is almost a factor of four less than the EOC-7 value of 1.22×10^{-2}. Thus high values for POD at the EOC-6 Byron-1 inspection would result in mid-cycle burst probabilities less than the NRC guideline. This is shown for the POD1 and POD2 results of Table 10-1.

10.4 Projected Free Span SLB Burst Probability for EOC-7 Distribution

Results of the tube burst probability analyses are also given in Table 9-1. The total (sum of single and multiple tube bursts) tube burst probabilities for the assumed POD = 0.6 are 1.90×10^{-2} at EOC-6 and 3.29×10^{-2} for the projected EOC-7 distribution. The total and single tube burst probabilities are approximately equal since the probabilities of multiple tube ruptures are very small. No occurrences of multiple tube ruptures with more than two ruptures were found in the Monte Carlo analyses and the values reported in Table 9-1 for three tube ruptures reflect the 95% confidence limit for the number of Monte Carlo samples with no occurrences. A few occurrences of multiple ruptures (two) occurred but the burst probabilities are significantly lower than the single tube burst probability.

10.5 Burst Probability Dependence on POD

At BOC-7, it is seen that the difference in the burst probability between PODs of 0.6 and 1.0 (1.51×10^{-2} versus 3.10×10^{-4}) is a factor of 50 increase for the very low POD of 0.6. This

difference is principally due to the large voltage indications left in service for POD = 0.6 (0.67 indication left in service for each indication repaired). The factor of 50 difference is reduced to about a factor of 7 at mid-cycle 7 and a factor about 2.7 at EOC-7. The reduced dependence on POD with increasing cycle length for Byron-1 is attributable to the larger growth rates included in the growth distribution for the projections. With the large growth rate tail of the growth distribution, the projections include indications near 10 volts independent of POD although the lower POD values result in more high voltage indications. The largest voltage indications dominate the contribution to the burst probability. This influence of the large voltage indications is also shown by the small increase (factor of 2) in burst probability for POD = 0.6 between BOC-7 and EOC-7, since the POD = 0.6 distribution includes high voltage indications in both the BOC and EOC distributions.

Table 10-1
Byron-1, SG-C Estimated Hot Standby SLB Burst Probability at EOC-6 With Uncertainty Adjustment

Tube/Location			Free Span Burst		Limited TSP Disp. Burst [1]		
Row	Col	TSP	Volts	Burst Prob.	Local TSP Displ.	TW Burst Probability	Applicable SLB Burst Prob. [2]
20	7	3	10.95	2.7E-02	0.128	1.8E-22	~ 0.0
25	13	5	3.80	6.7E-04	< 0.10	9.2E-24	~ 0.0
32	30	3	3.64	5.7E-04	0.100	9.2E-24	~ 0.0
27	98	3	2.68	1.6E-04	0.090	3.2E-24	~ 0.0
47	35	3	2.68	1.6E-04	< 0.10	9.2E-24	~ 0.0
20	102	3	2.58	1.4E-04	0.118	6.2E-23	~ 0.0
21	98	3	2.50	1.2E-04	0.111	2.9E-23	~ 0.0
27	59	3	2.45	1.1E-04	< 0.10	9.2E-24	~ 0.0
16	59	3	2.38	1.0E-04	< 0.10	9.2E-24	~ 0.0
27	93	3	2.29	8.5E-05	0.116	5.0E-23	~ 0.0
35	26	3	2.14	6.4E-05	0.105	1.6E-23	~ 0.0
12	3	3	2.10	5.9E-05	0.344	4.0E-12	~ 0.0
46	52	5	2.02	5.0E-05	< 0.10	9.2E-24	~ 0.0
9	3	3	1.99	4.7E-05	0.394	6.2E-10	6.2E-10
46	70	5	1.99	4.7E-05	< 0.10	9.2E-24	~ 0.0
18	42	3	1.97	4.5E-05	< 0.10	9.2E-24	~ 0.0
25	10	3	1.95	4.3E-05	< 0.10	9.2E-24	~ 0.0
40	78	5	1.88	3.7E-05	< 0.10	9.2E-24	~ 0.0
40	65	3	1.85	3.4E-05	< 0.10	9.2E-24	~ 0.0
12	74	5	1.81	3.1E-05	< 0.10	9.2E-24	~ 0.0
5	1	3	1.19	5.0E-06	0.500	5.3E-06	5.0E-06
1	3	3	1.74	2.6E-05	0.492	2.9E-06	2.9E-06
3	1	3	0.94	1.8E-06	0.522	2.5E-05	1.8E-06
2	2	3	0.70	5.0E-07	0.507	8.8E-06	5.0E-07
7	2	3	1.00	2.4E-06	0.446	7.2E-08	7.2E-08
8	2	3	0.65	3.6E-07	0.431	1.9E-08	1.9E-08
1	6	3	0.72	5.6E-07	0.412	3.4E-09	3.4E-09
2	6	3	0.68	4.4E-07	0.402	1.3E-09	1.3E-09
8	4	3	0.71	5.3E-07	0.385	2.6E-10	2.6E-10
5	5	3	0.72	5.6E-07	0.397	8.3E-10	8.3E-10
6	4	3	1.00	2.4E-06	0.411	3.1E-09	3.1E-09
4	112	3	0.56	1.9E-07	0.458	2.0E-07	1.9E-07
3	114	3	0.51	1.3E-07	0.522	2.5E-05	1.3E-07
4	111	3	0.44	6.7E-08	0.433	2.3E-08	2.3E-08
4	110	3	1.11	3.7E-06	0.408	2.4E-09	2.4E-09
2	109	3	0.74	6.3E-07	0.402	1.3E-09	1.3E-09
8	111	3	1.11	3.7E-06	0.385	2.6E-10	2.6E-10
Total Burst Probability				3.0E-02			1.1E-05

Notes:
1. Analysis conservatively assumes the TSP displacement exposes a throughwall crack equal to the displacement.
2. The applicable burst probability is the lesser of the free span and TW burst probabilities.

11.0 REFERENCES

11.1 NRC Letter, "Safety Evaluation by the Office of Nuclear Reactor Regulation Related to Amendment No. 66 to Facility Operating License No. NPF-37 and Amendment No. 36 to Facility Operating License No. NPF-66; Commonwealth Edison Company Byron Station Unit Nos. 1 and 2; Docket Nos. STN 50-454 and STN 50-455", USNRC. November 1994.

11.2 NRC Generic Letter 94-XX, "Voltage-Base Repair Criteria for the Repair of Westinghouse Steam Generator Tubes Affected by Outside Diameter Stress Corrosion Cracking", USNRC Office of Nuclear Reactor Regulation, August 1994.

11.3 CAE-94-233, "Byron-1 S/G EOC-6 IPC SLB Leak Rate and Tube Burst Probability Assessment", Westinghouse Electric Corp., Nuclear Services Division, October 17, 1994.

11.4 NP-7480-L Volume 2, SG-93-10-102, "Steam Generator Tubing Outside Diameter Stress Corrosion Cracking at Tube Support Plates - Database for Alternate Repair Criteria, Volume 2: 3/4 Inch Diameter Tubing", EPRI Report, October 1993.

11.5 NSD-RFK-95-002, "SLB Leak Rate and Tube Burst Probability Analysis Methods for ODSCC at TSP Intersections", Westinghouse Electric Corp., Nuclear Services Division, January 1995.

11.6 WCAP-14046 Rev. 1, "Braidwood Unit 1 Technical Support for Cycle 5 Steam Generator Interim Plugging Criteria", Westinghouse Electric Corp., Nuclear Services Division, August 1994.

11.7 WCAP-14222, "Braidwood Unit 1 and Byron Unit 1 Model D4 Steam Generator Limited Tube Support Plate Displacement Analysis in Support of Interim Plugging Criteria", Westinghouse Electric Corp., Nuclear Services Division, November 1994.

11.8 TR-100407, Revision 1 (draft), "PWR Steam Generator Tube Repair Limits - Technical Support for Outside Diameter Stress Corrosion Cracking at Tube Support Plates," Electric Power Research Institute, August 1993.