SG-93-11-015
Revision 2

FARLEY-2
CYCLE 9 IPC ASSESSMENT AND PROJECTED EOC-10 SLB LEAKAGE

January 14, 1994

Prepared By:

T.A. Pitterle
R.F. Keating
R. Waisman
D.D. Malinowski

Westinghouse Electric Corporation
Nuclear Service Division

FARLEY-2

CYCLE 9 IPC ASSESSMENT AND PROJECTED EOC-10 SLB LEAKAGE

TABLE OF CONTENTS

FARLEY-2
CYCLE 9 IPC ASSESSMENT AND PROJECTED EOC-10 SLB LEAKAGE

TABLE OF CONTENTS
(CONTINUED)

1.0 INTRODUCTION

This report provides a Cycle 9 IPC assessment and projected EOC-10 SLB leakage for Farley Unit-2 steam generators. Included in this report is information requested by the NRC Safety Evaluation Report for application of the IPC for Cycle 10. This information includes comparisons of projected EOC-9 bobbin voltage distributions with actual values found in the EOC-9 inspection, projections of EOC-10 voltage distributions based on indications left in service at BOC-10, projected potential SLB leak rates at EOC-10 and tube burst probability at EOC-10.

The Farley-2 EOC-9 S/G eddy current inspection represents the first full cycle inspection following implementation of IPC repair limits. Thus the EOC-9 inspection results provide the first opportunity to compare actual voltage distributions with projected values. Alternate methods for defining BOC indications left in service are used to project EOC voltage distributions for comparisons with the actual EOC-9 inspection results. The alternate methods for defining BOC indications evaluated include the NRC recommended method of draft NUREG-1477 which includes RPC NDD and adjustments for a probability of detection of 0.6, a distribution including RPC NDD with no adjustment for detection probability and a distribution of indications less than the repair limit of 1.0 volt which ignores RPC NDD indications as well as no adjustment for probability of detection. In addition, an alternate or recommended method for defining the BOC distribution is evaluated. This method assumes that a fraction of the RPC NDD indications may be undetected flaws and accounts for undetected BOC indications based on the prior cycle voltages for new indications found in the latest inspection.

The Monte Carlo methods of the Farley APC WCAP-12871, Revision 2 are applied to the BOC voltage distributions to project the EOC distributions. This is consistent with the NRC guidance given in the Farley-2 SER. SLB leak rates are calculated using the NRC methodology of draft NUREG-1477 as well as the IPC/APC methods described in WCAP-12871 which utilize Monte Carlo methods applying the APC correlations for probability of leakage and SLB leak rate. S/G C is the most limiting S/G for SLB leakage and burst considerations for both Cycles 9 and 10 as this S/G has the largest number of indications left in service. The latest correlations of EPRI Report NP-7480-L, Volume 2, Revision 1 are applied in this report. Tube burst probability analyses apply the WCAP-12871 methodology and the latest EPRI burst pressure versus bobbin voltage correlations. Consistent with the guidance of the Farley-2 SER, analysis data such as voltage distributions and growth rates are given in both graphical and tabulated form. Tabulated data are given in an appendix of this report.

2.0 SUMMARY AND CONCLUSIONS

2.1 Overall Conclusions

The distribution of voltages found by inspection at EOC-9 in 1993 is in good agreement with the projections made at EOC-8 in 1992. As a consequence, SLB leak rates and tube burst probabilities were acceptable in Cycle 9 and consistent with the correlations used to perform the analyses. In addition, the agreement between projected and actual voltage distributions found at EOC-9 enhances the confidence in projections made for the end of the next operating cycle (EOC-10). EOC-10 projections were made applying the NRC model of Draft NUREG-1477 to define the BOC distribution with a probability of detection (POD) adjustment factor of 0.6, the NRC SLB leak rate model and the correlation of burst pressure with voltage to obtain the SLB tube burst probability. The resulting EOC-10 SLB leak rate is estimated at 0.27 gpm which is well below the allowable limit of 22.8 gpm for Farley-2 cycle 10. The projected EOC-10 SLB tube burst probability is 6.1×10^{-5} which is well below the acceptance guideline of 2.5×10^{-2} based on NUREG-0844 analyses. Overall, it is concluded that SLB leakage and burst probability acceptance limits were satisfied in Cycle 9 and will be satisfied with large margins for Cycle 10.

2.2 1993 EOC-9 Inspection Results

For the 1993 inspection, additional signal classifications were utilized to categorize indications previously classified as bobbin potential indications (PIs). The 1993 classifications include potential indications (PIs), unusual ID phase angles (UIAs), unusual OD phase angles (UOAs) and indications not reportable (INRs). RPC sample inspections confirmed some of the UIA signals to be flaw indications while none of the UOA signals have been RPC confirmed indications in the present or prior inspections. All UIA indications above 1.0 volt were then RPC inspected and confirmed indications were repaired. For this report, the PI and UIA signals are considered potential flaw indications while the UOA and INR signals are not considered indicative of flaws. RPC inspection of all UOA and INR indications above the IPC repair limit of 1.0 volt is not required to leave these indications in service. However, since the NRC Farley-2 SER requires that RPC NDD indications be included in SLB leak rate analyses, all signals including UOAs and INRs have been included in the reference leak rate analyses.

The number of potential flaw indications found in the 1993 inspection is 170 which includes 21 in S/G A, 70 in S/G B and 79 in S/G C. The number of RPC confirmed indications is 24 of the 46 potential indications RPC inspected. When INR and UOA signals are added to the potential flaw indications, the total number of indications is 355 which includes 59 in S/G A, 155 in S/G B and 141 in S/G C. The largest bobbin indication found that was confirmed by RPC was 2.81 volts. Two larger voltage PIs at 2.95 and 4.11 volts, both on the same tube, were not confirmed as flaw indications by RPC. However, this tube was repaired as the voltage exceeded the maximum bobbin voltage of 3.6 volts permitted to be left in service for unconfirmed or RPC NDD indications.

Of 18 indications that were RPC NDD in 1992, 14 were reclassified as UOAs and INRs in the current inspection and were not reinspected by RPC. Four RPC indications found NDD in 1992 were also found to be RPC NDD in 1993. Thus, for the last cycle, there is no trend for RPC NDD indications to become confirmed flaws over one cycle of operation.

New indications were found in the 1993 inspection that were not reported at the 1992 inspection. The new indications include 12 of the 18 indications found above 1.4 volts in . inspection. However, only 4 of the 12 new indications above 1.4 volts were confirmed by RPC. Of the 170 total bobbin potential indications, 104 were reported in 1992 while 65 can be considered new indications. The number of new indications in the 1993 inspection is considerably smaller than found in the 1992 inspection. For example, S/G C had 27 new indications in 1993 compared to 126 in 1992. The large reduction in new indications for the last cycle indicates that the 1992 application of Appendix A analysis guidelines resulted in a significant improvement in calling criteria over the prior 1991 inspection. However, the number of new indications found in the 1993 application of Appendix A guidelines implies that EOC voltage projections should include a provision for undetected indications. It is doubtful that the new indications would add significantly to potential SLB leakage due to the lower voltage range of the new indications relative to the larger voltages required for a significant probability of leakage. It is shown in this report that the NRC recommended method of applying a probability of detection (POD) of 0.6 to account for undetected indications is excessively conservative compared to actual EOC-9 voltage distributions. An alternate method is recommended that provides allowances for BOC undetected indications based on the prior cycle voltages (from growth rate evaluation) for new indications found in the latest inspection.

2.3 Voltage Growth

The 2.81 volt RPC confirmed indication had a 1992 voltage of 0.92 volts and has the largest voltage growth of 1.89 volts found for Cycle 9. For Cycle 8, the largest growth was 2.1 volts. The Cycle 9 growth rates are lower in average and maximum value compared to prior Farley-2 cycles. The average voltage growth was 0.09 volts or 12% of the average BOC voltages compared to 0.14 volt (19%) growth for Cycle 8.

2.4 Comparison of Projected and Actual EOC-9 Bobbin Voltage Distributions

The 1993 Farley-2 inspection represents the first full cycle of operation following IPC implementation for any domestic plant. Thus the resulting data permits comparisons of projected and actual EOC voltage distributions. These comparisons were made applying the NRC draft NUREG-1477 methodology including a POD = 0.6 adjustment to detected indications, a method including RPC NDD indications without a POD adjustment and a method excluding RPC NDD indications as well as POD adjustments. An alternate method is also evaluated that includes provisions for undetected indications based on new indications found in the inspection and for a fraction (conservatively 50%) of the RPC NDD indications assumed to develop to confirmed flaws. This alternate method is proposed for further evaluation against actual EOC distributions as this method is shown to provide adequate conservatism while applying more realistic, plant specific adjustments for undetected indications and that only a fraction of RPC NDD indications are likely to develop into significant flaws in the subsequent cycle. The projection methods are compared with the actual EOC-9 distribution for RPC confirmed indications plus indications not RPC inspected. Since the primary purpose of the voltage projections for IPC/APC applications is to estimate tube leakage and burst probabilities, only indications found to be RPC confirmed (not inspected are conservatively assumed to be confirmed) are used for comparisons with the projected distributions as RPC NDD indications would not have any significant probability of leakage over the prior cycle.

It is found that the draft NUREG-1477 methodology considerably overestimates the number and magnitude of the EOC-9 indications. The projected maximum voltage is 4.2 volts compared to the actual value of 2.81 volts. It is found that this methodology introduces excessive conservatism in the voltage distributions and also results in SLB leakage a factor of 2 higher than found for the actual distribution. Results of this evaluation are provided in Section 7.2.

The method including RPC NDD indications left in service but without a POD adjustment yields very good agreement with the actual distribution. This method resulted in a maximum EOC voltage of about 3.3 volts compared to the 2.81 volts found by inspection. The higher voltage tail of the distribution above 1.7 volts is well represented by the projections while the projections are conservative below 1.7 volts. This method, however, applies the RPC NDD indications at BOC to compensate for potential new indications as well as potential growth to confirmed indications at EOC. Results of this evaluation are provided in Section 7.2.

The alternate method for EOC voltage projections, which accounts for undetected indications based on prior cycle experience and a fraction of RPC NDD indications growing to detectable flaws, also results in excellent agreement between projected and actual EOC-9 voltage distributions. The maximum projected EOC-9 voltage for this case is 3.1 volts compared to the 2.81 volts inspection result. This method accounts for plant specific detectability and is the method recommended for further comparisons between projections and actual distributions. This methodology is further developed in Section 10.0.

The method evaluated based on only RPC confirmed or uninspected indications left in service leads to an underestimate of the actual EOC-9 distributions as this method does not provide allowances for new indications. The maximum projected EOC voltage for this method was 2.5 volts. However, this method yields SLB leakage only 30% less than that obtained from the actual EOC voltage distribution while the other projection methods yield leak rates 40% to 200% higher than obtained from the actual distribution. Results of this evaluation are discussed in Section 7.2.

2.5 SLB Leak Rate Analyses

SLB leak rate analyses were performed to compare values based on projected EOC-9 voltage distributions with that obtained from the actual distribution as well as to project EOC-10 leak rates for comparison with allowable limits. Applying NRC draft NUREG-1477 methods for calculating leakage given a voltage distribution, the actual EOC-9 distribution resulted in a 0.107 gpm SLB leak rate. For the NRC method of defining BOC voltages, which includes a POD = 0.6 adjustment and RPC NDD indications, the predicted EOC leakage was a factor of two high at 0.220 gpm. Methods excluding the POD adjustment and excluding both the POD adjustment and RPC NDD indications yielded 0.144 and 0.078 gpm, respectively which bracket the actual distribution leakage by about 40%. The conservatism of the POD = 0.6 adjustment thus results in excessively conservative leak rates as well as EOC voltage projections.

The draft NUREG-1477 methods were applied to projected EOC-10 voltage distributions (including POD = 0.6 and RPC NDD indications) to obtain a projected SLB leak rate of 0.270 gpm. This is well below the Farley-2 allowable leakage limit of 22.8 gpm. Thus potential SLB leakage is well within acceptable limits for Cycle 10 operation. When the full APC leak rate versus voltage correlation (WCAP-12871 methods) is applied to the EOC-10 voltage distribution, the projected SLB leakage is only 0.009 gpm or a factor of 25 lower than the draft NUREG methodology. This demonstrates the conservatism in the draft NUREG methods which apply the leak rate database independent of bobbin voltage.

2.6 Tube Burst Probability Assessments

The tube burst probability at EOC-10 was estimated by applying the draft NUREG method for defining BOC voltage distributions and the WCAP-12871, Rev. 2 methods for burst probability analyses. This is the methodology recommended in the NRC Farley-2 IPC SER. The resulting tube burst probability at EOC-10 is 6.1×10^{-5} which is well below the WCAP-12871 guideline of 2.5×10^{-2} based on NUREG-0844 analyses. Thus the tube burst probability is also well within acceptable limits for Cycle 10 operation.

2.7 Considerations for UIAs in Future Farley S/G Inspections

Given that 4 of the 5 UIA indications above 1.0 volt were confirmed as flaws by RPC inspection, it is appropriate that future inspections redefine UIAs as potential indications (PIs) requiring RPC inspection for all indications above the voltage threshold for RPC testing (1.0 volt for current IPC). This change will be incorporated into WCAP-12871 Appendix A eddy current analysis guidelines to be applied at future Farley S/G inspections implementing IPC/APC. In addition, the need for RPC sampling of UOA and INR indications above the RPC inspection threshold will be evaluated for future inspections and appropriate inspections will be conducted. Indications with ID phase angles are included in the existing APC database for the burst pressure correlation so that the existing correlation is applicable to indications with ID phase angles.

2.8 Assessments of NDE Uncertainty for Analyst Variability

The laboratory reevaluation of the 1992 bobbin voltages performed as part of the growth study in 1993 identified a number of voltages which had been undercalled in the field analyses in 1992 at EOC-8. Of 11 indications for which the 1992 voltages were 0.5 volts or more lower than the 1993 reevaluation, only 2 indications were confirmed by RPC inspection. Two potential contributing factors to these voltage analysis differences are clear undercalls in the 1992 inspection and the fact that larger 1993 voltages were available for the laboratory reevaluation which helped to better interpret distorted signals at the low voltage levels of the 1992 inspection. The latter effect will likely continue to occur for low voltage (less than about 1.5 to 2.0 volts) signals, for which the flaws are not well defined. After full APC repair limits are implemented, the low voltage undercalls would not be significant for the indication voltages left in service.

NDE uncertainty distributions were developed as the difference between laboratory and field calls for the 1992 EOC-8 inspection and for the 1993 EOC-9 inspection. The resulting NDE uncertainties can be compared to the allowance of a 10% standard deviation for analyst variability uncertainty included in the Farley IPC analyses. For EOC-8, which was the first IPC inspection implementing Appendix A analysis guidelines, the field versus laboratory voltage differences resulted in a standard deviation of 36%. This large uncertainty is a combination of voltage undercalls resulting from analysts with minimal experience with the peak to peak voltage criteria used for IPC/APC and the benefits of reanalyzing the low voltage 1992 data with the 1993 data as an interpretation guide. For the current EOC-9 inspection, the field versus laboratory differences resulted in a standard deviation of 7.5% which is less than the 10% allowance for analyst variability in the NDE uncertainties for IPC/APC. The lower uncertainty at EOC-9 results from the increased analyst experience with the voltage sizing criteria and that the analyst has the benefit of later, larger indications to guide the low voltage indication sizing. Based on these evaluations, it is concluded that allowances for NDE uncertainties in WCAP-12871, Rev. 2 (essentially same as EPRI allowances in TR-100407, Rev. 1 draft of August 1993) are adequate and no revisions are necessitated by the Farley-2 data.

3.0 EOC-8 AND EOC-9 S/G INSPECTION RESULTS

3.1 EOC-8 Inspection Results

EOC-8 inspection results are required in this report to define the BOC-9 indications left in service that are used as the starting point for projecting EOC-9 voltage distributions for comparison with the actual results from the EOC-9 inspection. The 1992 inspection at EOC-8 was the first inspection applying IPC/APC eddy current data collection and analysis guidelines given in Appendix A of WCAP-12871, Rev. 2. This included use of ASME calibration standards normalized to the reference laboratory standard as described in Appendix A.

Figure 3-1 shows the bobbin indications found at EOC-8 and the indications confirmed as flaws by RPC inspection. For Figure 3-1 and all figures given in this report, the voltage values given on the x-axis of the plots represent the upper or right-side value for the voltage bin. Only indications above the IPC repair limit of 1.0 volt were RPC inspected. The figure includes the sum of indications over all S/Gs (for information only) and the results for S/G C which had the most indications left in service and has been applied for projected EOC-9 voltages and leak rates. A total of 308 indications were found summed over all 3 S/Gs. Above 1.0 volt, 39 indications were found on 36 tubes and 19 of these indications were confirmed as flaws by RPC.

Figure 3-1 also shows the comparable results for S/G C which was the most limiting S/G for SLB leakage analyses. S/G C had 121 bobbin indications of which 20 were > 1.0 volt and 9 were confirmed RPC indications. The indications left in service at BOC-9 are discussed in Section 4.1.

The largest bobbin voltage found in the inspection was 3.84 volts on tube R4C78 in S/G C. RPC inspection found no flaw on this tube. This tube was plugged since it exceeded the 3.6 volt IPC repair limit for leaving bobbin indications in service without RPC confirmation. The next largest bobbin voltage was 2.67 volts on tube R4C77 in S/G C and this indication was also RPC NDD and left in service. The largest bobbin indication confirmed by RPC was 2.65 volts on tube R28C78 in S/G B.

No indications at TSPs were identified that had cracks extending outside the TSPs by either the bobbin or RPC inspections. In addition, no abnormal indications such as circumferentially oriented indications were found in the 1992 inspection.

3.2 EOC-9 Indications at TSPs

The 1993 inspection at EOC-9 was completed in early November. This inspection is the first full cycle inspection following implementation of an IPC which permitted leaving indications of 1.0 volt or less in service for indications at TSPs. For this reason, the results of the inspection are evaluated for IPC methodology considerations including comparisons between projected and actual indications in this report. This section summarizes the inspection results.

A summary of the inspection results are given in Table 3-1. At this inspection, additional classifications were assigned to indications compared to prior inspections in order to enhance tracking in future inspections of bobbin signals that do not satisfy flaw guidelines. The principal classifications are noted at the bottom of Table 3-1 and included Potential Indications (PIs), Unusual ID Phase Angle Indications (UIAs), Unusual OD Phase Angle Indications (UOAs) and Indications Not Reportable (INRs). A UIA signal corresponds to a bobbin response which has a phase angle clearly in the ID plane where only OD indications are expected. A UOA phase angle corresponds to a large phase angle response which lies beyond the 0% depth intercept on the phase angle versus depth calibration curve. The INR classification corresponds to signals having some potential flaw characteristics but insufficient to classify as a PI. The INR category is provided primarily to track indications called PIs in the prior inspection for at least one additional future inspection to determine if flaw signals develop for these indications. An additional classification was Indication Not Found (INF). INF applies to a TSP intersection previously reported as having a PI for which no flaw indication is found in the current inspection. The INF category provides for tracking of the intersection but is not considered a flaw indication for the current outage. The bobbin signals (typically > 1.0 volt) that are RPC inspected are further designated by a C at the end (PIC, UIC) if confirmed as a flaw by RPC or by a N at the end (PIN, UIN, UON) if not confirmed by RPC. The INR classification is not considered as a reportable flaw signal in the current outage and does not require RPC inspection to leave in service if over 1.0 volt. UIA and UOA signals have been included in the RPC sampling plan in the current and the prior outage. Prior to this outage, none of the UIA or UOA signals were confirmed by RPC. In this outage, three of the six UIA signals sampled by RPC were confirmed and the RPC inspection was extended to inspect the additional three UIA signals > 1.0 volt which resulted in confirmation of two additional UIAs as flaw signals. Based on these results, the UIAs are considered potential flaw signals and will be classified as PIs in future inspections. None of the five UOA signals RPC tested were confirmed and the UOAs are not considered to be flaw signals. In summary, the UOA, INR and INF signals are not considered flaws to require further RPC inspection of indications above 1.0 volt. However, the NRC SER for Farley-2 conservatively requires that RPC NDD indications be included in the SLB leakage calculations. This conservatism may be considered to apply to UOA and INR indications which are historically based RPC NDD indications. It can be noted that 12 of the 1993 UOAs above 1.0 volt were classified as PIs above 1.0 volt in 1992 and found to be RPC NDD. For consistency with the NRC conservatism on RPC NDD indications, the UOA and INR indications are included in the voltage distributions for indications left in service and applied to project EOC-10 SLB leakage and burst probability. This adds considerable conservatism to the SLB analyses as a number of the UOA signals left in service are greater than 1.0 volt.

Based on Table 3-1, the total number of potential flaw indications (PI, PIC, PIN, UIA, UIC, UIN) summed over all 3 S/Gs is 170 which includes 21 in S/G A, 70 in S/G B and 79 in S/G C. The total number of RPC confirmed potential flaw indications is 24 out of 46 indications RPC inspected. When INR and UOA signals are added to the potential flaw indications, the total number of indications is 355 which includes 59 in S/G A, 155 in S/G B and 141 in S/G C. The 1993 EOC-9 bobbin voltage distributions (excluding UOA signals) are shown in Figure 3-2 for both the sum over all 3 S/Gs and for S/G C. The figures include the distribution of RPC confirmed indications above 1.0 volt as well as the total bobbin voltage distributions.

Table 3-2 provides a summary of the largest bobbin voltage indications found in the current inspection. RPC inspection results, voltages at the prior inspection and whether or not it is a new indication not reported at the last inspection are also included in the Table. The largest bobbin voltage indication found in 1993 was 4.11 volts on tube R2C3 at TSP 5 in S/G C. This tube also had the next largest indication of 2.95 volts at TSP 3. Both of these indications were found to be NDD by RPC inspection. This tube had significant TSP residual or artifact signals also at TSPs 4 and 6 with TSPs 3 and 5 showing potential flaw characteristics such that the latter intersections were identified as PIs to assure RPC inspection. The RPC NDD results support no flaws or insignificant flaws on this tube. However, the IPC repair criteria require repair of bobbin indications > 3.6 volts independent of RPC confirmation and this tube was repaired which removes the largest potential indication voltages from the BOC-10 distribution.

The largest RPC confirmed indication was on tube R31C68 in S/G C with a bobbin voltage of 2.81 volts. This indication was left in service in 1992 with a bobbin voltage of 0.92 volts and has the largest voltage growth of 1.89 volts found in the last cycle. Tube R26C79 had a bobbin response of 2.78 volts and represents a new indication not reported in 1992 although the reevaluated voltage for the prior outage is 1.48 volts. For the RPC confirmed indications above 1.4 volts in Table 3-2, four of the seven confirmed indications were not reported in the last inspection. A more extensive assessment of new indications is given later in this section. In Table 3-2, it is noted that three of the indications identified at the last outage and left in service have bobbin voltages > 1.0 volt based on reevaluation of the 1992 data. The 1992 inspection was the first implementing Appendix A eddy current guidelines and a small number (about 5 PIs, all in S/G C) of indications were found in the growth study to have > 1.0 volt indications undercalled in 1992. The 1992 inspection was the first implementing Appendix A guidelines and a modest number of undercalls would be realistically expected. The 1993 growth study was independently performed in the laboratory and no comparable field voltage undercalls were found in the 1993 field evaluations. This would indicate that field experience with Appendix A guidelines is resulting in improved guideline implementation.

Indications that were RPC NDD in 1992 were tracked to the 1993 inspection as shown in Table 3-3. It is seen that 14 of the 18 NDDs are reclassified in 1993 as UOAs or INRs and were not reinspected by RPC. The 4 RPC NDD indications in 1992 that were reinspected by RPC in 1993 were again found to be NDD. These indications that were NDD in two consecutive cycles show negligible growth. Thus, for the last cycle, there is no trend for RPC NDD indications to become confirmed flaws over one cycle of operation. This would indicate that RPC NDD indications should not be included in leakage projections for subsequent cycles. However, this repeated trend of NDD indications is not found at 100% across industry experience as some occurrences have been found for NDD indications to become confirmed indications in the subsequent cycle. However, it is expected that RPC NDD indications would not become significant leakers over one cycle of operation.

Given the occurrence of new indications in the largest bobbin voltages of Table 3-2, the 1993 inspection results were evaluated to categorize the 1993 indications as prior or new (not reported in 1992) indications. Table 3-4 summarizes this evaluation. Of the 170 bobbin potential flaw indications (PI, PIN, PIC, UIA, UIC, UIN), 105 were reported in 1992 while 65 can be categorized as new indications. As shown in more detail in Section 10, the number of new indications in S/G C is 27 in 1993 and was 126 in 1992. These results represent potential indications not identified at the previous inspection. The large reduction in new indications for the last cycle indicates that the 1992 application of Appendix A guidelines resulted in a significant improvement in calling criteria over the prior 1991 inspection. Of the 20 new potential flaw indications above 1.0 volt, 10 were confirmed by RPC. This would indicate that leakage projections should include provisions for new indications (see Section 10) although it is shown later in this report that the inclusion of all RPC NDD indications in leakage projections strongly compensates for the influence of new indications.

Voltage projections from BOC to EOC conditions for IPC/APC applications are performed to estimate SLB leakage and burst probability. Thus the desired EOC voltages are those having significant potential for throughwall cracks or leakage. Indications that are RPC NDD at EOC can be confidently expected to have no potential for leakage over the prior cycle as RPC detectability (as well as bobbin detectability) approaches 100% for ODSCC at TSPS with near throughwall or throughwall indications. It can be noted that the confidence for no leakage over the prior cycle for RPC NDD is much higher than the judgement for leakage potential over the next cycle from RPC indications left in service (i.e. the NRC requirement to include RPC NDD in projected leakage analyses). Therefore, for comparisons of projected EOC-9 voltage distributions to be used in leakage analyses with actual distributions, the appropriate actual EOC-9 voltage distribution is the sum of RPC confirmed indications (above 1.0 volt for Farley-2) and bobbin indications not RPC inspected (below 1.0 volt for Farley-2). UOAs are not included as none of the RPC sample inspections have confirmed UOAs as flaw indications. INRs are included in the EOC-9 distribution although they could be excluded as not contributing to potential leakage over the prior cycle. For actual EOC-9 distributions, this includes PIs /INRs/UIAs ≤ 1.0 volt and PICs/INRs/UICs > 1.0 volt. S/G C has the only reported INR above one volt. These distributions are shown in Figure 3-3 for the sum over all S/Gs and for S/G C which is the limiting S/G for SLB leakage analyses for both Cycles 9 and 10. The S/G C actual distributions of Figure 3-3 for EOC-9 are compared with projections from BOC-9 to EOC-9 in Section 7.

Table 3-1. SUMMARY OF FARLEY 2 1993 S/G INDICATIONS AT TSP's

Voltage Range	Steam Generator A						Steam Generator B									Steam Generator C					
	PI	PIC	PIN	UIA	INR	UOA	PI	PIC	PIN	UIA	UIC	UIN	INR	UOA	UON	PI	PIC	PIN	UIA	INR	UOA
0 - 0.4	1			1	6	3	5			1			22	2		1			3	17	1
0.41 - 0.5	5			3	5		9			1			11	1		7				7	1
0.51 - 0.6	3			2		2	7			3			3	1		7			3	3	2
0.61 - 0.7	1			1		5	6			3		1	3	5		12			2	5	
0.71 - 0.8						3	7			1		1	1	3		3			2	3	2
0.81 - 0.9					1	1	3					1	1	3		6			2	1	6
0.91 - 1.0				1	2		2			1	1		5	4	1	6			2	1	1
1.01 - 1.2		1				5		3	2		4			7	1		6	2			2
1.21 - 1.4		1				3			3					1			2	1		1	2
1.41 - 1.6						2		1	1			1		1	1			2			1
1.61 - 1.8														2			1	1			2
1.81 - 2.0								1	1					2			1	1			1
2.01 - 2.5			1											2	2		1	1			1
2.51 - 3.0																	2	1			2
4.11																		1			
TOTALS	10	2	1	8	14	24	39	5	7	10	5	4	46	34	5	42	13	10	14	38	24
No. > 1.0v	0	2	1	0	0	10	0	5	7	0	4	1	0	15	4	0	13	10	0	1	11
No. < or = 1.0v	10	0	0	8	14	14	39	0	0	10	1	3	46	19	1	42	0	0	14	37	13

PI = Potential Indication
PIC = Potential Indication >1v Confirmed by RPC
PIN = Potential Indication >1v Not Confirmed by RPC
INR = Indication not Reportable
UIA = Unusual ID Phase Angle, Not RPC Inspected
UIC = Unusual ID Phase Angle Confirmed by RPC
UIN = Unusual ID Phase Angle, Not Confirmed by RPC
UOA = Unusual OD Phase Angle, Not RPC Inspected
UON = Unusual OD Phase Angle, Not Confirmed by RPC

Table 3-2. SUMMARY OF LARGEST EOC 9 BOBBIN VOLTAGES							
S/G	Tube	TSP	Class.	EOC 9		EOC 8 Bobbin Volts	New Indication
				Bobbin Volts	RPC Volts		
C	R2C3	5	PIN	4.11	NDD	3.53	Yes
		3	PIN	2.95	NDD	2.40	Yes
C	R31C68	1	PIC	2.81	2.55	0.92	No
C	R26C79	1	PIC	2.78	2.26	1.48	Yes
A	R37C28	6	PIN	2.26	NDD	2.13[1]	No
C	R21C58	5	PIN	2.15	NDD	2.03[2]	No
C	R14C87	3	PIC	2.07	2.30	0.62	Yes
B	R12C90	1	PIC	1.89	0.65	1.97	Yes
C	R9C93	1	PIC	1.89	1.00	1.29	Yes
C	R31C22	5	PIN	1.83	NDD	1.93[2]	No
B	R4C11	3	PIN	1.82	NDD	2.08	Yes
C	R18C83	1	PIC	1.71	1.51	1.55[2]	No
C	R12C83	6	PIN	1.61	NDD	1.89	Yes
B	R11C91	1	UIN	1.56	NDD	0.96	Yes
B	R15C86	1	PIC	1.54	0.64	0.90	No
B	R30C78	3	PIN	1.54	NDD	1.81	Yes
C	R29C21	6	PIN	1.43	NDD	1.38	Yes
C	R40C38	7	PIN	1.42	NDD	1.05	Yes

Notes: 1) Indication was RPC NDD in 1992. 2) Bobbin voltage underestimated in 1992 and indication not RPC inspected.

Table 3-3. RPC NDD INDICATIONS LEFT IN SERVICE

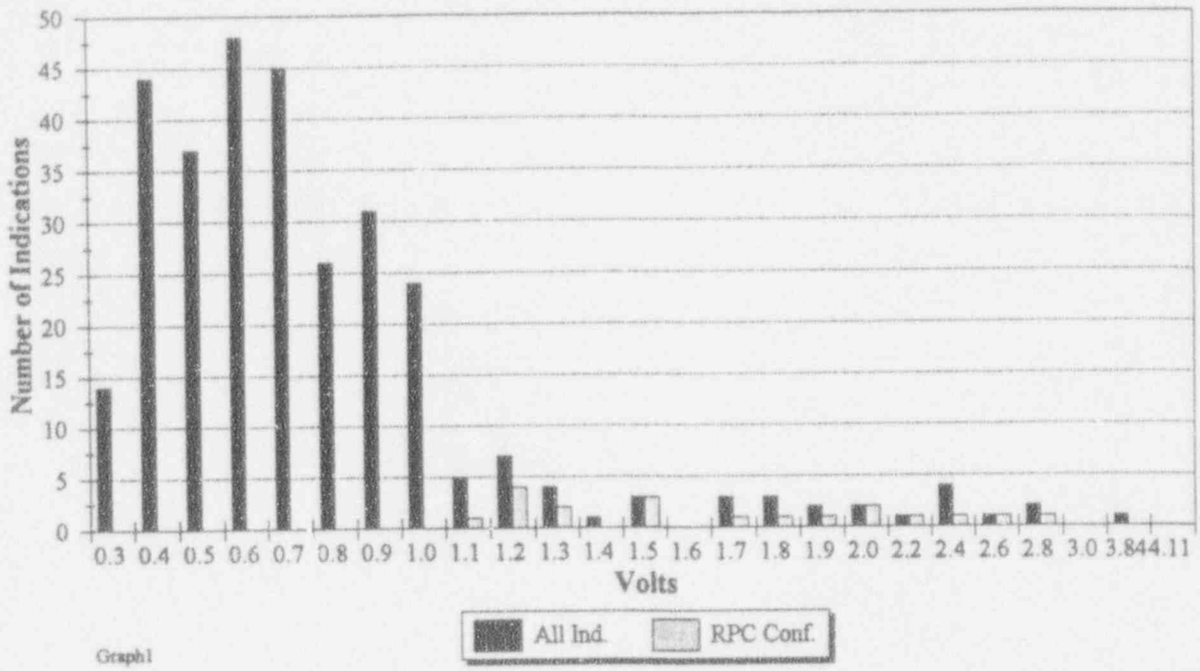
BOC 9 Indications						BOC 10 Indications		
Tube	TSP	BOC 9 Volts	EOC 9			Tube	TSP	BOC 10 Volts
			Volts	RPC	Classification			
S/G C								
R6C13	7C	1.39	1.73	--	UOA	R29C21	6H	1.43
R31C25	6H	2.39	2.53	--	UOA	R31C22	5H	1.83
R44C44	1H	0.99	1.13	NDD	PIN	R40C38	7H	1.42
R4C59	6C	2.03	1.89	--	UOA	R44C44	1H	1.13
R3C68	5C	1.45	1.32	--	UOA	R21C57	6H	1.26
R4C68	5C	1.84	0.89	--	UOA	R21C58	5H	2.15
	6C	2.43	2.03		UOA	R13C79	5C	1.16
R3C69	5C	1.85	0.84	--	UOA	R12C83	6H	1.61
	7C	0.67	0.63		INR	R30C82	5H	1.39
R4C77	5C	2.93	2.71	--	UOA			
S/G B								
R6C45	7C	0.74	0.67	--	INR	R4C1	5H	1.33
R18C46	5H	1.15	1.02	--	UOA	R4C11	3H	1.82
R12C64	7C	1.15	1.21	NDD	PIN	R41C51	2H	1.17
R6C69	7H	1.22	1.12	--	UOA	R12C64	7C	1.21
R18C73	2C	1.07	1.12	NDD	PIN	R18C73	2C	1.12
						R13C75	7C	1.32
						R30C78	3H	1.54
						R11C91	1H	1.56
S/G A								
R14C8	7H	1.50	1.52	--	UOA	R37C28	6H	2.26
R37C28	6H	2.13	2.26	NDD	PIN			
R17C51	5H	1.03	1.16	--	UOA			

Table 3-4. SUMMARY OF PRIOR AND NEW INDICATIONS AT EOC-9

Volts	PI	PIC	UIA	UIC	INR	UOA	INF
			Prior Indications				
0.01-0.5	20	--	9	--	66	9	7
0.51-1.0	42	--	12	1	28	33	7
1.01-1.5	6	7		2	1	18	
1.51-2.0	1	2				6	
2.01-2.5	2					3	
2.51-3.0		1				2	
TOTALS	71	10	21	3	95	71	14
			New Indications				
0.01-0.5	8	--	1	--	2	--	
0.51-1.0	21	--	13	--	1	6	
1.01-1.5	4	6		2		3	
1.51-2.0	3	2	1			5	
2.01-2.5	0	1				2	
2.51-3.0	1	1					
> 3.0	1						
TOTALS	38	10	15	2	3	16	
OVERAL TOTALS	109	20	36	5	98	87	

Figure 3-1

Farley-2 EOC-8 Voltage Distribution
All S/G Bobbin Indications and RPC Confirmed



Farley-2 EOC-8 Voltage Distribution
S/G C Bobbin Indications and RPC Confirmed Indications

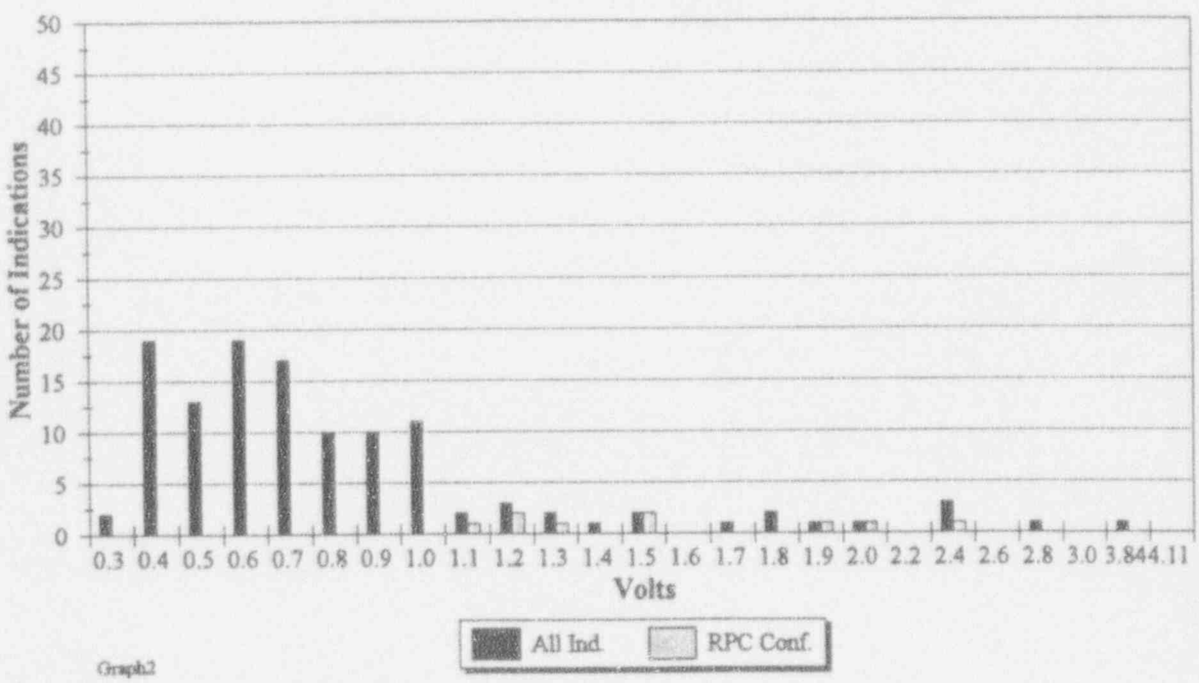
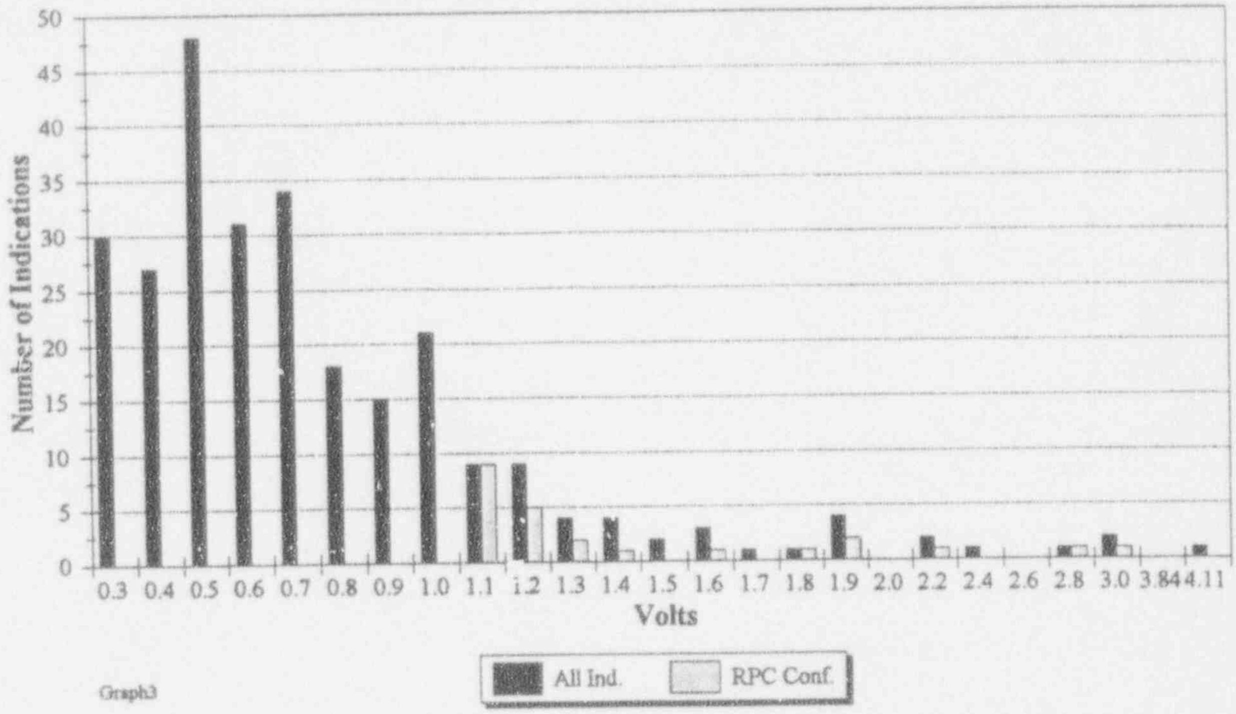


Figure 3-2

Farley-2 EOC-9 Voltage Distributions
All S/G Bobbin Indications and RPC Confirmed Indications



Farley-2 EOC-9 Voltage Distribution
S/G C Bobbin Indications and RPC Confirmed Indications

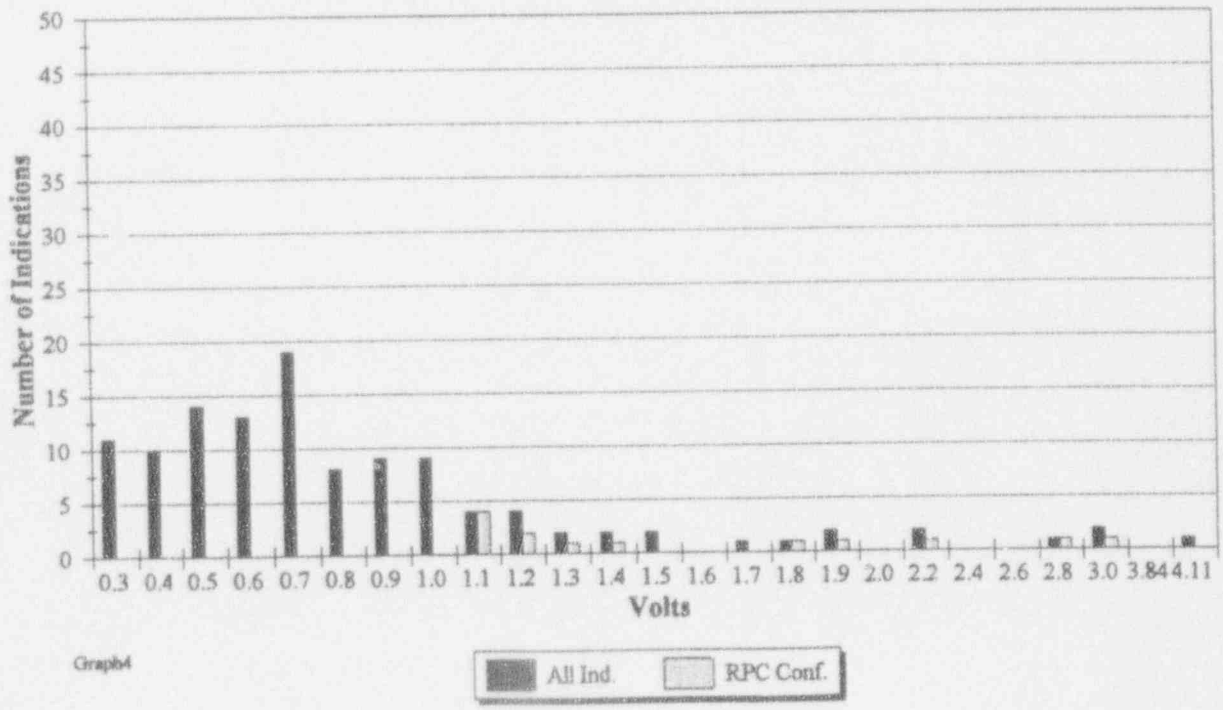
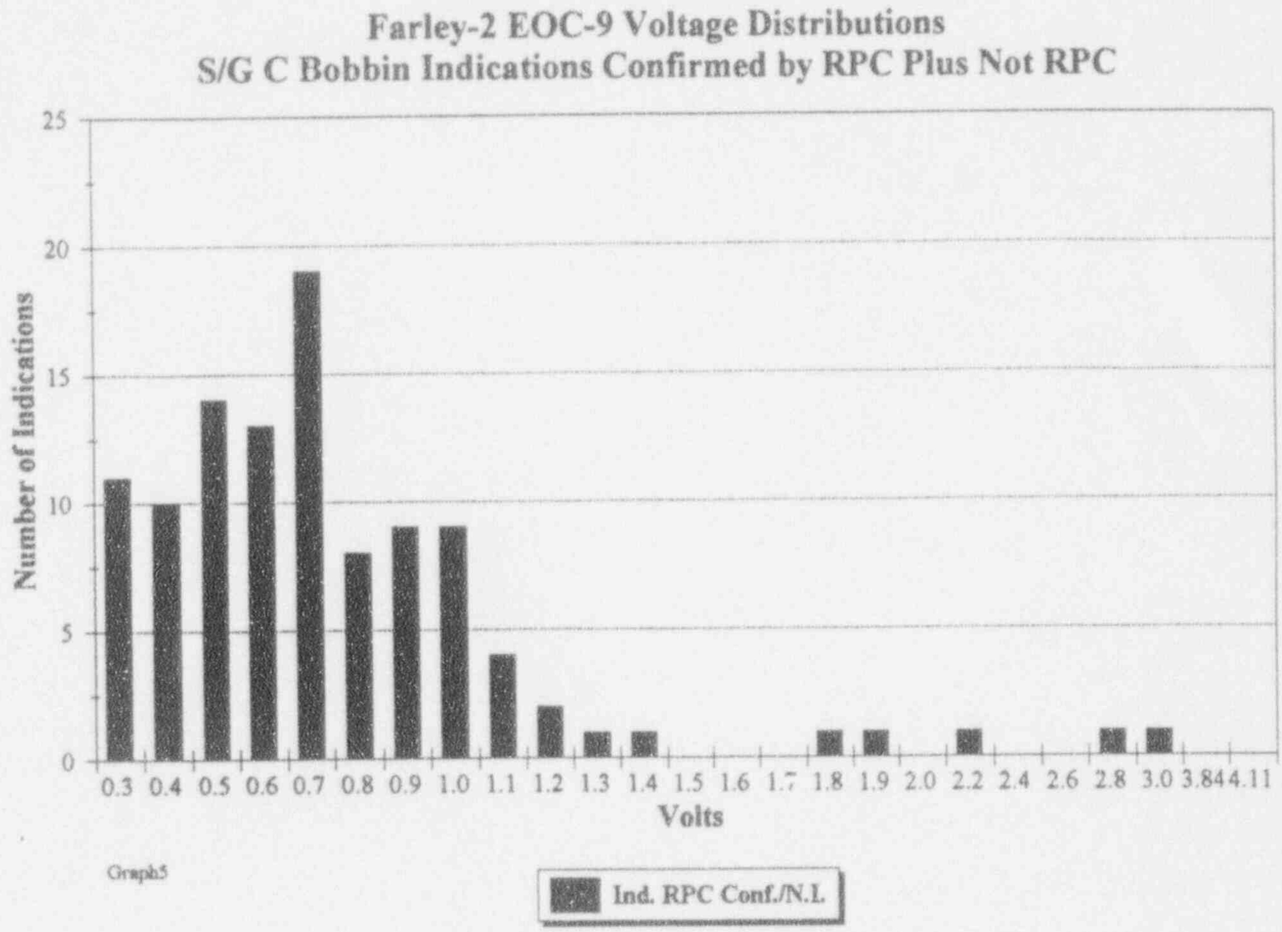


Figure 3-3



c:\qpw\TP002sid:11/18/93

4.0 BOBBIN VOLTAGE INDICATIONS LEFT IN SERVICE

4.1 BOC-9 Indications Left in Service

The indications left in service at BOC-9 are used to project the EOC-9 voltage distribution for comparisons with the actual distributions found at the EOC-9 inspection as described in Section 3.2 above. Three representations of the BOC-9 distributions are utilized in this report. The Farley-2 NRC SER requires that the indications found in the inspection be divided by a POD of 0.6 and then reduced by the indications repaired to define the BOC distribution. Bobbin indications found to be NDD by RPC inspection are conservatively included as indications left in service. The second distribution used in this report is the same as the NRC required distribution except that there is no adjustment for POD. That is the second distribution includes all detected bobbin indications not repaired independent of RPC confirmation. The third distribution used in analyses includes only indications ≤ 1.0 volt left in service which excludes RPC NDD indications and is the same as the second distribution for the ≤ 1.0 volt range. The BOC-9 distributions are given for S/G C which was the most limiting S/G with regard to the number and size of indications left in service for potential leakage considerations in Cycle 9.

The BOC-9 indications left in service for S/G C are shown in Figure 4-1. The upper figure shows the NRC required distribution with a POD of 0.6 applied while the lower figure does not include the POD adjustment. Both figures include RPC NDD indications left in service. The BOC distribution without RPC NDD can be obtained from the lower figure for voltages ≤ 1.0 volt. Since the POD adjustment is applied before the distribution is reduced for repaired tubes, the upper figure shows more indications than obtained by dividing the lower figure by 0.6. For example, the upper figure includes 0.7 indications at 3.84 which is obtained by dividing the one indication (RPC NDD and repaired) by 0.6 to obtain 1.7 indications which is then reduced by 1.0 since the indication was repaired. The effect of this conservative methodology is equivalent to assuming that a 3.84 volt indication was missed in the inspection even though the potential indication found was RPC NDD and repaired. The S/G C distributions are tabulated in the appendix to this report.

4.2 BOC-10 Indications Left in Service

Bobbin voltage distributions for BOC-10 were developed in the same manner and for the comparable three distributions as described above for BOC-9. The reference distributions include all bobbin signals in the PI, UIA, UOA and INR classifications. For sensitivity analyses, distributions were also developed excluding the UOA classification from the data. The reference distributions are shown in Figure 4-2 and the distributions without UOA signals are shown in Figure 4-3.

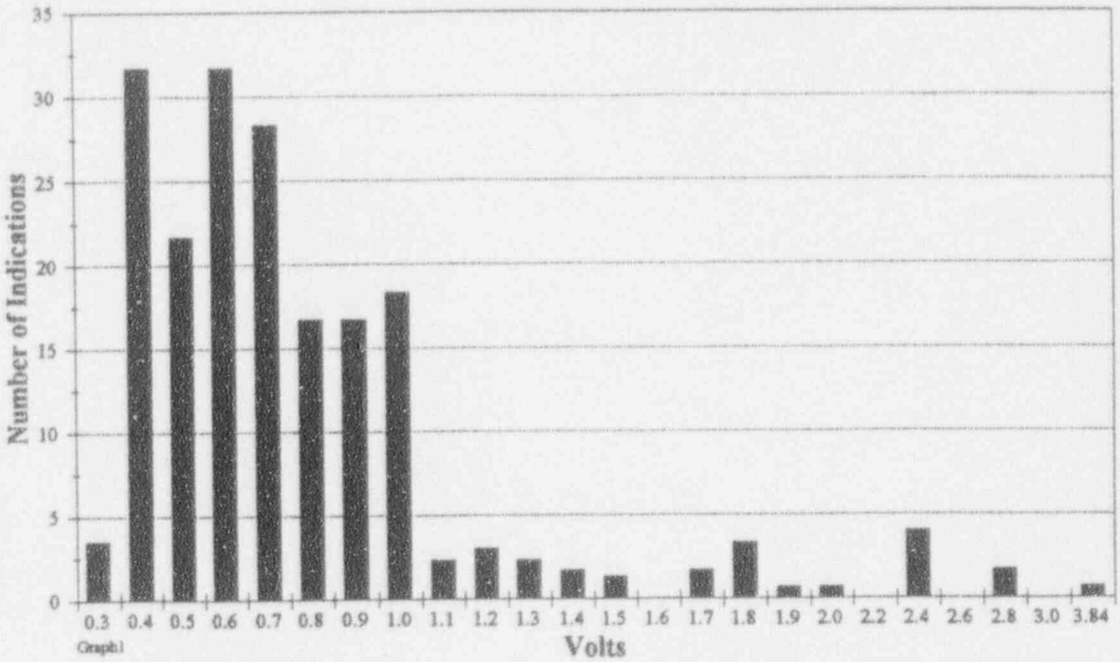
S/G C is the most limiting S/G for Cycle 10 leakage considerations although S/G B is very similar in number and size of indications left in service. S/G C had more potential flaw indications (79 in S/G C versus 70 in S/G B) although S/G B has more total indications (155 versus 141 in S/G B). After tube repair, S/G C has 123 total indications left in service while S/G B has 139 indications left in service. However, for the NRC model with probability of detection applied before removing repaired indications, S/G C results in more large indications postulated to be left in service. Only the large indications above about 1.5 volt at BOC contribute significantly to leakage for 7/8 inch diameter tubing due to the low probability of leakage. Therefore, S/G C is judged to be the most limiting S/G for Cycle 10 although differences from S/G B are insignificant.

It is seen that the POD = 0.6 adjusted distribution includes 0.7 indications at 4.11 volts and 1.4

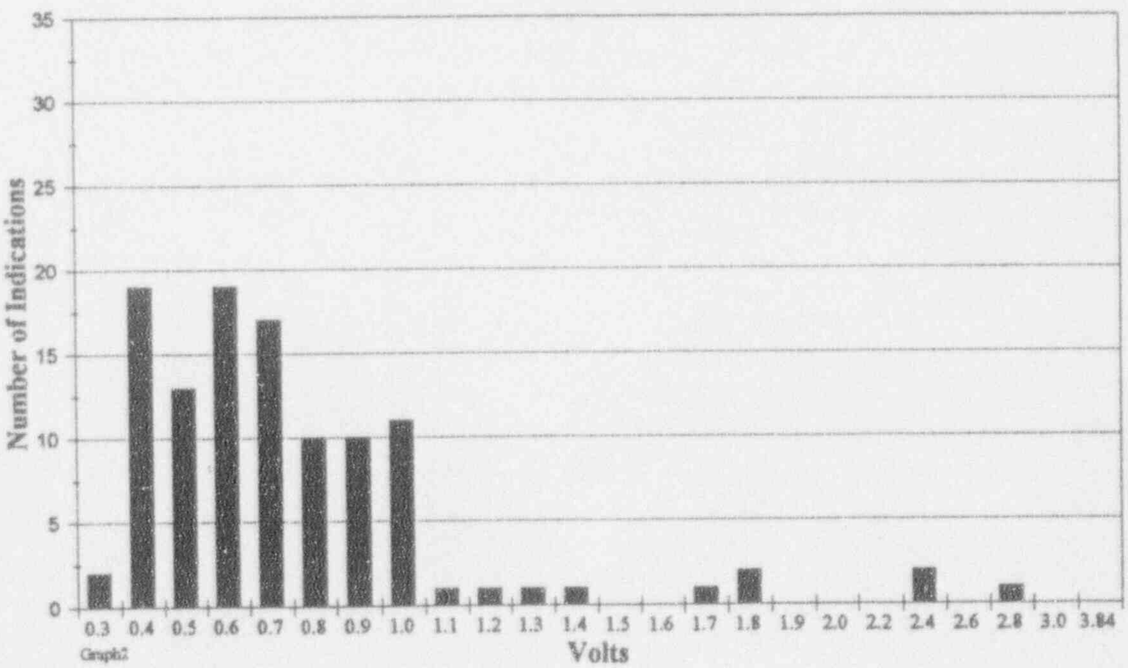
indications at 3.0 volts in the upper Figure 4-2 that are not present in the unadjusted data of the lower figure. This results because the three largest indications were repaired even though the two largest indications at 2.95 and 4.11 volts were RPC NDD. Comparison of Figures 4-2 and 4-3 show the conservatism of including the UOA indications in the reference distribution. The UOA distribution includes a number of indications above 1.0 volt as shown in Table 3-1 and includes indications in the 2.6 and 2.8 volt bins. The distributions of these figures are applied in Section 7 to obtain the projected EOC-10 voltage distributions for leakage and burst probability analyses given in Sections 9 and 10.

Figure 4-1

Farley-2 BOC 9 Voltage Distribution
SG "C", All Indications, PoD = 0.6



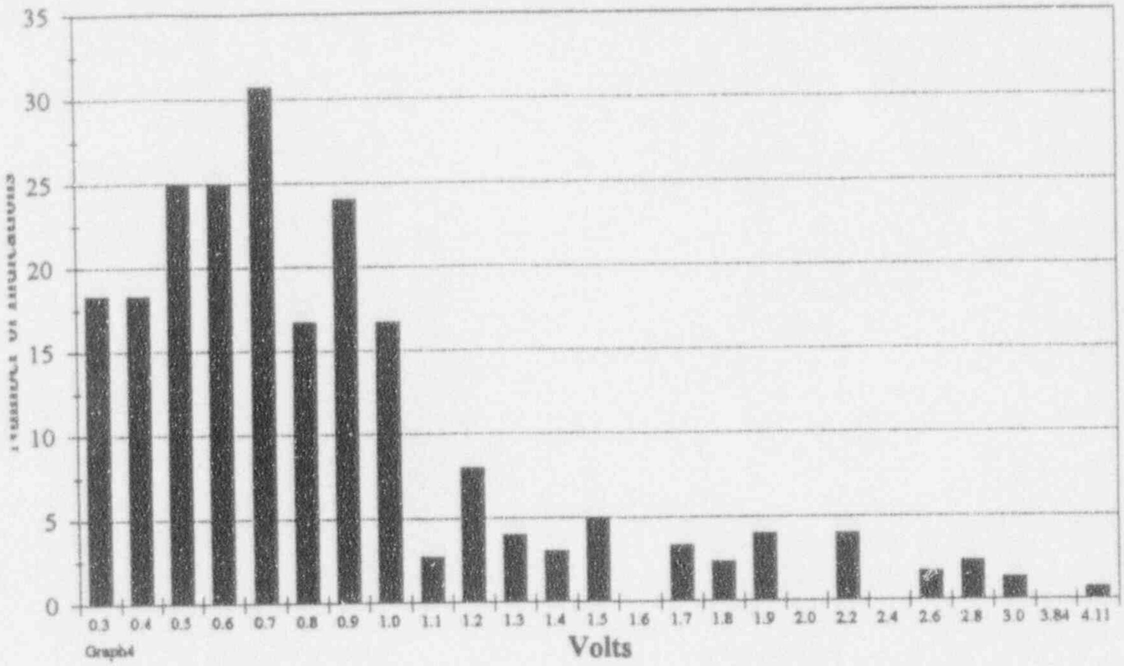
Farley-2 BOC 9 Voltage Distribution
SG "C", All Indications



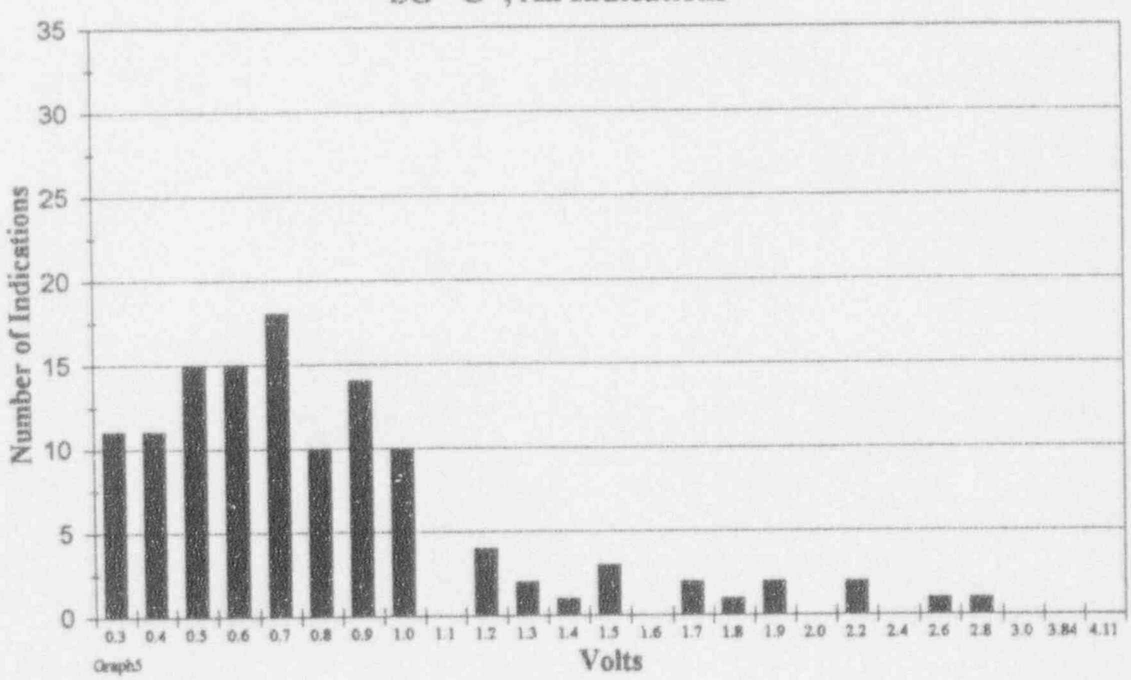
\qpw\TP001sid:11/18/93

Figure 4-2

Farley-2 BOC 10 Voltage Distribution
SG "C", All Indications, PoD = 0.6

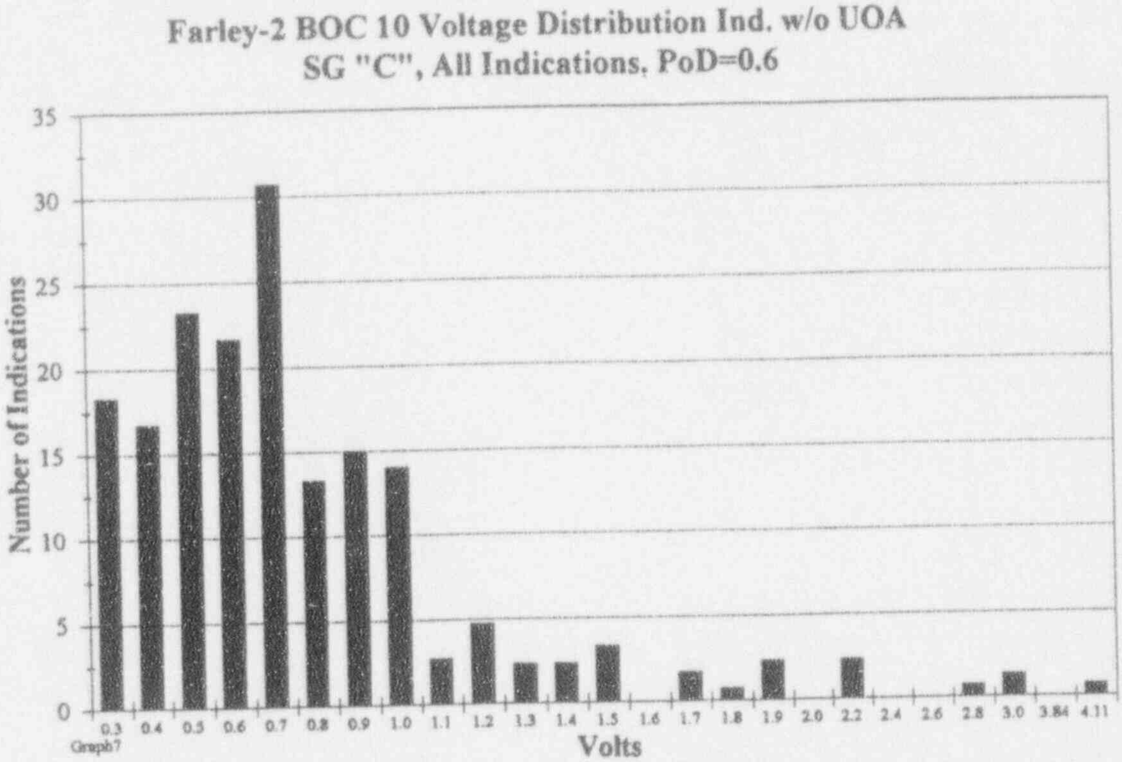


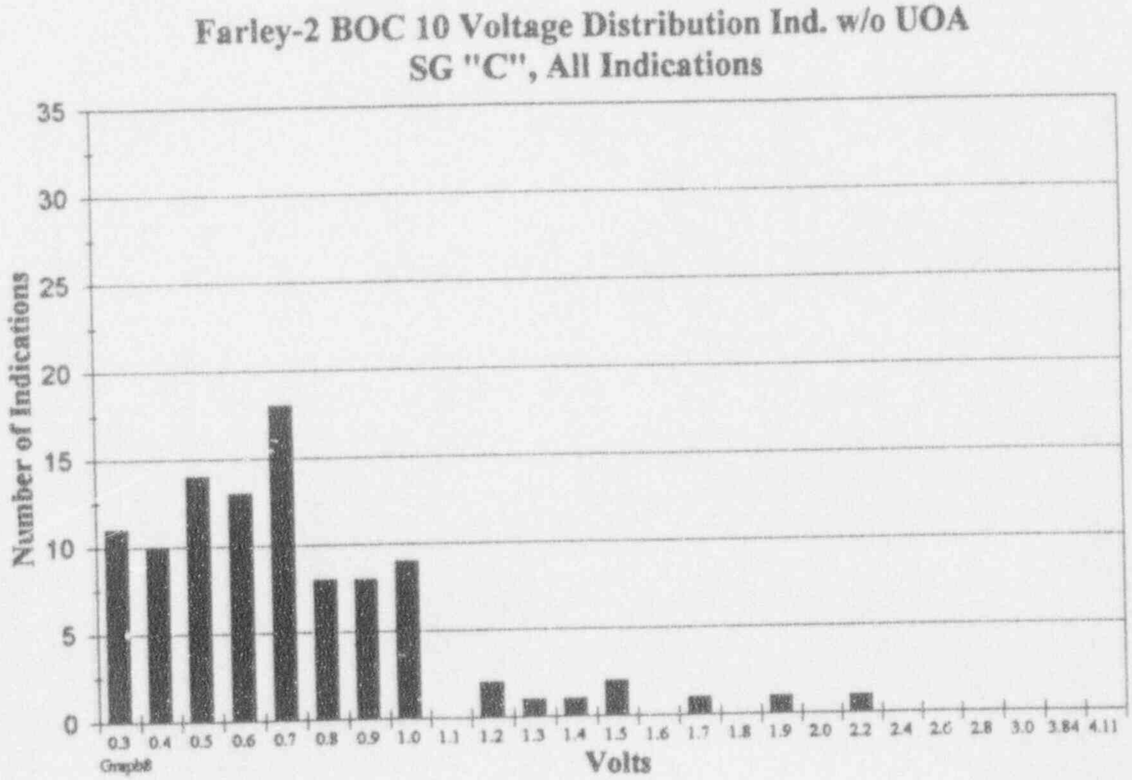
Farley-2 BOC 10 Voltage Distribution
SG "C", All Indications



\qpw\TP001sld:11/18/93

Figure 4-3


Farley-2 BOC 10 Voltage Distribution Ind. w/o UOA
SG "C", All Indications, PoD=0.6
Number of Indications
0
5
10
15
20
25
30
35
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1.8
1.9
2.0
2.2
2.4
2.6
2.8
3.0
3.84
4.11
Graph7
Volts


Farley-2 BOC 10 Voltage Distribution Ind. w/o UOA
SG "C", All Indications
Number of Indications
0
5
10
15
20
25
30
35
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1.8
1.9
2.0
2.2
2.4
2.6
2.8
3.0
3.84
4.11
Graph8
Volts

5.0 VOLTAGE GROWTH RATES

5.1 Cycle 8 Voltage Growth Rates

Voltage growth rates for Cycle 8 were developed at EOC-8 by the field analysts. The final 1992 bobbin voltages were all performed by the same analyst. The effort was limited to three analysts. The evaluation included calibration corrections for normalizing ASME standard voltages to the reference laboratory standard used in the APC database development.

These data were used to develop growth distributions for both the largest 200 indications and all indications. The use of the largest 200 indications yields a slightly more conservative (higher voltage at a given cumulative probability) growth than obtained for all data and has been used for the IPC projections from BOC-9 to EOC-9. Figure 5-1 shows the Cycle 8 voltage growth distribution. The largest growth value was 2.1 volts and found for only one indication. Only 3 indications had voltage growth values > 1.0 volt. The Cycle 8 growth distribution of Figure 5-1 is applied to project BOC-9 voltage distributions to EOC-9 conditions for comparisons with actual distributions as described in Section 7.

Table 5-1 summarizes the average growth rates for Farley Units 1 and 2 for all prior cycles and the 1993 results for Farley-2. The Cycle 8 (1990 to 1992) average growth was 0.14 volt or 19% of the BOC-8 average of 0.73 volt. The average growth for BOC indications < 0.75 volt was 30% while the average growth for indications > 0,75 volt was only 3%.

5.2 Cycle 9 Voltage Growth Rates

The Cycle 9 voltage growth rates were developed using a single analyst to finalize the 1993 voltages and to reevaluate the 1992 data for the same indications. The use of a single analyst for both years evaluations provides consistency to the analysis and more accurate growth data. Appendix A guidelines were used in the 1993 inspection including cross calibration of the field ASME standards to the reference laboratory standard. Growth rates were developed for all potential flaws (PI and UIA classifications) and including the INR and the INR + UOA classifications. The growth rate for the potential flaw group gave the most conservative distribution and is applied for the Cycle 9 growth rate distribution.

The Cycle 9 growth distribution is shown in Figure 5-1. The largest growth value is 1.9 volts which is similar to the largest value of 2.1 volts found for Cycle 8. Also both cycles show only 3 growth values > 1.0 volt. The Cycle 9 distribution peaks at the ≤ 0 volt bin while the Cycle 8 peak occurs for the 0.2 volt bin which indicates a modest reduction in overall growth from Cycle 8 to Cycle 9. The growth distribution of Figure 5-1 is applied to project BOC-10 indications left in service to EOC-10 conditions in Section 7.

Table 5-2 shows the bobbin and RPC results for all indications with a growth rate > 0.4 volts. Also shown is whether the indication was a new indication reported in the 1993 inspection. Nine of the 12 indications with the largest growth rates were confirmed by RPC. The 3 indications not confirmed by RPC had growth rates of 0.6 volts or less. Nine of the indications, including the 3 RPC NDD indications, were new indications in the 1993 inspection. Four of the growth values are associated with UIA indications while the remaining are PI indications.

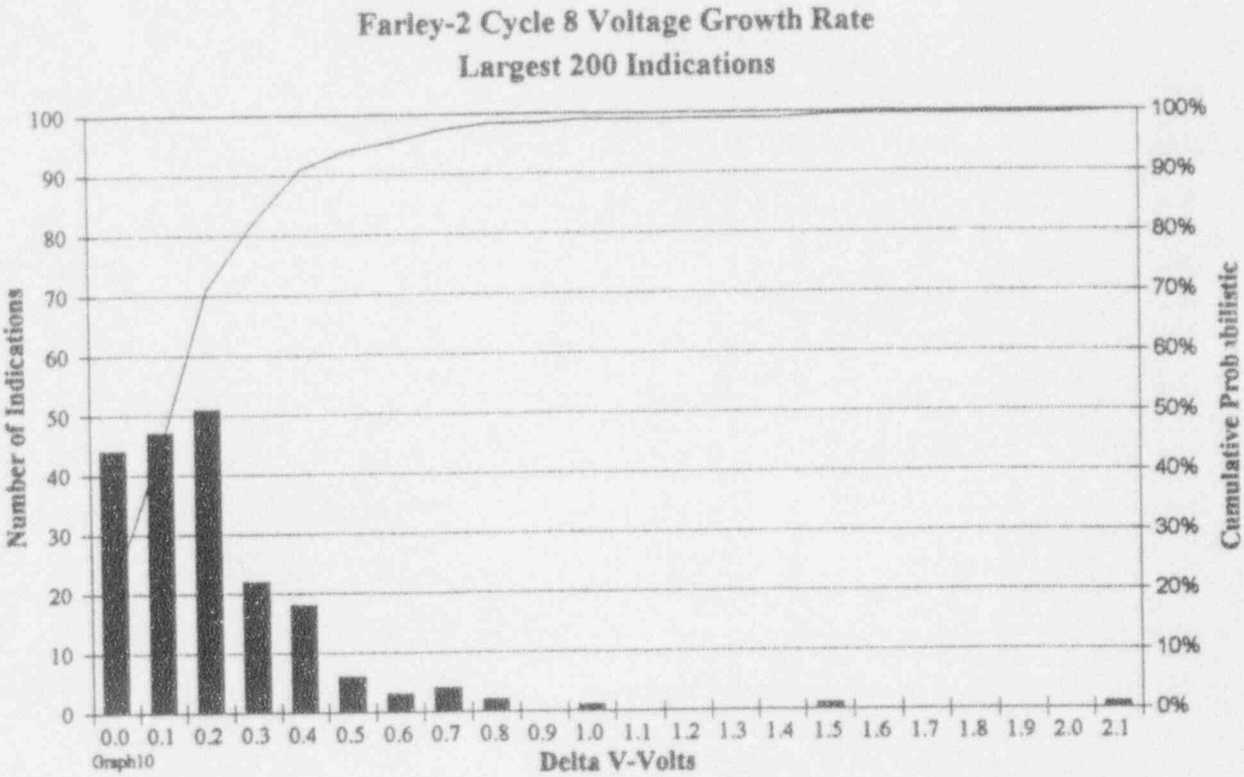
Table 5-1 summarizes the average voltage growth rates for Cycle 9 (1992 to 1993). The average growth rate is 0.09 volts or 12% for Cycle 9 which is slightly smaller than the 19% found for Cycle 8. The average growth rate for BOC indications ≤ 0.75 volt is 20% while growth for indications > 0.75 volt is 8%. The Farley data consistently show lower percentage growth for the larger BOC indications as shown in Table 5-1. Overall, the Farley growth data for both units show a trend of decreasing growth rates since about 1987. The data of Table 5-1 for Cycle 9 includes growth results for 169 of the 170 1993 indications as a prior cycle voltage for one indication could not be reasonable estimated (i.e., indication was NDD in prior cycle). The growth rates of Unit-2 are slightly smaller than found for Unit-1. The decreasing growth rate trends for the Farley S/Gs demonstrate the effectiveness of plant operations such as chemistry and cleaning efforts to control and reduce the growth of ODSCC at TSP intersections.

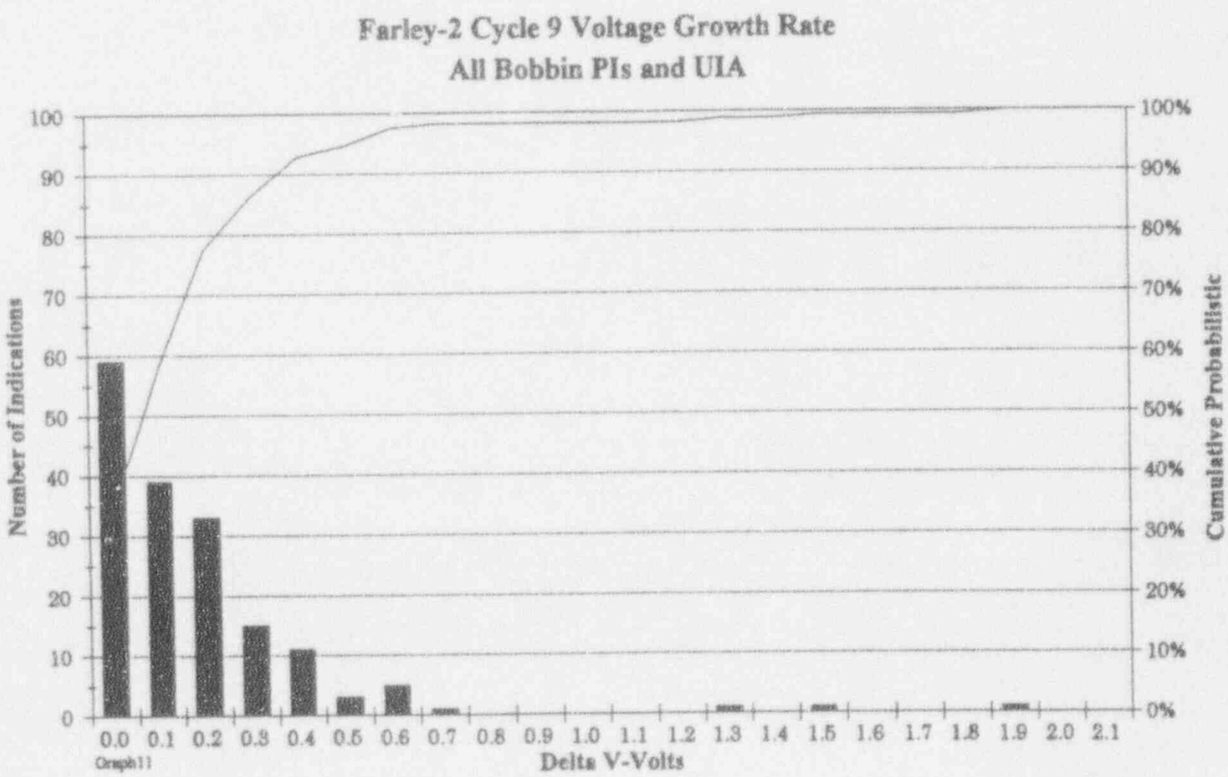
Table 5-1. AVERAGE VOLTAGE GROWTH PER CYCLE FOR FARLEY UNITS 1 AND 2						
Unit/Cycle	Number Indications	Average BOC Voltage	Average ΔV Growth/Cycle	Average % Growth		
				%/Cycle	EFPY	%/EFPY
Farley Unit 1						
1985 to 1986	123	0.45	0.20	45%	1.30	35%
1986 to 1988	274	0.48	0.28	59%	1.11	53%
1988 to 1989	431	0.62	0.22	36%	1.30	28%
1989 to 1991						
Entire voltage range	499	0.70	0.23	33%	1.25	26%
$V_{BOC} < 0.75$ volt	306	0.51	0.24	48%		
$V_{BOC} \geq 0.75$ volt	193	1.01	0.08	8%		
1991 to 1992						
Entire voltage range	1267	0.85	0.22	26%	1.29	20%
$V_{BOC} < 0.75$ volt	546	0.57	0.21	37%		
$V_{BOC} \geq 0.75$ volt	721	1.08	0.23	21%		
Farley Unit 2						
1986 to 1987	291	0.55	0.13	24%	1.26	19%
1987 to 1989	316	0.59	0.20	34%	1.14	30%
1989 to 1990						
Entire voltage range	326	0.71	0.11	15%	1.28	12%
$V_{BOC} < 0.75$ volt	207	0.52	0.16	30%		
$V_{BOC} \geq 0.75$ volt	119	1.04	-0.12	-13%		
1990 to 1992						
Entire voltage range	308	0.73	0.14	19%	1.11	17%
$V_{BOC} < 0.75$ volt	233	0.57	0.17	30%		
$V_{BOC} \geq 0.75$ volt	75	1.23	0.04	3%		
1992 to 1993						
Entire voltage range	169	0.76	0.09	12%		
$V_{BOC} < 0.75$ volt	105	0.51	0.10	20%		
$V_{BOC} \geq 0.75$ volt	64	1.18	0.09	8%		

Table 5-2. SUMMARY OF CYCLE 9 LARGEST BOBBIN VOLTAGE GROWTH RATES							
S/G	Tube	TSP	EOC 9		BOC 9 Bobbin Volts	ΔV Volts	New Indication
			Bobbin Volts	RPC Volts			
C	R31C68	1	2.81	2.55	0.92	1.89	No
C	R14C87	1	2.07	2.30	0.62	1.45	Yes
C	R26C79	1	2.78	2.26	1.48	1.30	Yes
B	R15C86	1	1.54	0.64	0.90	0.64	No
B	R11C91[1]	1	1.56	NDD	0.96	0.60	Yes
C	R9C93	1	1.89	1.00	1.29	0.60	Yes
C	R2C3	5	4.11	NDD	3.53	0.58	Yes
		3	2.95	NDD	2.40	0.55	Yes
C	R24C68[1]	1	0.95	0.33	0.44	0.51	Yes
B	R6C93[1]	1	1.17	0.27	0.68	0.49	Yes
B	R43C63[1]	2	1.13	0.36	0.72	0.41	No
C	R16C80	1	1.06	0.63	0.65	0.41	Yes

Note 1. Unusual ID phase angle indications. Other indications in table are bobbin potential indications

Figure 5-1


Farley-2 Cycle 8 Voltage Growth Rate
Largest 200 Indications
Number of Indications
Cumulative Prob ıbilistic
0 10 20 30 40 50 60 70 80 90 100
0% 10% 20% 30% 40% 50% 60% 70% 80% 90% 100%
0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0 1.1 1.2 1.3 1.4 1.5 1.6 1.7 1.8 1.9 2.0 2.1
Graph10
Delta V-Volts


Farley-2 Cycle 9 Voltage Growth Rate
All Bobbin PIs and UIA
Number of Indications
Cumulative Probabilistic
0 10 20 30 40 50 60 70 80 90 100
0% 10% 20% 30% 40% 50% 60% 70% 80% 90% 100%
0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0 1.1 1.2 1.3 1.4 1.5 1.6 1.7 1.8 1.9 2.0 2.1
Graph11
Delta V-Volts

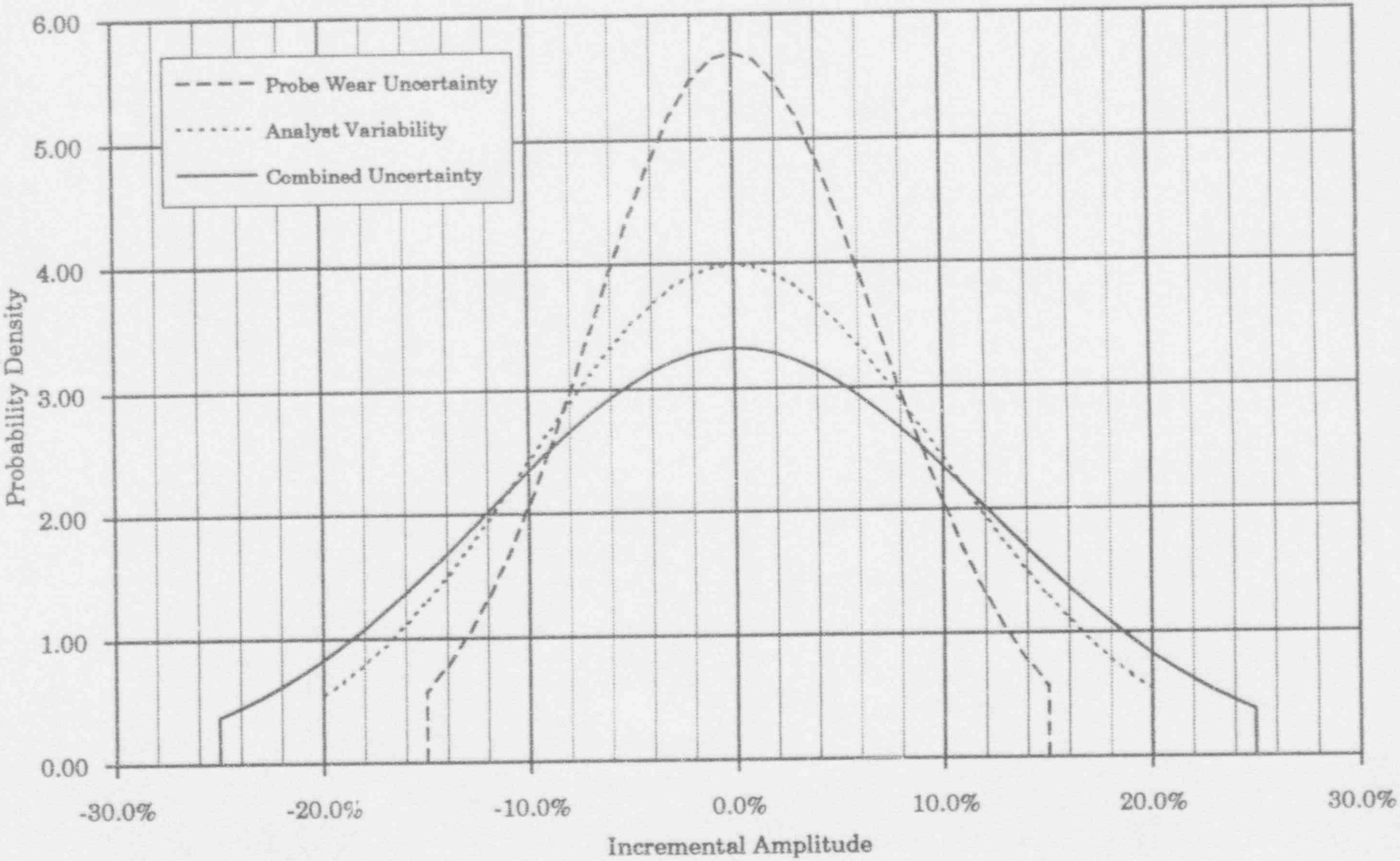
6.0 NDE UNCERTAINTIES

NDE uncertainties for voltage measurements were developed for Farley units in WCAP-12871, Revision 2, Section 8. The net NDE uncertainty developed in this WCAP is essentially the same as developed in the EPRI Report TR-100407, Revision 1 (Draft of August 1993). While the WCAP and EPRI reports differ slightly in the components of the net NDE uncertainty and in the development, the net NDE uncertainty is not significantly different (12% standard deviation in the WCAP versus 12.5% in the EPRI report) and the WCAP NDE uncertainty is applied for both Cycles 8 and 9 for Farley-2.

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%. These distributions are applied as normal distributions and combined to obtain a net NDE uncertainty of 12% for one standard deviation. The upper bound on the probe wear uncertainty is limited to 15% by the Farley 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 is 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%. An upper limit on the net NDE uncertainty of 25% is obtained by combining the 15% and 20% upper limits by the square root of the sum of squares.

The net NDE uncertainty applied to obtain projected EOC voltages is then a 12% standard deviation about a mean of zero with a maximum cutoff at 25%. Normal distributions are applied for the NDE uncertainty. The NDE uncertainty normal distributions are shown graphically in Figure 6-1.

Figure 6-1. NDE UNCERTAINITY FOR ODSCC AT TSP'S



[NDEUNCRT.XLW]Prob Density Plot

RFK: 11/11/93, 11:53 AM

7.0 PROJECTED EOC VOLTAGE DISTRIBUTIONS

7.1 Projected EOC-9 Voltage Distributions

Consistent with the methodology of WCAP-12871, Revision 2 (as suggested in the Farley-2 SER), Monte Carlo analyses are applied to develop projected EOC distributions from the BOC distributions. The BOC voltages are increased by allowances for NDE uncertainties (from Section 6) and voltage growth (from Section 5) to obtain the EOC values. In the Monte Carlo analyses, each voltage bin of the BOC voltage distributions (Figure 4-1 for example) is increased by a random sample of the NDE uncertainty and growth distributions to obtain a 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. In the present analyses, 1,000,000 samples of the BOC distribution were applied with the large number required to obtain adequate accuracy for tube burst probability analyses. EOC voltage distributions and SLB leakage could be adequately obtained with about 10,000 samples. The EOC projections were performed for S/G C which is the limiting S/G for both Cycles 9 and 10.

The projected EOC-9 bobbin voltage distributions are shown in Figure 7-1 for the three categories of BOC distributions discussed in Section 4.1 and shown in Figure 4-1. For the POD adjusted distribution, the maximum projected EOC-9 voltage is 4.2 volts. Since the Monte Carlo analyses yield a cumulative probability distribution of EOC voltages, a method must be defined to obtain a discrete maximum EOC voltage value. The method adopted in this report is to integrate the tail of the Monte Carlo distribution over the largest 1/3 of an indication to define a discrete value with an occurrence of 0.33 indications. For N indications in the distribution, this is equivalent to evaluating the cumulative probability distribution of voltages at a probability of (N-0.33)/N. The largest voltages for all distributions developed by Monte Carlo in this report have been obtained with this definition for the maximum EOC discrete voltage. The largest EOC-9 voltage for the distribution of all indications without POD adjustment is 3.3 volts and for the BOC distribution ≤ 1.0 volt is 2.5 volts. In the 1992 SLB leak rate evaluation, a maximum EOC-9 voltage of 3.6 volts was reported for all indications without POD adjustment. The difference between 3.6 volts and the 3.3 volts of this report is due to the method (1/3 of an indication in this report) used to define the reported voltage.

7.2 Comparison of Projected and Actual EOC-9 Distributions

For purposes of comparing projected and actual distributions, it is necessary to consider the applied purpose of the projections in order to define the actual distributions appropriate for the comparison. This results as the Farley-2 EOC inspection results include many RPC NDD indications such as PIN, UIN, UOA and UON classifications. INRs could also be considered as a RPC NDD classification although they are included for comparisons with projections. The UOA are included as RPC NDD based on Farley historical experience even if all of these signals were not RPC inspected in the current outage. The projected EOC voltage distributions for IPC applications are applied to project SLB leakage and tube burst probability. As discussed in Section 3.2 in developing the EOC-9 distribution for comparisons with projections, RPC NDD indications have a negligible likelihood of potential SLB leakage over the prior cycle and should be ignored in comparing IPC projections with the actual distributions. Thus the comparisons of IPC projections with actual distributions are made for EOC-9 RPC confirmed indications summed with indications not RPC inspected since it cannot be stated with confidence that the latter indications would not have leaked over the prior cycle. The appropriate S/G C EOC-9 actual distributions for this comparison were given in Figure 3-3. There are 107 indications in this EOC distribution which includes PI, PIC, INR, UIA and UIC indications. For information only, comparisons of projected voltage distributions are also compared with the distribution of all indications, including PINs and UOAs, at EOC-9.

Figure 7-2 shows the comparison of projected and actual EOC-9 voltage distributions (excluding RPC NDDs as discussed above). The upper figure shows the NRC model (Figure 4-1 for BOC-9 distributions) which includes a POD = 0.6 applied to the EOC-8 inspection results. It is seen that the NRC model leads to excessive conservatism both in the number of indications with leakage potential and in the largest EOC voltages. The NRC model leads to projected voltages as high as 4.2 volts and overestimates the number of indications in all voltage bins except < 0.3 volt and a very minor underestimate in the 2.8 to 3.0 volts bin. The middle figure of Figure 7-2 shows the comparison for the projection of all indications without a POD adjustment. This projection is in quite good agreement with the actual above 1.7 volts and conservative compared to actual voltages between 0.7 and 1.7 volts. Above 1.7 volts, the projection based on Monte Carlo analyses has distributed the indications more continuously over the voltage range, as would be expected, in comparison to the discrete actual indications and represents a good estimate of the number of indications above 1.7 volts. As discussed previously (Section 3.2), this good agreement results in part from RPC NDD indications included in the BOC distribution acting to compensate for new RPC confirmed indications. An alternate approach to defining BOC indications including considerations for undetected indications is described in Section 10. The lower figure of Figure 7-2 compares the actual distribution with the projection based on BOC indications less than 1.0 volt which ignores RPC indications left in service and includes no provision for new indications. The basis for this type of a projection is that RPC NDD and new indications will not result in significant leakage over the subsequent cycle. It is seen that this projection underestimates the RPC confirmed indications above 1.7 volts. The adequacy of this projection for SLB leakage calculations cannot be readily assessed as it is not known whether or not the new indications above 1.7 volt would leak at SLB conditions. Farley Units 1 and 2 pulled tubes including voltages up to 3.3 volts have not leaked or had significant leakage (one indication at 2.8 volts had a 7.5×10^{-4} gpm leak rate at SLB conditions). Assuming the potential for leakage is adequately accounted for in the probability of leakage correlation, it can be concluded that the use of only indications RPC confirmed or not inspected and left in service would underestimate the EOC RPC confirmed indications. A recommended method for defining the BOC distributions is described in Section 10.

A comparison of projected distributions with the EOC-9 distribution for all indications independent of RPC confirmation is shown in Figure 7-3. As noted above, this actual distribution includes RPC NDD and UOA indications which would not be expected to leak at EOC-9. For this case, the NRC model (POD = 0.6) provides the closest comparison between projections and actual distributions. However, these distributions would lead to excessive conservatism if applied to SLB leakage analyses.

7.3 Projected EOC-10 Voltage Distributions

The BOC-10 voltage distributions are described in Section 4.2 and Figures 4-2 and 4-3 with and without UOAs included in the distributions, respectively. Monte Carlo methods are applied using the Cycle 9 voltage growth distribution of Figure 5-1 to obtain the projected EOC-10 distributions. As above for Cycle 9, projections to EOC-10 have been made for three distributions including the NRC model with a POD = 0.6, all bobbin indications left in service including RPC NDD and all indications left in service confirmed by RPC or not RPC inspected. The latter case is labeled as < 1.0 volt although, for the distributions including UOAs, the UOA signals above one volt are included in the BOC distribution.

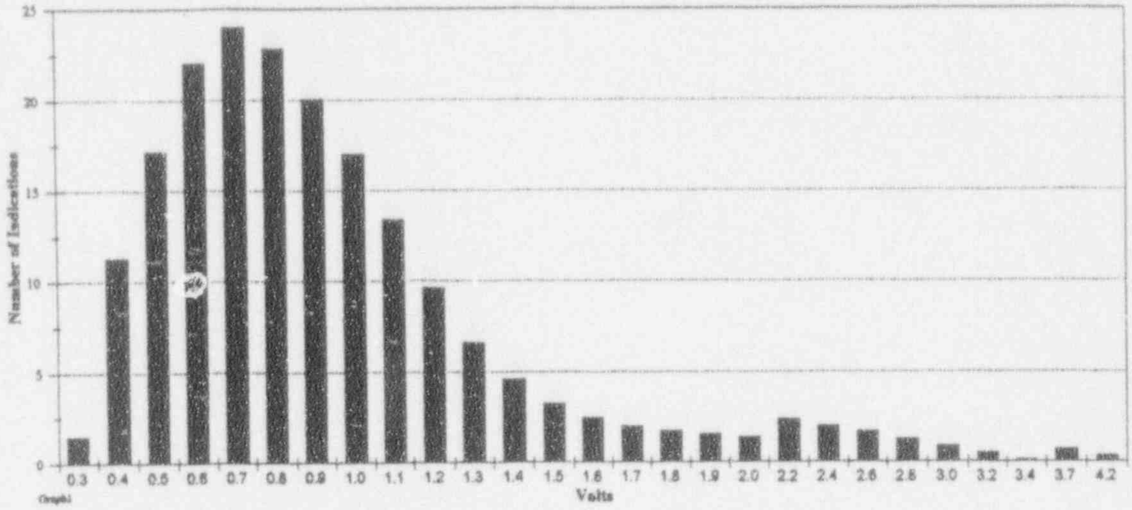
Figure 7-4 shows the projected distributions with UOAs included and Figure 7-5 shows the projections without UOAs. The conservatism of the NRC model, as reflected in the BOC distributions of Figures 4-2 and 4-3, are seen in the EOC-10 distributions. The NRC model with UOAs projects to an EOC maximum voltage of about 4.5 volts compared to 3.3 volts for all indications left in service and for the < 1.0 volt BOC distribution. In this case, the latter two projections are the same as the highest UOA voltages lead to the maximum EOC voltage. Without UOAs, the NRC model projects a maximum EOC voltage of 4.4 volts which is essentially the same as with UOAs. This results as the maximum EOC voltage results from the POD adjustment to the RPC NDD indication of 4.11 volts found in the inspection even though this indication was removed from service. From Figure 7-5, the distributions for all indications and < 1.0 volt indications without UOAs project to maximum EOC voltages of 2.7 and 2.4 volts, respectively.

The EOC-10 distributions given in Figures 7-4 and 7-5 are applied to SLB leakage analyses in the following Section.

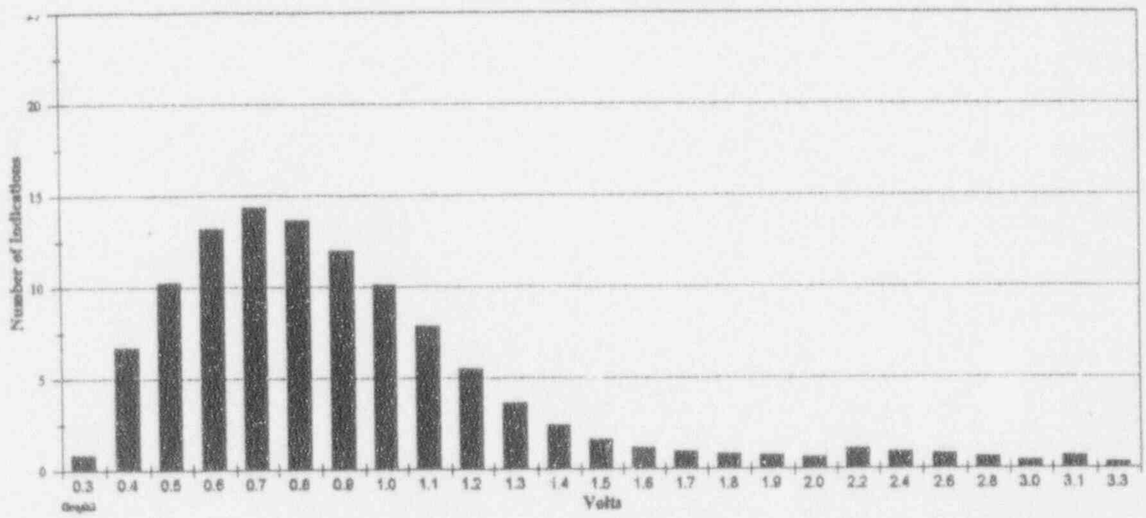
Figure 7-1

Farley-2 Projected EOC-9 Voltage Distributions

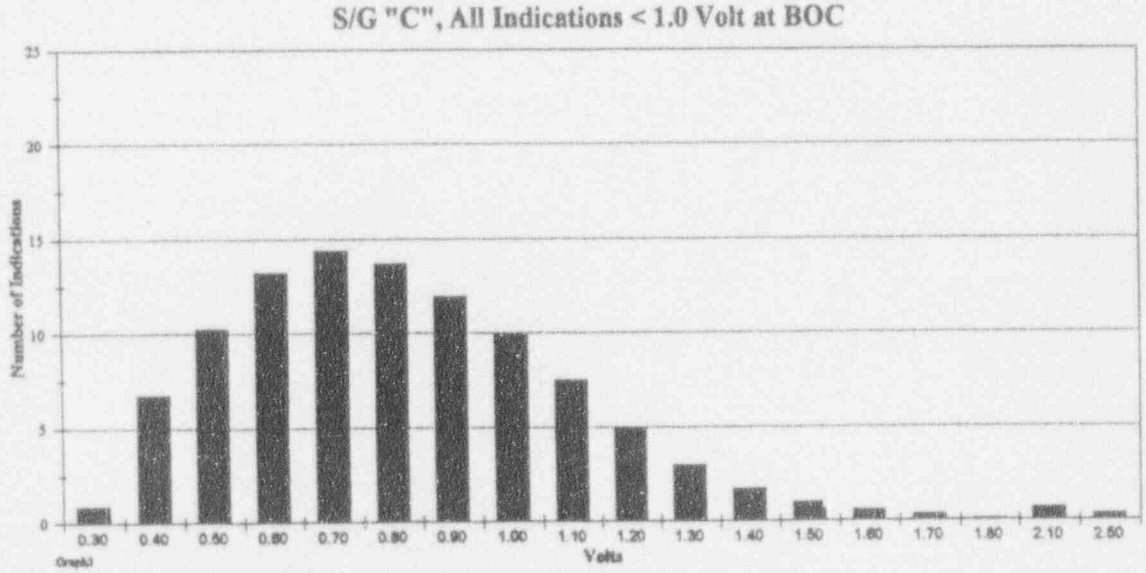
S/G "C", All Indications, PoD=0.6



S/G "C", All Indications



S/G "C", All Indications < 1.0 Volt at BOC

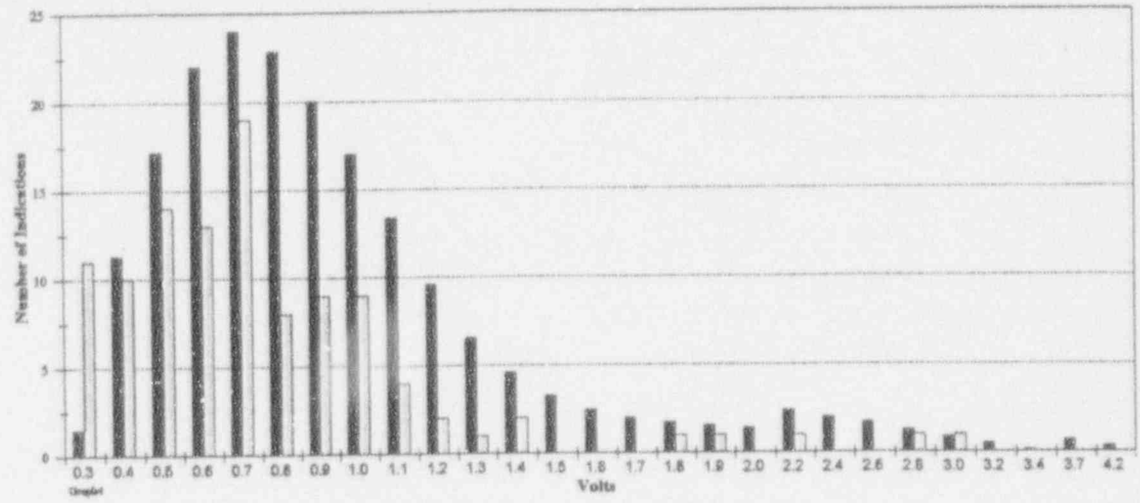


tp003sid.wb1:12/08/93

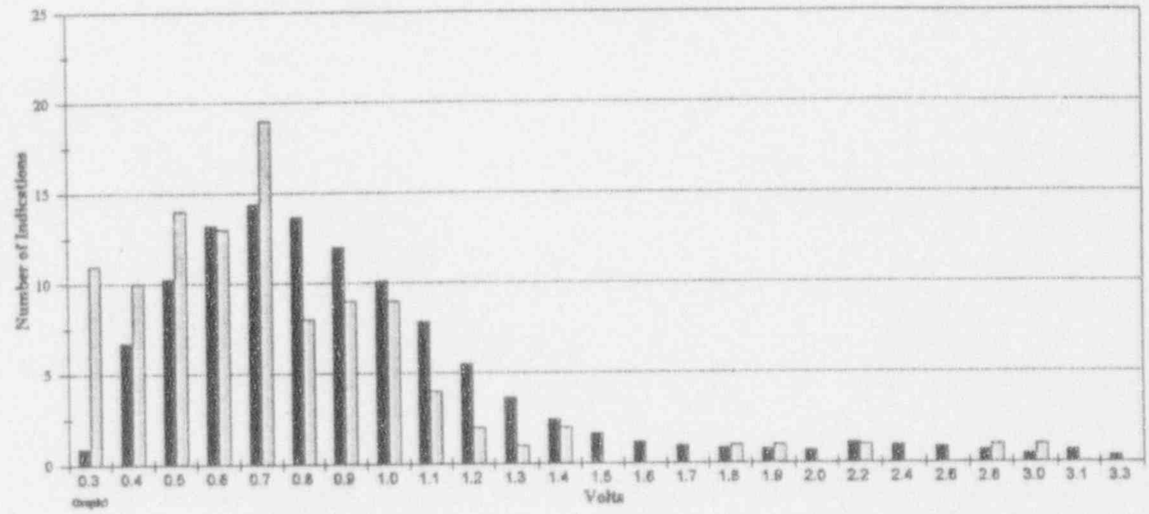
Figure 7-2

Farley-2 Comparison of Projected and Actual EOC-9 Voltage Distributions

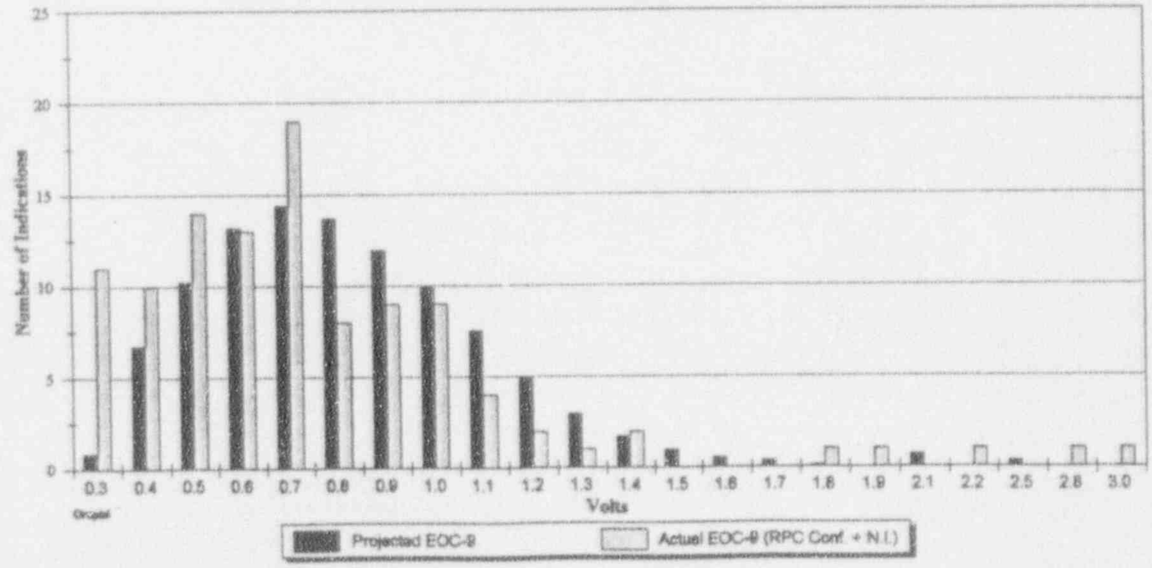
S/G "C" Projection: All Indications, PoD=0.6



S/G "C": All Indications



S/G "C" Projection: All Indications < 1.0 Volt at BOC

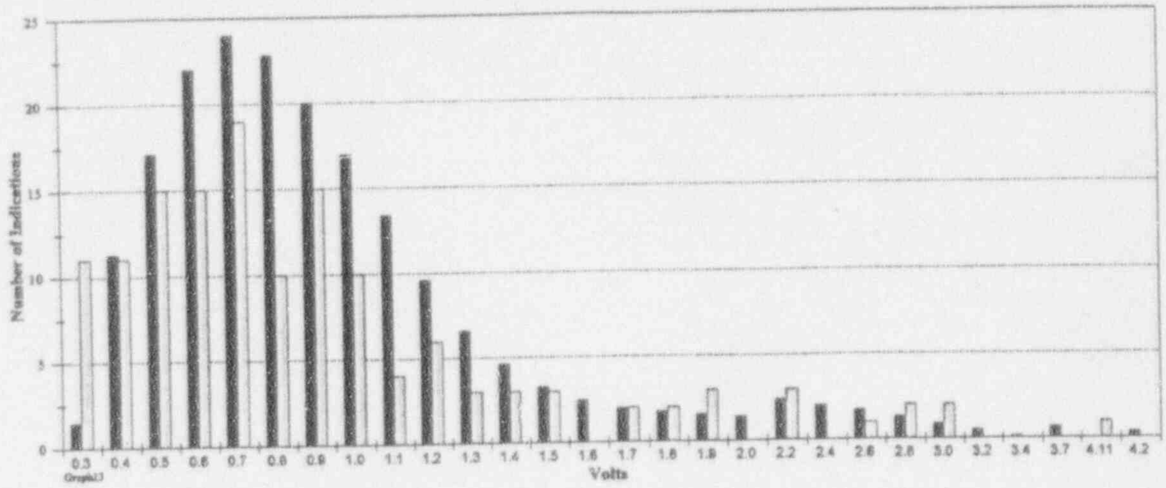


tp003sld.wb1:12/08/93

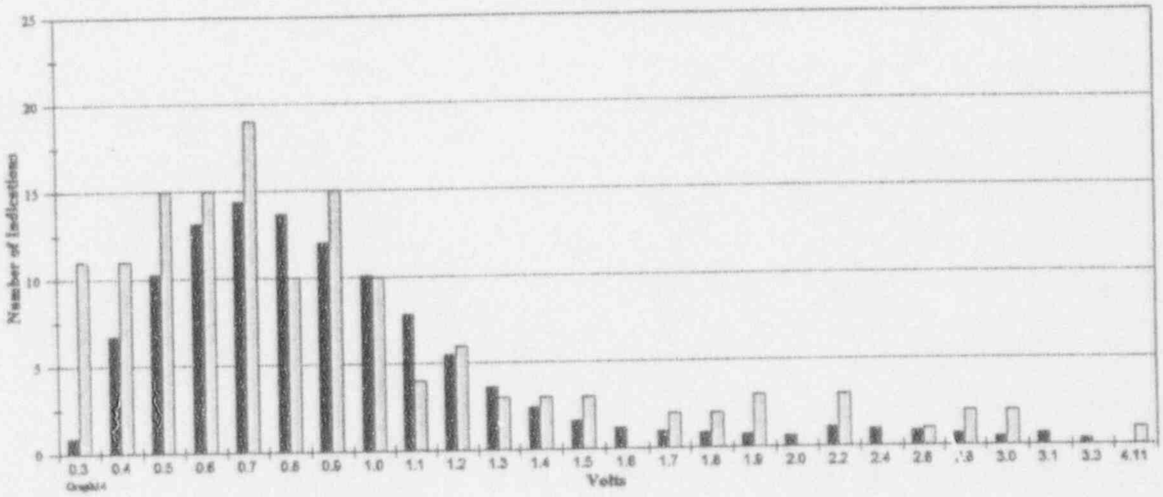
Figure 7-3

Farley-2 Comparison of Projected and All Ind. EOC-9 Voltage Distributions

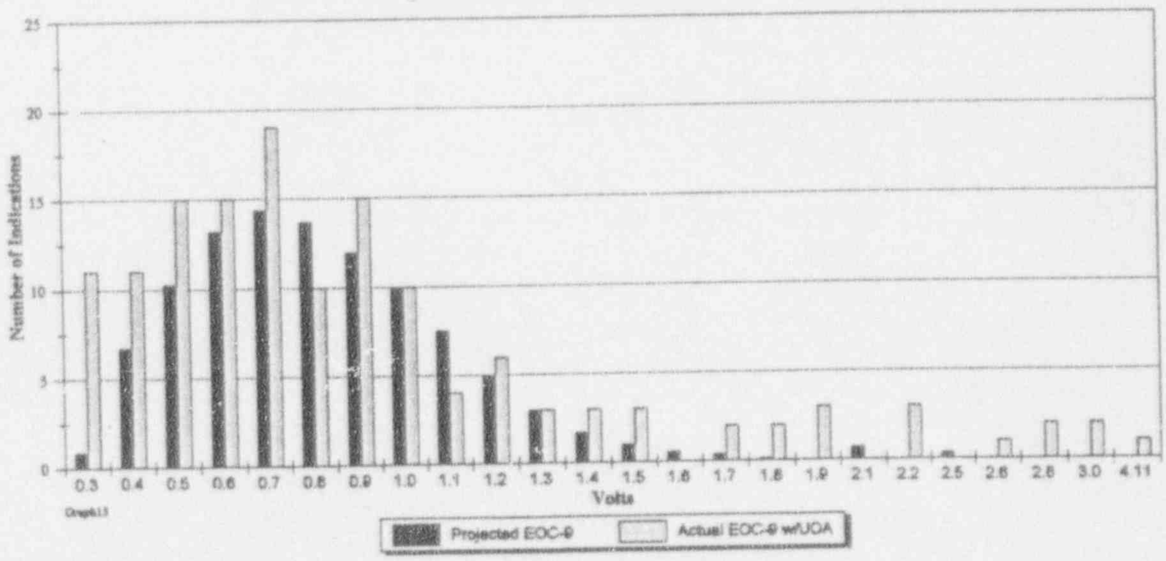
S/G "C" Projection: All Indications, PoD=0.6



S/G "C" Projection: All Indications



S/G "C" Projection: All Indications < 1.0 Volt at BOC

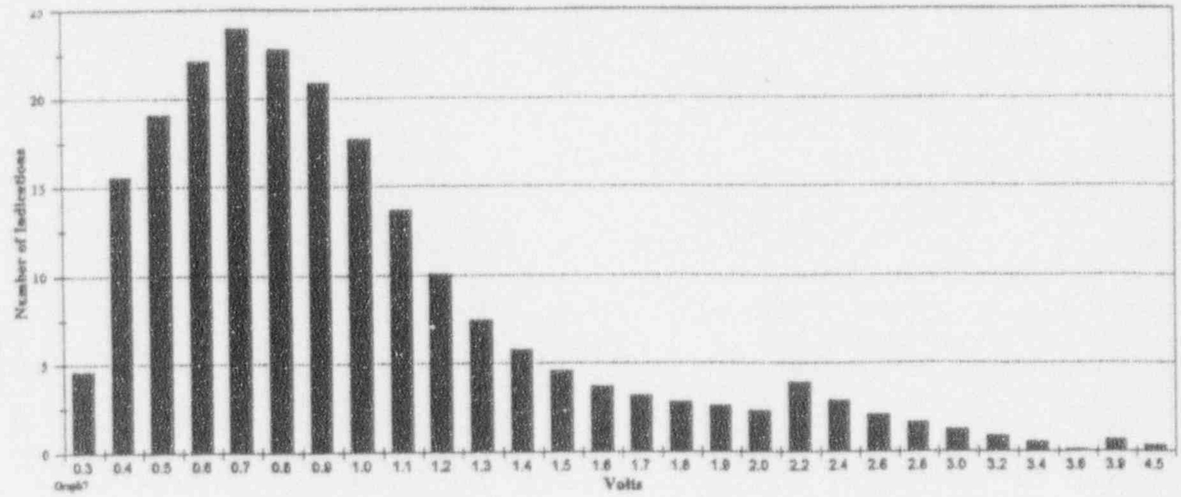


tp003sld.wb1:12/08/93

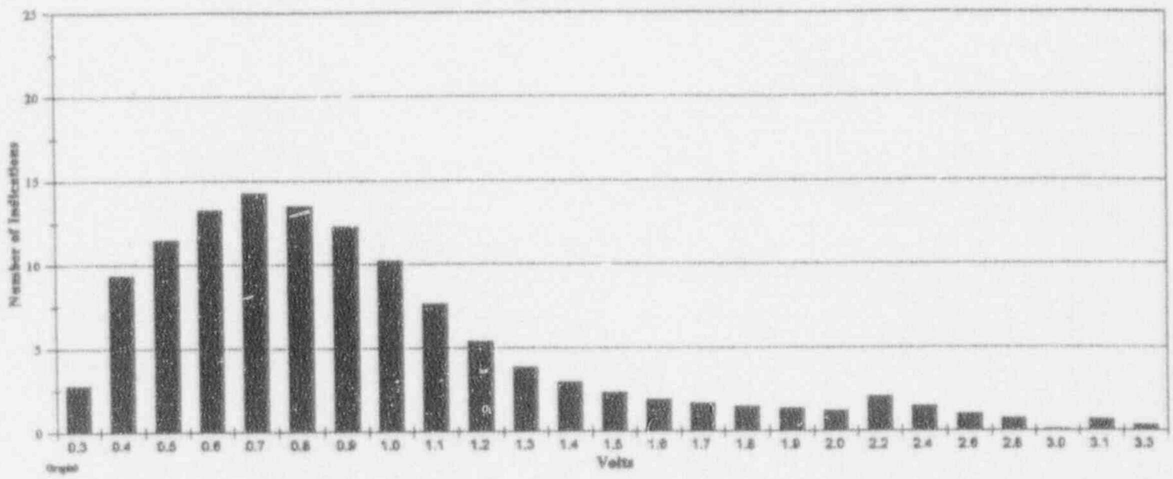
Figure 7-4

Farley-2 Projected EOC-10 Voltage Distributions

S/G "C" Projection: All Indications, PoD=0.6



S/G "C" Projection: All Indications



S/G "C" Projection: All Indications < 1.0 Volt at BOC

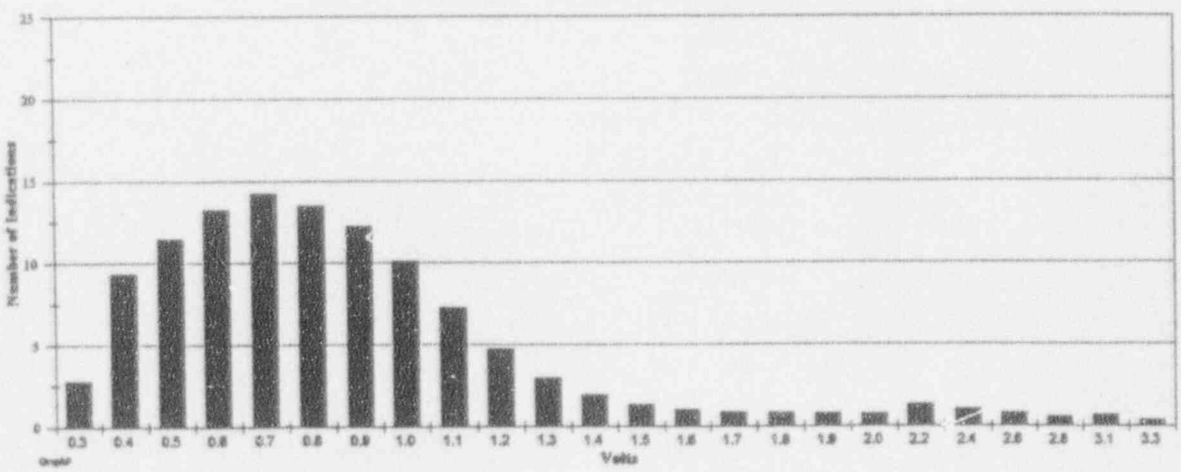
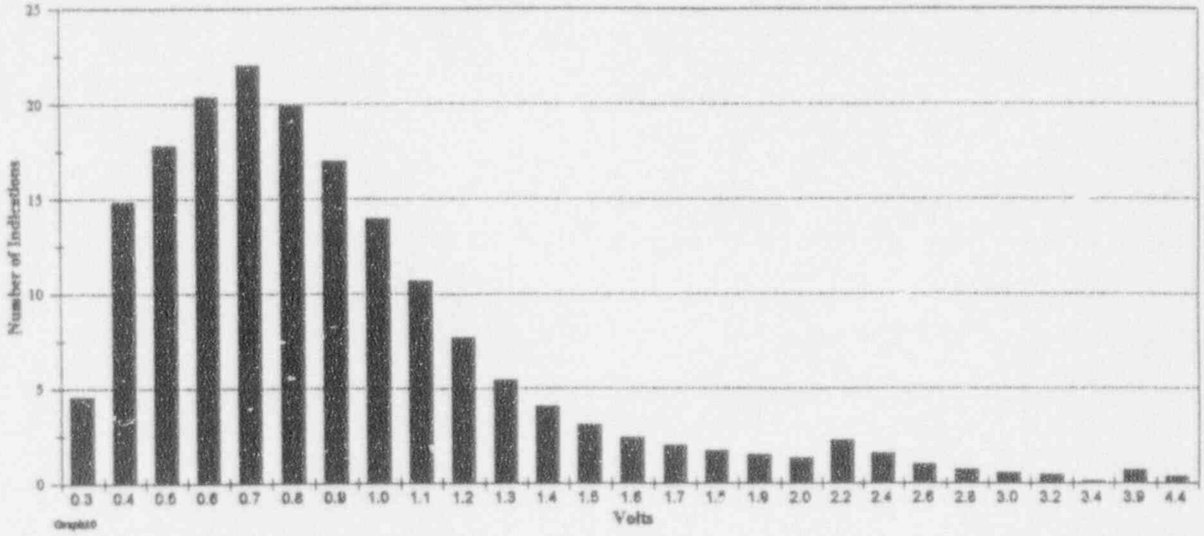


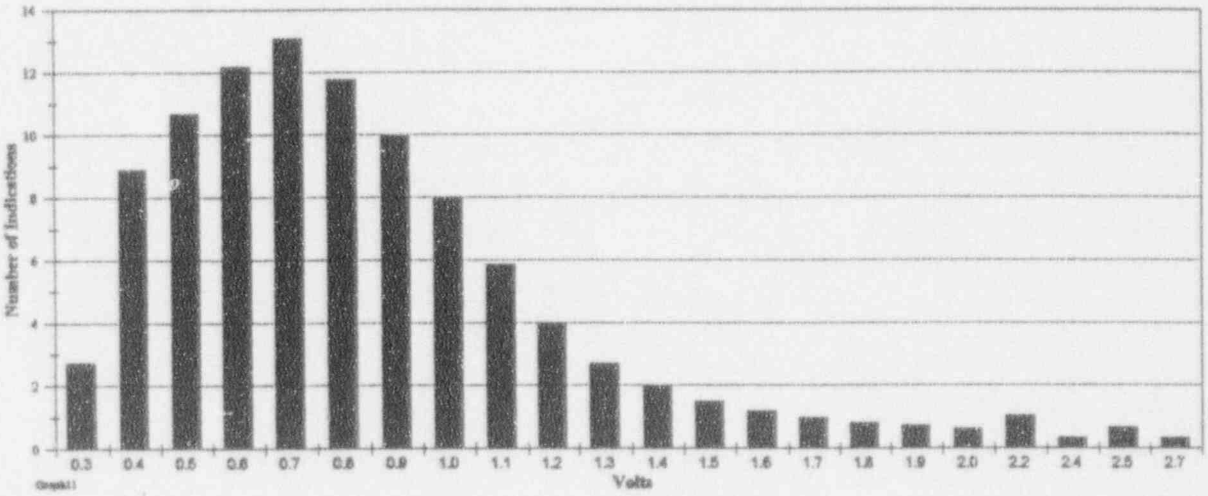
Figure 7-5

Farley-2 Projected EOC-10 Voltage Distributions w/o UOA

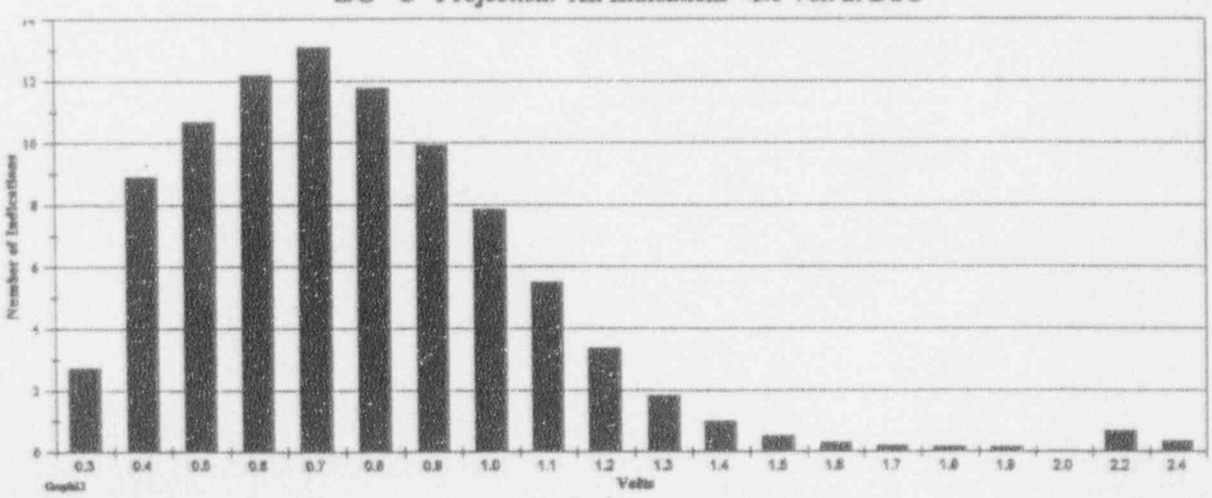
S/G "C" Projection: All Indications, PoD=0.6



S/G "C" Projection: All Indications



S/G "C" Projection: All Indications <1.0 Volt at BOC



8.0 SLB Leak Rate Analyses

SLB leak rate analyses are given below for both the methodology of draft NUREG-1477, as required by the Farley-2 SER and the methods of WCAP-12871, Rev. 2. The WCAP methods are based on Monte Carlo analyses. As used to develop EOC voltages, the Monte Carlo methods produce many samples of the EOC voltage distribution. For leak rate analyses, the voltage for each sample is used to sample the probability of leakage correlation and the leak rate correlation to develop a leak rate sampled weighted by the probability of leakage and the number of indications in each voltage bin. The leakage correlations used in this analysis are the EPRI correlations of report NP-7480-L, Vol. 1, Rev. 1. Each voltage bin is sampled and the leak rates summed over all EOC voltage bins to obtain one sample of total SLB leakage. By repeating the sampling over all bins, a cumulative probability distribution for total leakage is developed. Per WCAP-12871, the SLB leakage value reported is the 90% cumulative probability value which, for a large number of samples, is 90% confidence on the leak rate.

The NRC methodology of draft NUREG-1477 obtains the number of indications as:

$$N = N_d + N_{nd} - N_r = N_d + [(1-POD)/POD]*N_d - N_r = N_d/POD - N_r$$

where, N_d = number of detected bobbin indications
N_r = number of repaired indications
N_{nd} = number of indications not detected by the bobbin inspection
POD = probability of detection (0.6 for NRC methodology)

The above adjustments for POD have been incorporated in the BOC and EOC voltage distributions developed in Sections 4 and 7 so that no further adjustments are required for the leakage calculation. Section 3.3 of draft NUREG-1477 states that the total leak rate, LR, should be determined as:

$$LR = \mu P + Z \sqrt{[\sigma^2 P + \mu^2 P - \mu^2 \Sigma_i(N_i P_i^2)]}$$

where, μ = mean of the leak rate data independent of voltage
σ = standard deviation of the leak rate data independent of voltage
P_i = probability that a tube leaks for the i-th voltage bin
N_i = number of indications (after POD adjustment) in the i-th voltage bin
$P = \Sigma_i(N_i P_i)$ = expected number of indications that leak summed over all voltage bins
Z = standard normal distribution deviate (establishes level of confidence on leakage)

For the total leakage, the first term of the above equation represents a mean expected leak rate while the square root term is an effective standard deviation for the total leakage. Draft NUREG-1477 recommends that Z be applied as 2 which corresponds to a level of confidence of 98%. Leakage data for the above equation are obtained from EPRI Report NP-7480, Volume 1, Revision 1. These data include the probability of leakage correlation, μ = 14.85 liter/hour and σ = 468.7 liter/hour.

8.1 Projected EOC-9 SLB Leak Rates

SLB leak rates were calculated for the projected EOC-9 voltage distributions of Figure 7-1. The results are given in Table 8-1. For the NRC methodology, which applies a POD = 0.6, the projected leak rate is 0.220 gpm. The Monte Carlo analyses using the APC leak rate correlations yields 0.009 gpm. This difference (factor of about 25) is typical of the differences between the NRC method which ignores the leak rate dependence on voltage and methods applying the leak rate versus voltage correlation. Both methods utilize the same probability of leakage correlation. Without the adjustment for POD, the NRC method leak rate is 0.144 while the Monte Carlo is 0.003 gpm. The differences in the NRC results are approximately equal to the POD correction while the Monte Carlo methods show a larger reduction due to the strong dependence of leakage on voltage. If RPC NDD indications are excluded from the analyses to obtain the ≤ 1.0 volt distribution, the leak rates are further reduced by about a factor of 2. Following the 1992 outage at EOC-8, the projected SLB leak rate at EOC-9 was 0.003 gpm for all indications without a POD adjustment. This result is the same as found by the current analysis indicating negligible changes resulting from updates in the leakage correlations.

8.2 Comparison of Leak Rates for Projected and Actual EOC-9 Distributions

SLB leak rates were also calculated for the actual EOC-9 voltage distribution of Figure 3-3 which includes bobbin indications confirmed by RPC plus indications not RPC inspected. This distribution and leak rate represents the target that the projections are attempting to predict. The resulting leak rates are given in Table 8-1 for the Actual EOC-9 Dist. rows of the table. The leak rate for the NRC methodology is 0.107 gpm compared to 0.220 gpm for the projected methods with the POD adjustment. Without the POD adjustment, the projected leak rate is 0.144 gpm which is in good agreement (35% high) with the leak rate for the actual distribution. These results, like the voltage distribution comparisons of Section 7.2 indicate that the NRC application of a POD = 0.6 leads to excessive conservatism. The use of the voltage distribution of ≤ 1.0 volt indications leads to an underestimate of the leak rates.

8.3 Projected EOC-10 SLB Leak Rates

Leak rates at EOC-10 were calculated in the same manner as described above for EOC-9. As a sensitivity assessment, leak rates were calculated with and without the inclusion of UOAs in the voltage distribution. The results are given in Table 8-1 for the last two rows of the table. Per the Farley-2 SER, the reference SLB leak rate at EOC-10 using the draft NUREG-1477 methodology is 0.270 gpm. This result includes the POD adjustment and RPC NDD indications left in service including the UIA, UOA and INR classifications as well as the PI classification. This projected leak rate is well below the allowable leak rate limit of 22.8 gpm agreed upon by the NRC in the Farley-2 SER. The low leak rate, even for the NRC methodology, results from the relatively low voltages, modest number of indications and the low probability of leakage for 7/8 inch diameter tubing.

It is seen from Table 8-1 that the Monte Carlo results based on the leak rate versus bobbin voltage correlation consistently yields about a factor of 25 lower leak rates than the NRC methodology. Exclusion of the UOAs, which have a negligible likelihood of developing to a leaking indication in the next cycle, from the voltage distributions reduces the projected leak rates by about 25% to 50%. Without the POD adjustment, the leak rates are also reduced by about 25% to 50%.

Table 8-1. SUMMARY OF SLB LEAK RATES (GPM) FOR EOC-9 AND EOC-10

Method of Analysis	Bobbin Ind. RPC Confirmed + Not RPC Inspected	All Bobbin Ind. Left in Service Adj. by POD=0.6	All Bobbin Ind. Left in Service	Bobbin Ind. ≤ 1.0 Volt Left in Service
Actual EOC-9 Dist.				
• Draft NUREG-1477	0.107	-	-	-
• WCAP-12871	0.004*	-	-	-
Projected EOC-9 Dist.				
• Draft NUREG-1477	-	0.220	0.144	0.078
• WCAP-12871	-	0.009	0.003	0.001
Projected EOC-10 Dist. with UOAs				
• Draft NUREG-1477	-	0.270	0.158	0.136
• WCAP-12871	-	0.012	0.004	0.002
Projected EOC-10 Dist. without UOAs				
• Draft NUREG-1477	-	0.202	0.101	0.069
• WCAP-12871	-	0.008	0.002	0.001

Notes:
- Draft NUREG-1477 mthodology applies mean and upper bound (about 98%) uncertainty on average of all leak rate data independent of voltage.
- WCAP-12871 methodology applies cumulative probability of leakage at 90% probability from Monte Carlo analyses utilizing leak rate versus bobbin voltage correlation of EPRI Report NP-7480-L, Vol. 1, Rev. 1.

* Approximates Monte Carlo analyses by applying leak rate correlations at 90% prediction interval to the discrete EOC-9 distribution.

9.0 SLB Tube Burst Probability Analyses

9.1 Projected EOC-9 SLB Burst Probability

Monte Carlo methods are applied to calculate the probability of tube burst at EOC conditions using the methods described in WCAP-12871. Each EOC voltage sample is used to randomly sample the burst pressure versus voltage correlation. The distribution of material tensile properties at temperature is also sampled to obtain a flow stress used to adjust the burst pressure correlation (which is based on a flow stress of 75 ksi. The resulting burst pressure sample is weighted by the number of indications in the BOC voltage bin. The process is repeated to obtain 1,000,000 samples of each voltage bin covering the total voltage range. The resulting burst pressures are used to obtain the cumulative probability of burst pressures at the plant operating temperature. The cumulative probability of burst up to 2560 psid yields the probability of burst at SLB conditions. This method differs from WCAP-12871 only by the additional sampling of the material tensile properties rather than applying a constant factor reduction for LTL properties and temperature. The burst pressure correlations and material property distributions of EPRI Report NP-7480-L, Vol. 1, Rev. 1 are used in the analysis.

The results for SLB burst probabilities are given in Table 9-1. With the POD adjustment, the burst probability at EOC-9 is 4.6×10^{-5} while for all indications left in service, the probability is 2.1×10^{-5}. Thus the POD adjustment results in greater than a factor of two increase in the burst probability. The tube burst probability projected at the prior 1992 outage for EOC-9 and all indications left in service was 2×10^{-5} which is the same as the current result. While the EPRI report burst correlation yields slightly lower burst pressures at a given voltage than the WCAP-12871 correlation, this difference is offset in the burst analyses by including sampling of material properties in the current analysis.

9.2 Projected EOC-10 SLB Burst Probability

Table 9-1 also includes the Monte Carlo results for the EOC-10 tube burst probabilities including distributions with and without UOAs. Applying the NRC methodology with the POD adjustment yields an EOC-10 burst probability of 6.1×10^{-5}. This result is much lower than the WCAP-12871, Rev. 2 acceptance guideline of 2.5×10^{-2} which is based on the NUREG-0844 analyses. Thus the EOC-10 burst probability is acceptable with substantial margin.

The POD adjustment factor is seen from Table 9-1 to increase the burst probabilities by more than a factor of two. The inclusion of UOAs in the distribution, which are very unlikely to have degradation over the next cycle of concern for tube burst, increases the burst probability by 25% to 50%.

Table 9-1. SUMMARY OF SLB BURST PROBABILITIES FOR EOC-9 AND EOC-10

Method of Analysis	All Bobbin Ind. Left in Service Adj. by POD=0.6	All Bobbin Ind. Left in Service	Bobbin Ind. ≤ 1.0 Volt Left in Service
Projected EOC-9 Dist.	4.6×10^{-5}	2.1×10^{-5}	1.8×10^{-5}
Projected EOC-10 Dist. with UOAs	6.1×10^{-5}	2.4×10^{-5}	2.3×10^{-5}
Projected EOC-10 Dist. without UOAs	4.6×10^{-5}	1.6×10^{-5}	1.9×10^{-5}

Note: Burst probabilities are at EOC and based on Monte Carlo results for cumulative probability of burst at temperature evaluated at 2560 psid presssure differential and utilize burst pressure versus voltage correlation of EPRI Report NP-7480-L, Vol. 1, Rev. 1.

10.0 Alternate Method for Defining BOC Indications Left in Service

It is noted in Section 7.2 that the application of a POD = 0.6 to obtain BOC voltage distributions leads to excessive conservatism when EOC-9 projections are compared with actual inspection results for the distributions. The BOC distribution based on all bobbin indications left in service, including RPC NDD indications, yielded good agreement with the actual EOC distribution. However, this method compensates for ignoring new indications by the inclusion of all RPC NDD indications and equivalent compensation may not be likely in future outages. Thus it is desirable to develop an improved method for defining BOC distributions that accounts for potentially new indications without the extreme conservatism of the POD = 0.6 adjustment and that recognizes that some RPC NDD indications might develop to flaw indications over the next cycle. It is unlikely that new or RPC NDD indications at TSP intersections will develop to leakers over the next operating cycle such that inclusion of these indications at any magnitude in the BOC distribution is, by itself, conservative. New indications at a given outage or time includes indications missed at the prior inspection, indications grown from nondetectable to detectable levels and growth from no indication to a detectable indication. For IPC/APC applications, there is no need to distinguish these sources for new indications as the only consequence of importance to leakage or burst is that the new indication is sufficiently large to be detectable by both bobbin and RPC probes.

The objective for a desirable BOC distribution is that projections to EOC conditions yield good overall agreement with the larger voltage (greater than 1-2 volts) RPC confirmed indications which have finite probabilities of leakage or burst. Only RPC confirmed indications would have a significant probability of leakage over the prior cycle and are consistent with the leak rate and burst correlation database which is dominantly comprised of RPC confirmed indications. The methodology should recognize that new indication and POD considerations are highly plant specific due to varying degrees of the influence of residual signals on detectability of small indications, enhancements in eddy current analysis guidelines and corrosion controls implemented at a specific time. In addition, the methodology should recognize that historical data (although not quantified for this report) indicates that only a few RPC indications tend to develop to RPC confirmed indications over the subsequent operating cycle. The following sections define a BOC distribution methodology consistent with these objectives that is then applied to obtain EOC-9 projections for comparison with the actual distributions. This methodology is found to result in good agreement with the 1993 EOC-9 voltages and is proposed for further evaluation against other EOC voltage distributions following IPC or APC implementation.

10.1 Allowance for Undetected or New Indications

An undetected or new indication is defined as an indication found in the current outage inspection that was not identified at the prior inspection independent of the causative factor for the new indication. The method used to develop growth rates in this report is based upon reevaluating the prior outage eddy current data for all indications found in the current inspection. For most indications when given the somewhat larger flaw indication in the current inspection, reevaluation of the prior data permits identification of the smaller flaw and assignment of a voltage at the prior inspection even if the flaw was not reported at the prior inspection. This process permits assignment of voltages to indications which were not reported at the prior outage and leads to a distribution of prior cycle voltages for new indications which can be described/applied as a voltage distribution for undetected (NDD) indications as an alternative to applying more arbitrary POD adjustments to detected indications. This process can lead to a highly conservative distribution of new or undetected voltages when the current inspection involves an "inspection transient" resulting from implementation of significantly more conservative eddy current analysis guidelines than applied at the prior inspection. This implementation of more conservative guidelines might occur at first time implementation of an IPC which was in 1992 for Farley-2. Since the 1993 inspection is the second application of IPC guidelines, the currently developed distribution of voltages for new indications not detected at the prior outage provides a meaningful description of an undetected voltage distribution. By comparing the prior cycle voltage distribution for new indications found in 1993 (NDD in 1992) with the similarly developed voltage distribution for new indications found in the 1992 (NDD in 1990) inspection, a comparative assessment of the influence of IPC guidelines on flaw detectability can be obtained. This method for defining undetected indication voltage distributions has been presented to the NRC in WCAP-13692 (April, 1993) prepared in response to the NRC APC Task Team questions on analytical models for SLB leakage analyses.

As bobbin analysis guidelines are made increasingly more conservative, the potential for false bobbin calls increases. Current inspection practices and IPC implementations utilize RPC inspection to assess the significance of the bobbin call. If the bobbin indication is not detected by the RPC inspection, the bobbin call is either a false call or the indication is too small to be detected by the RPC probe. An indication not detected by RPC would not challenge tube integrity (burst or leakage) and need not be considered as a significant undetected indication at the prior outage. Thus the latest inspection results for indications confirmed by RPC inspection or not RPC inspected provide the population of tubes for which the prior cycle eddy current data is reviewed to develop the undetected or NDD voltage distribution. Applying the prior inspection undetected voltage distribution as the current inspection NDD indications for the next BOC distribution is conservative since the data analysis guidelines tend toward the same or more conservative guidelines in successive outages. The undetected voltage distribution is added to the detected distribution for indications left in service to obtain the net BOC voltage distribution adjusted for POD considerations on a plant specific and time dependent basis.

Based on the above, the following guidelines are used to estimate the voltage distribution of undetected or NDD indications:

- Population for Evaluation: Latest inspection indications confirmed by RPC or not RPC inspected that were not reported in the prior inspection (i.e., new indications). The only assumption for this population is that NDD indications have grown in one cycle to detectable indications to be of a concern for leakage considerations. Alternately, an indication not detected in two successive inspections can be assumed to result in negligible leakage over the next cycle.

- Process: For the above population, the prior cycle eddy current data is reevaluated by applying the latest analysis guidelines to assign a voltage to the indication at the prior cycle. This process is the same as that applied to develop voltage growth rates for Farley S/G indications.

- Undetected (NDD) or New Indication Voltage Distribution: The reevaluated voltages at the prior inspection in which the indication was not detected are used to define the new indication distribution for inclusion in the next BOC distribution.

Based on these guidelines, voltage distributions were developed for undetected indications to be included in the BOC-9 and BOC-10 distributions. These distributions were developed for all new indications summed over all three S/Gs. The distributions differ between S/Gs and only the most limiting S/G is used for EOC voltage projections. The differences between undetected indications between S/Gs could vary over successive cycles. For this reason, the S/G C undetected distribution was conservatively assumed to be 50% of the sum over all three S/Gs. The resulting undetected indication voltage distributions are given in Table 10-1 for BOC-9 and BOC-10. Note that the BOC-9 distribution represents the undetected indications at EOC-7 (prior to IPC implementation) and the BOC-10 distribution represents the undetected indications at EOC-8 (first IPC inspection). It is seen from Table 10-1 that the first implementation of IPC guidelines substantially reduced the number of undetected indications compared to the prior inspection from 126 to 27. The undetected maximum voltage is < 2 volts for both cycles.

10.2 Considerations for RPC NDD Indications

As previously discussed, only a few, if any, RPC NDD indications develop to RPC confirmed indications at subsequent inspections. In the current Farley-2 inspection, none of the prior inspection RPC NDD indications developed to RPC detectable indications. Although all RPC NDD indications less than the maximum voltage repair limit of 3.6 volts are left in service, it would be excessively conservative to include all of these indications in the BOC distribution as potential leakers at the end of the next operating cycle. Although a more systematic study of consecutive inspection results for RPC NDD indications could be performed, a conservative assumption that 50% of the RPC NDD indications left in service in S/G C will develop to RPC confirmed indications was applied to define the contribution of RPC NDD indications to the BOC distribution. This assumption provides adequate conservatism and avoids the excessively conservative assumption that all RPC NDD indications left in service will develop to confirmed indications and only a fraction of the RPC NDD indications should therefore be included in the BOC distribution. The resulting contributions to the BOC-9 and BOC-10 voltage distributions are included in Table 10-1 as the bobbin voltage indications above 1.0 volt. The indications in Table 10-1 below 1.0 volt are included in the BOC distributions as these indications have not been RPC inspected. The BOC-9 and BOC-10 voltage distributions resulting from applying the alternate methods described above are shown in Figure 10-1. Both cycles include bobbin voltages up to 2.7 volts left in service for RPC NDD indications.

10.3 Comparison of Projections Applying Alternate Method with Actual EOC-9 Distributions

Figure 10-2 compares the projected EOC-9 voltage distributions obtained with the above alternate method (proposed methodology for defining BOC distributions with the actual EOC-9 voltage distributions). The maximum projected EOC-9 voltage is 3.1 volts compared to the largest RPC confirmed indication that had a bobbin voltage of 2.81 volts. It is seen that the alternate method provides good agreement with the actual voltage distribution for the more limiting voltages above 1.7 volts and conservatively bounds the actual distribution below 1.7 volts. This agreement between projections and inspection results is comparable to that obtained in the middle figure of Figure 7-2 obtained by including all RPC NDD indications in the BOC distribution with no allowance for undetected indications. The alternate method achieves the good agreement with inspection results by applying a rational, plant specific basis for accounting for undetected indications and for including allowances for RPC NDD indications. This alternate method is proposed for further evaluation against inspection results and provides an improved methodology over the other methods for defining BOC distributions evaluated in this report.

10.4 Projected EOC-10 Voltage Distributions and SLB Leak Rates

Figure 10-3 shows the projected EOC-10 bobbin voltage distribution obtained by applying the alternate method for defining BOC distributions. The maximum projected EOC voltage is 3.1 volts which compares to the Figure 7-4 results of 3.3 volts maximum for all indications left in service and 4.5 volts maximum for the POD adjusted distributions.

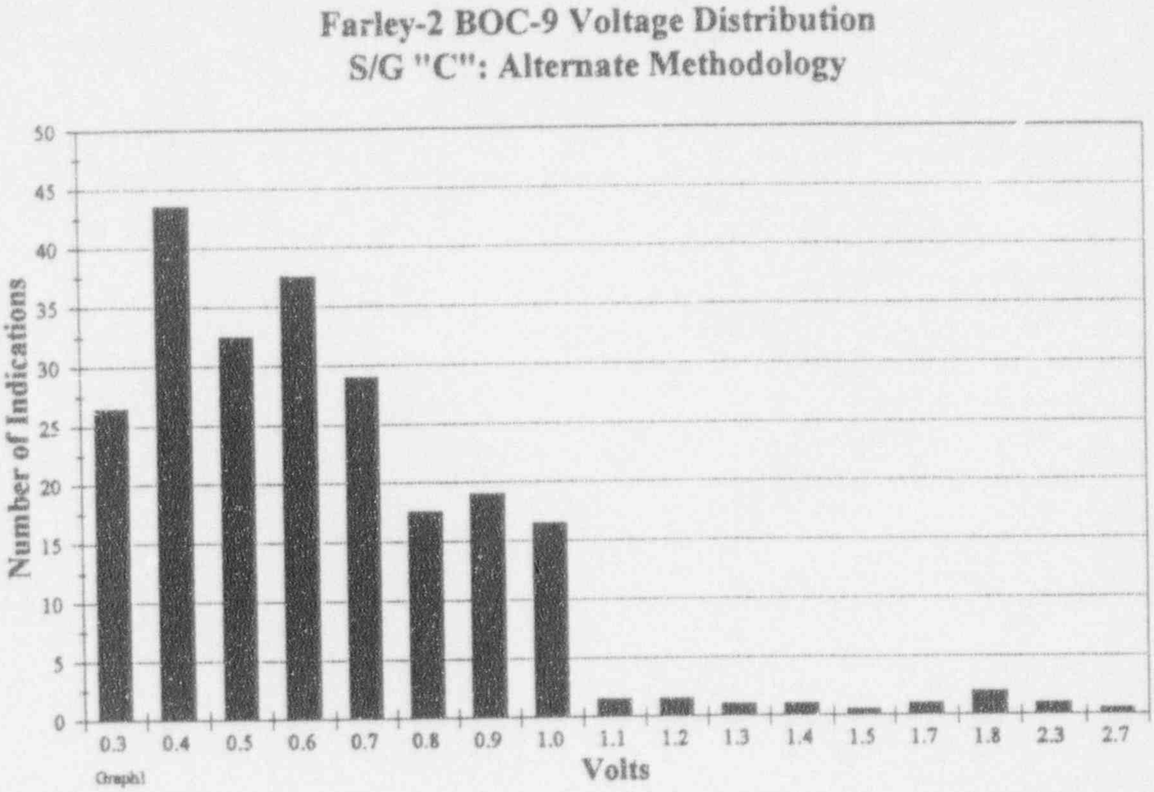
The EOC-10 distribution leads to a SLB leak rate of 0.140 gpm for the draft NUREG-1477 methodology excluding the POD factor and 0.004 gpm for the WCAP-12871 methodology. These results can be compared to the Table 8-1 results at EOC-10 of 0.270 gpm for the NRC methodology and 0.012 gpm for the WCAP methodology where both methods include the POD adjustment. Thus the more realistic treatment for undetected and RPC NDD indications leads to the order of a factor of two reduction in projected SLB leak rates.

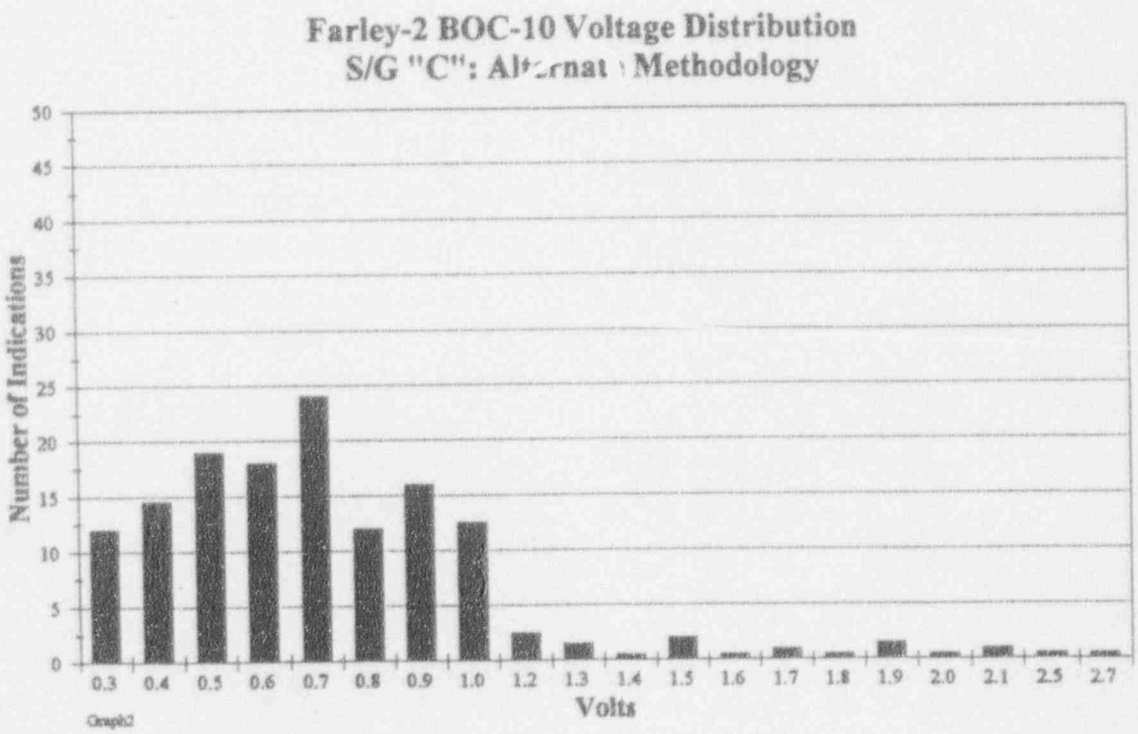
Table 10-1. BOC-9 AND BOC-10 S/G C BOBBIN VOLTAGE DISTRIBUTIONS FOR ALTERNATE METHODOLOGY						
Voltage Range	BOC-9 Ind. In Service			BOC-10 Ind. In Service		
	Detected Ind.[1]	New Ind.[2]	Total Ind.	Detected Ind.[1]	New Ind.[2]	Total Ind.
≤ 0.3	2.0	24.5	26.5	11.0	1.0	12.0
0.31-0.40	19.0	24.5	43.5	11.0	3.5	14.5
0.41-0.50	13.0	19.5	32.5	15.0	4.0	19.0
0.51-0.60	19.0	18.5	37.5	15.0	3.0	18.0
0.61-0.70	17.0	12.0	29.0	18.0	6.0	24.0
0.71-0.80	10.0	7.5	17.5	10.0	2.0	12.0
0.81-0.90	10.0	9.0	19.0	14.0	2.0	16.0
0.91-1.00	11.0	5.5	16.5	10.0	2.5	12.5
1.01-1.10	0.5	1.0	1.5			
1.11-1.20	0.5	1.0	1.5	2.0	0.5	2.5
1.21-1.30	0.5	0.5	1.0	1.0	0.5	1.5
1.31-1.40	0.5	0.5	1.0	0.5		0.5
1.41-1.50		0.5	0.5	1.5	0.5	2.0
1.51-1.60					0.5	0.5
1.61-1.70	0.5	0.5	1.0	1.0		1.0
1.71-1.80	1.0	1.0	2.0	0.5		0.5
1.81-1.90				1.0	0.5	1.5
1.91-2.00					0.5	0.5
2.01-2.10				1.0		1.0
2.11-2.20						
2.21-2.30	1.0		1.0			
2.31-2.40						
2.41-2.50				0.5		0.5
2.51-2.60						
2.61-2.70	0.5		0.5	0.5		0.5
TOTALS	106.0	126.0	232.0	113.5	27.0	140.5

Note: 1. Includes 50% of S/G C RPC NDD and UOA (BOC-10) indications above 1.0 volt

2. Includes 50% of all 3 S/G new indications found at EOC inspection and confirmed by RPC or not RPC inspected

Figure 10-1





c:\qpw\TP004sld.wb1:12/10/93

Figure 10-2

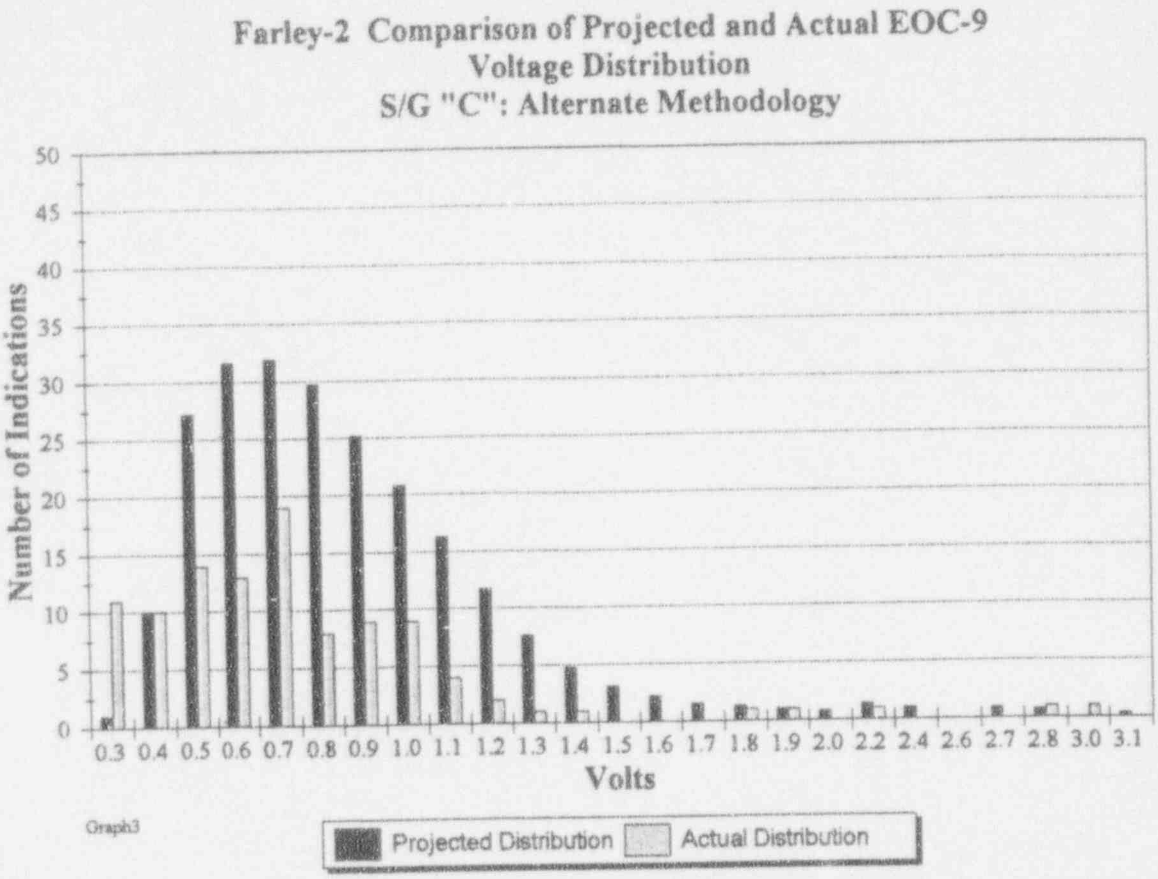
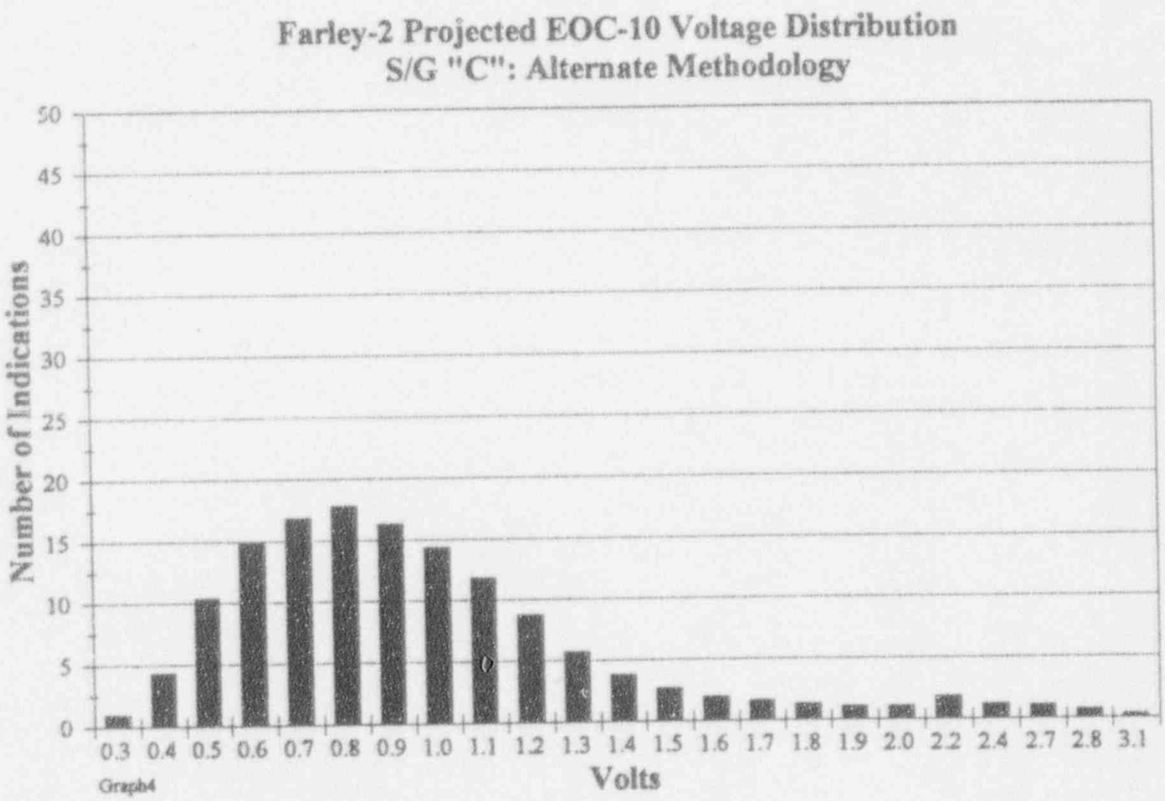


Figure 10-3



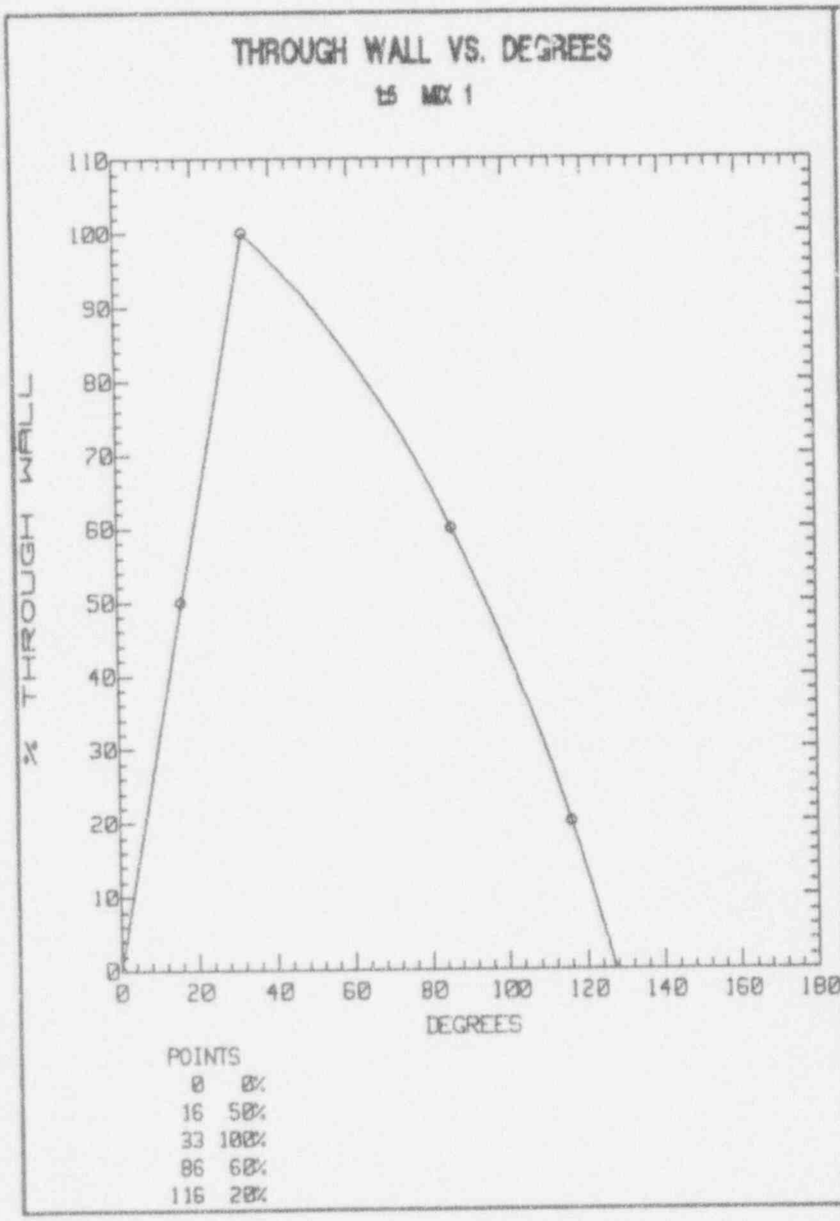
c:\qpw\TP004sld.wb1:12/10/93

11.0 Future Considerations for Unusual Phase Angle Signals

As noted in Section 3, signals with unusual ID phase angles (UIAs) were confirmed as flaws in the RPC sampling plan while unusual OD phase angle (UODs) signals were not confirmed by RPC in the present or prior outages. Based on this inspection result, the WCAP-12871, Appendix A eddy current guidelines will be modified to require that, at future Farley Units 1 and 2 inspections, UIA signals are to be classified as PIs and subject to RPC inspection for indications above the threshold for RPC inspection (i.e., 1.0 volt for a 1.0 volt IPC). Phase angles in the 400/100 kHz mix between 10° and approximately 125° (corresponding to 0% depth) will be classified as PIs. Figure 11-1 presents a typical phase angle versus depth calibration curve for the bobbin probe 400/100 kHz mix channel responses. It is seen that the extrapolated curve intercept at 0% depth corresponds to a phase angle reading of approximately 125°. Signals with a UOA response (phase angles greater than about 125° in the mix) will be identified as UOA indications. While UOAs and INRs do not require mandatory RPC inspection for indications above the RPC inspection threshold, UOAs and INRs are to be incorporated in the RPC sampling plan with emphasis on inspecting indications above the IPC repair limit.

Indications with ID phase angles have been included in the APC burst pressure versus voltage correlation. Although no Farley pulled tubes have had unusual ID or OD phase angles, pulled tube intersections from Plant L had 7 ID phase angles by field analysis although only 1 of these indications had an ID phase angle by an independent laboratory evaluation of the data. Two of the Plant L pulled tubes had unusual OD phase angles and both of these indications had average depths < 40%. Therefore, the APC database adequately includes unusual phase angle indications and additional tube pulls specifically for unusual phase angle signals are not necessary.

Figure 11-1. TYPICAL PHASE ANGLE VERSUS DEPTH CALIBRATION CURVE



DEG	%	DEG	%	DEG	%	DEG	%
0	0	45	93	90	56	135	0
1	3	46	93	91	54	136	0
2	6	47	92	92	53	137	0
3	9	48	92	93	52	138	0
4	12	49	91	94	51	139	0
5	15	50	90	95	50	140	0
6	18	51	90	96	48	141	0
7	21	52	89	97	47	142	0
8	24	53	88	98	46	143	0
9	27	54	88	99	45	144	0
10	30	55	87	100	43	145	0
11	33	56	86	101	42	146	0
12	36	57	86	102	41	147	0
13	39	58	85	103	39	148	0
14	42	59	84	104	38	149	0
15	45	60	83	105	37	150	0
16	48	61	83	106	35	151	0
17	52	62	82	107	34	152	0
18	55	63	81	108	32	153	0
19	58	64	80	109	31	154	0
20	61	65	79	110	29	155	0
21	64	66	79	111	28	156	0
22	67	67	78	112	26	157	0
23	70	68	77	113	25	158	0
24	73	69	76	114	23	159	0
25	76	70	75	115	22	160	0
26	79	71	74	116	20	161	0
27	82	72	74	117	18	162	0
28	85	73	73	118	17	163	0
29	88	74	72	119	15	164	0
30	91	75	71	120	13	165	0
31	94	76	70	121	12	166	0
32	97	77	69	122	10	167	0
33	100	78	68	123	8	168	0
34	99	79	67	124	6	169	0
35	99	80	66	125	4	170	0
36	98	81	65	126	2	171	0
37	98	82	64	127	1	172	0
38	97	83	63	128	0	173	0
39	97	84	62	129	0	174	0
40	96	85	61	130	0	175	0
41	96	86	60	131	0	176	0
42	95	87	59	132	0	177	0
43	95	88	58	133	0	178	0
44	94	89	57	134	0	179	0

12.0 Assessments of NDE Uncertainty for Analyst Variability in EOC-8 and EOC-9 Inspections

As noted in Section 3 and Table 3-2, the reevaluation of the 1992 voltages performed as part of the growth study in 1993 identified a number of voltages which had been undercalled (low voltages) in the field analyses at EOC-8. Of 11 indications (including PIs, UOAs and INRs) for which the 1992 evaluation was 0.5 volts or more lower than the 1993 reassessment, only 2 indications were confirmed by RPC inspection. The 2 RPC confirmed indications differed by < 0.7 volts between the two analyses. There are two potential contributing factors to the differences between the 1992 and 1993 analyses. One is a clear voltage undercall in the 1992 analyses. The other factor is signal distortion and, in some cases, the 1993 data tend to have larger eddy current responses which help to guide placement of the peak voltage call on the 1992 data. Distorted signals are typical of responses that are not confirmed as flaws by the RPC inspection. The 2 indications that were confirmed by RPC had the voltages underestimated in 1992 in that peak to peak voltages were not obtained. Since the 1993 EOC-9 growth study was performed in the laboratory, differences between field and laboratory voltage calls for both the 1992 and 1993 inspections can be evaluated to assess eddy current analyst variability for comparison with the value of 10% standard deviation used for NDE uncertainty. This assessment is given below.

Figure 12-1 shows the 1992, EOC-8 analyst variability distribution defined as the difference between the field and laboratory voltage analyses. The large negative tail of the distribution represents the field voltage undercalls as described above. The figure shows the voltage differences for all indications (upper figure) and for indications above 0.5 volts (lower figure). There is little significant difference between the two figures as most of the undercalls were more than 0.5 volts by the laboratory analysis. Table 12-1 gives the mean and standard deviation for the 1992 inspection. The analyst variability for this inspection is seen to have a standard deviation of about 30%. This inspection was the first implementing WCAP-12871 eddy current analysis guidelines and it should be expected that some difficulties in voltage calls would result.

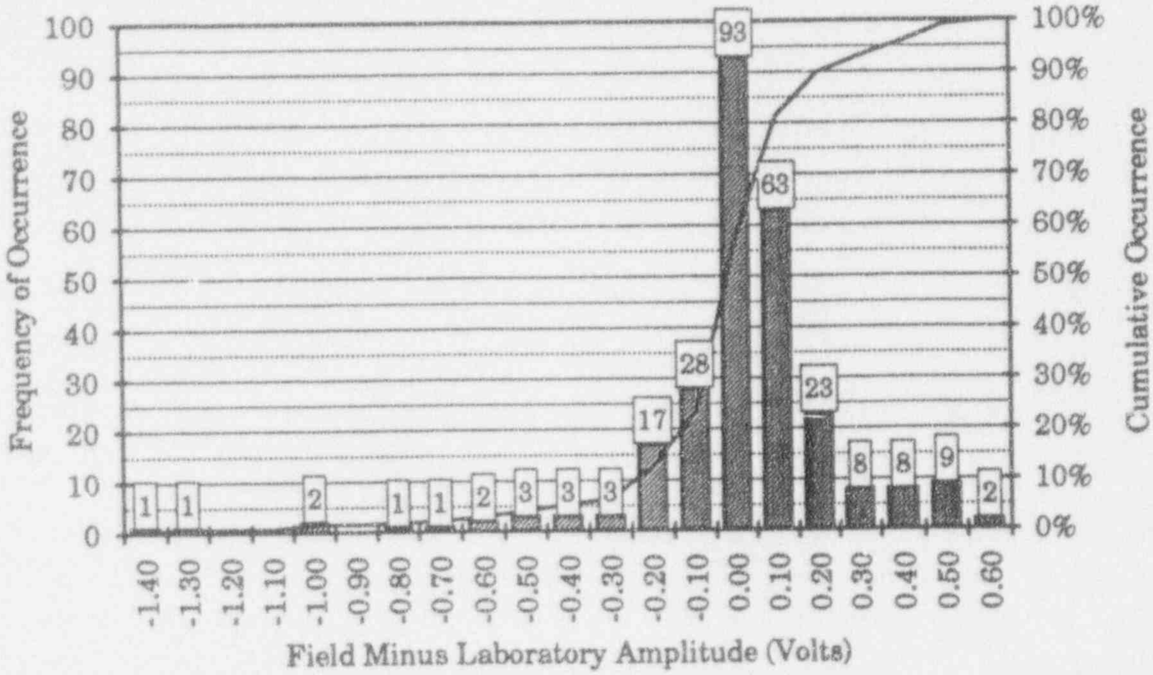
The 1993, EOC-9 analyst variability distribution was developed to compare experience at this second IPC application with the first implementation of the analyst guidelines. Figure 12-2 shows the difference between field and laboratory evaluations for this inspection. The differences are much smaller than found for the first IPC inspection in 1992 with the largest field undercall being only 0.4 volts. This occurred on a 2.8 volt indication such that the difference between analysts was < 15%. Figure 12-3 shows a plot of the field versus laboratory bobbin voltage calls. It is seen that the agreement is quite good. The standard deviation between field and laboratory analyses, as shown in Table 12-1, for the EOC-9 inspection is only about 7.5%. This compares to the 10% standard deviation included in the NDE uncertainty (Section 6) for the analyst variability in IPC applications. Thus the current field experience is consistent with the uncertainties included in the IPC/APC database. The differences between the EOC-9 and EOC-8 analyst variability implies that repeated eddy current analyst experience with the voltage sizing guidelines has resulted in improved sizing of the indications. However, it must be noted that a reevaluation of the 1993 data following the next inspection, scheduled for 1995, will likely result in some changes to the 1993 voltages and a larger variability between the current and future calls than found for the independent evaluations of the 1993 data. For the small (< 1.5 to 2.0 volts) indications currently found, voltages sized by comparison with larger 1995 values will, in some cases, differ significantly from the current calls. This effect can be expected to continue until the indications tracked are sufficiently large such that the flaw dominates the voltage response which would be expected for indications above about 2 volts. This effect of resizing the small indications after larger indications have been found at the same location is a contributor to the larger analyst variability described above for EOC-8 which compares the 1993 reanalysis to the 1992 analysis.

Based on the above assessment, it is concluded that the NDE uncertainty of 10% standard deviation applied in IPC/APC applications for analyst variability is adequate to reflect current field experience. However, the data suggests that while the analyst guidelines produce reasonable consistency between analysts, the indications from current IPC applications are small and subject to judgement in calling peak to peak voltages as seen by the reanalysis results following one additional cycle of growth. Thus, until larger indications such as those associated with a full APC implementation are left in service, it is necessary to reevaluate prior cycle voltages to obtain adequate accuracy in voltage growth for projections to the next operating cycle.

Table 12-1. Summary of Analyst Variability at EOC-8 and EOC-9 Inspections						
Voltage Range	Number of Ind.	Average Volts		Mean Volt Difference	Standard Deviation	
		Field	Laboratory		Volts	Percent
1992 EOC-8 Inspection						
All Ind.	268	0.66	0.69	-0.03	0.25	36%
Lab. > 0.5v	163	0.79	0.90	-0.11	0.26	29%
1993 EOC-9 Inspection						
All Ind.	138	0.94	0.94	0.01	0.07	7.4%
Lab. >0.5v	111	1.07	1.06	0.01	0.08	7.5%

Figure 12-1

J. M. Farley Unit #2, EOC 8, Analyst Variability Study
Field Minus Laboratory Bobbin Amplitudes (V>0)



J. M. Farley Unit #2, EOC 8, Analyst Variability Study
Field Minus Laboratory Bobbin Amplitudes (V>0.5)

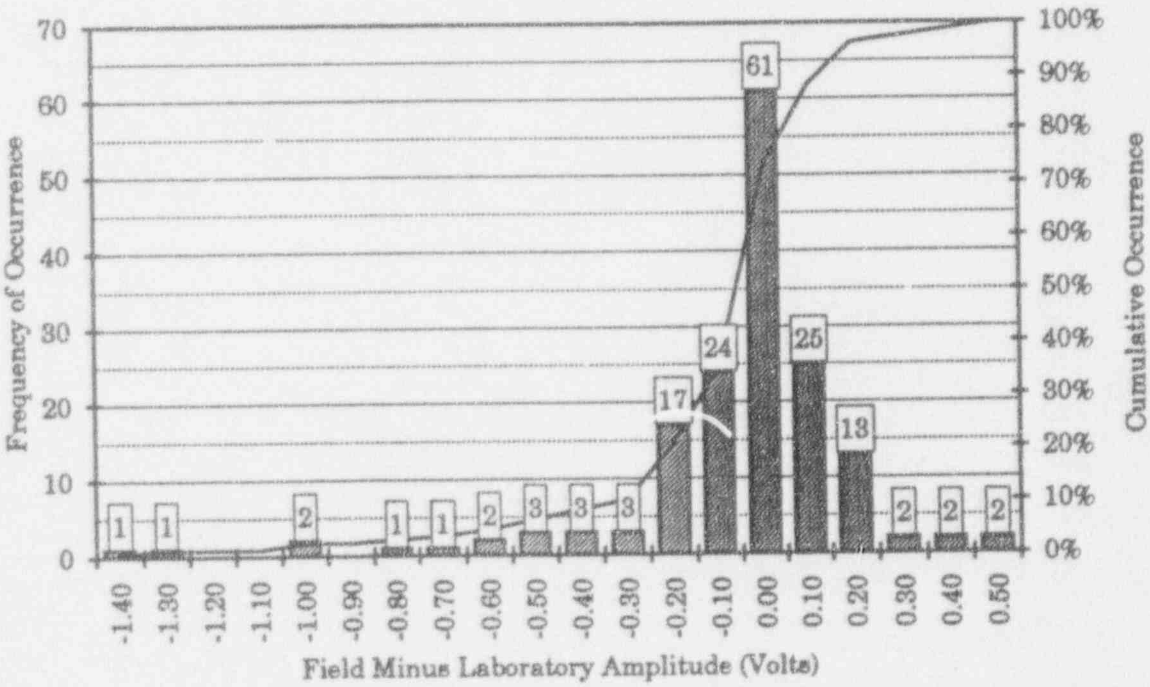
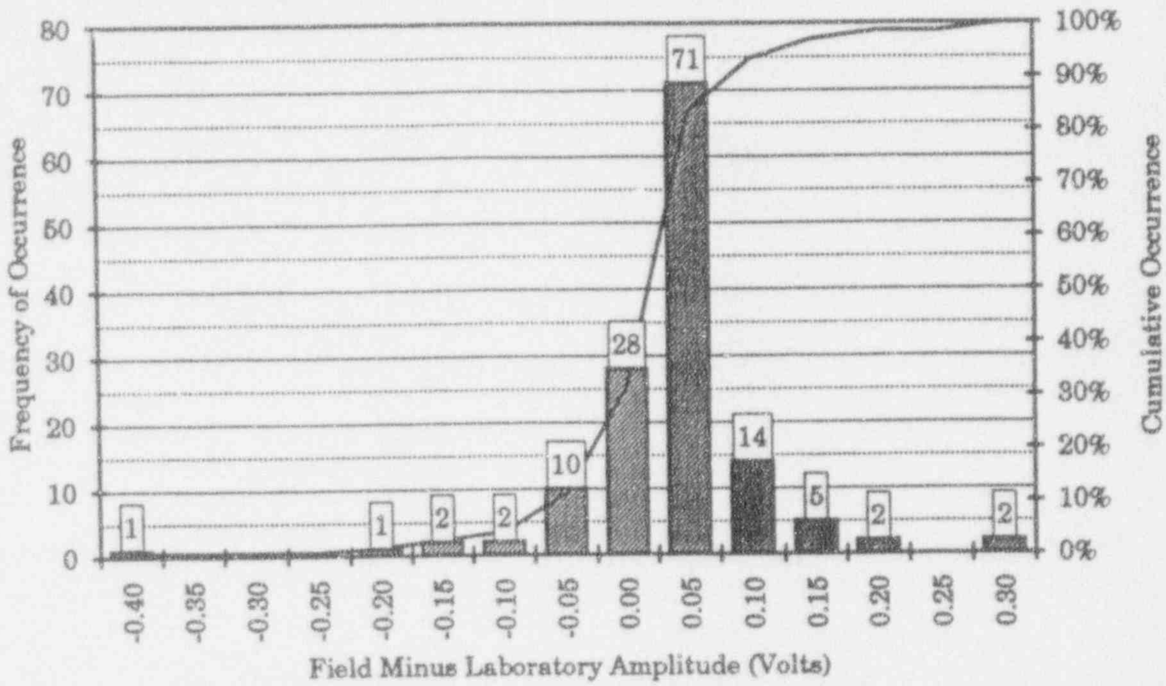


Figure 12-2

J. M. Farley Unit #2, EOC 9, Analyst Variability Study
Field Minus Laboratory Bobbin Amplitudes (V>0)



J. M. Farley Unit #2, EOC 9, Analyst Variability Study
Field Minus Laboratory Bobbin Amplitudes (V>0.5)

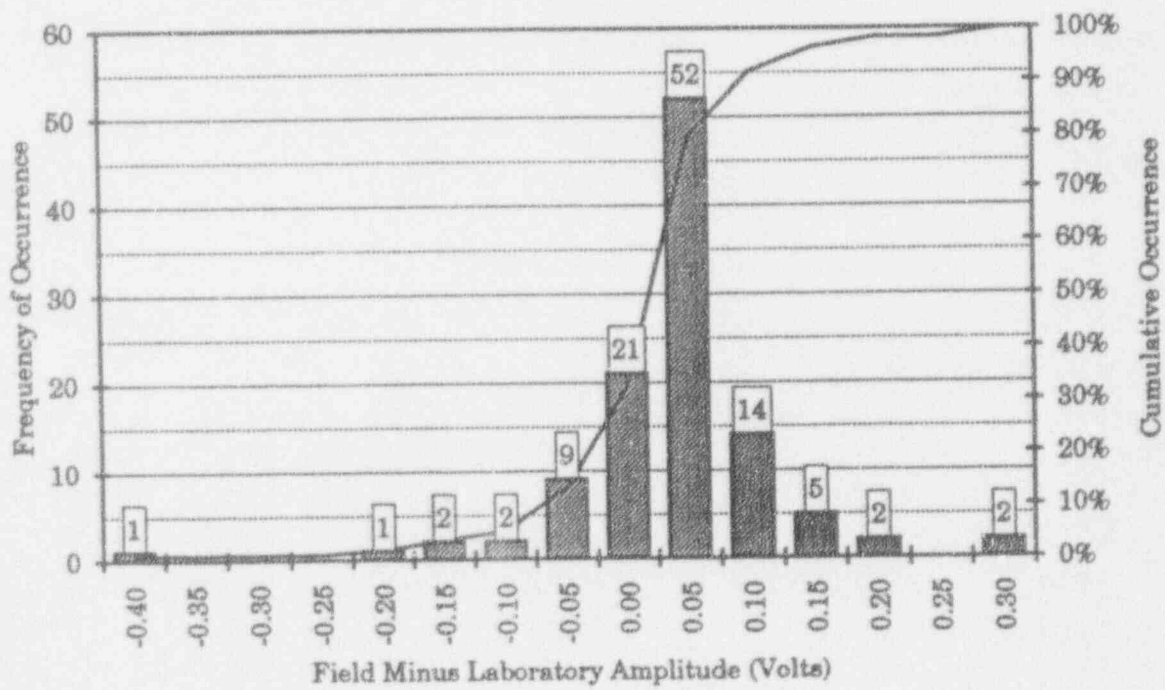
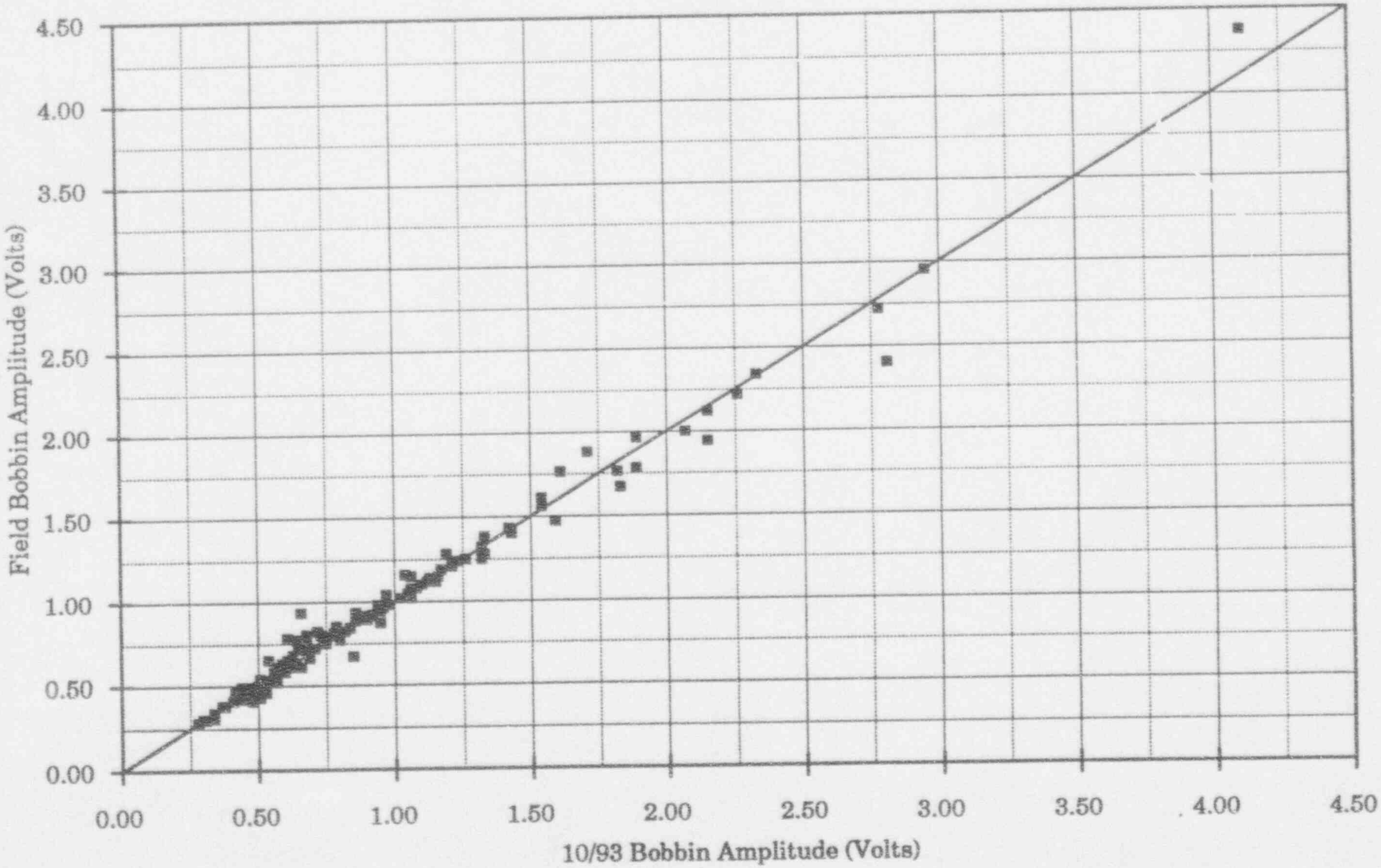


Figure 12-3: 1993 Analyst Variability



[ANAL_VAR.XLW]1993 Error % vs Lab

RFK: 11/23/93,5:06 PM

APPENDIX A
TABULATION OF S/G C BOBBIN VOLTAGE DISTRIBUTIONS AND GROWTH RATES

Table A-1. ACTUAL S/G C BOBBIN VOLTAGE DISTRIBUTIONS AT EOC-8 AND BOC-9				
Volts	EOC-8		BOC-9	
	All Ind.	Ind. Repaired	Ind. Left In Service	Ind. RPC Conf/N.I.[1]
0.00-0.3	2		2	2
0.31-0.4	19		19	19
0.41-0.5	13		13	13
0.51-0.6	19		19	19
0.61-0.7	17		17	17
0.71-0.8	10		10	10
0.81-0.9	10		10	10
0.91-1.0	11		11	11
1.01-1.1	2	1	1	
1.11-1.2	3	2	1	
1.21-1.3	2	1	1	
1.31-1.4	1	0	1	
1.41-1.5	2	2	0	
1.51-1.6	0	0	0	
1.61-1.7	1	0	1	
1.71-1.8	2	0	2	
1.81-1.9	1	1	0	
1.91-2.0	1	1	0	
2.01-2.2	0	0	0	
2.21-2.4	3	1	2	
2.41-2.6	0	0	0	
2.61-2.8	1	0	1	
2.81-3.0	0	0	0	
3.84	1	1	0	
TOTALS	121	10	111	101

Note 1. Bobbin indications confirmed by RPC or not RPC inspected and left in service

Table A-2. BOBBIN VOLTAGE GROWTH DISTRIBUTIONS FROM CYCLE 8 AND 9				
	Cycle 8		Cycle 9	
ΔV-Volts	No. Ind.	Cum. Prob.	No. Ind.	Cum. Prob.
≤0	44.00	22.0%	59.00	34.9%
0.10	47.00	45.5%	39.00	58.0%
0.20	51.00	71.0%	33.00	77.5%
0.30	22.00	82.0%	15.00	86.4%
0.40	18.00	91.0%	11.00	92.9%
0.50	6.00	94.0%	3.00	
0.60	3.00		5.00	97.6%
0.70	4.00	97.5%	1.00	98.2%
0.80	2.00	98.5%	0.00	
0.90	0.00		0.00	
1.00	1.00	99.0%	0.00	
1.10	0.00		0.00	
1.20	0.00		0.00	
1.30	0.00		1.00	98.8%
1.40	0.00		0.00	
1.50	1.00	99.5%	1.00	99.4%
1.60	0.00		0.00	
1.70	0.00		0.00	
1.80	0.00		0.00	
1.90	0.00		1.00	100.0%
2.00	0.00			
2.10	1.00	100.0%		
Total	200.00		169.00	

Table A-3. PROJECTED S/G C BOBBIN VOLTAGE DISTRIBUTIONS AT EOC-9			
Voltage Range	All Ind. POD=0.6	All Ind.	Ind. ≤1.0V
≤0.3	1.5	0.9	0.9
0.31-0.40	11.3	6.7	6.7
0.41-0.50	17.1	10.2	10.2
0.51-0.60	22.0	13.2	13.2
0.61-0.70	24.0	14.4	14.4
0.71-0.80	22.8	13.7	13.7
0.81-0.90	20.0	12.0	11.9
0.91-1.00	17.0	10.1	10.0
1.01-1.10	13.4	7.9	7.5
1.11-1.20	9.6	5.5	4.9
1.21-1.30	6.6	3.6	3.0
1.31-1.40	4.6	2.4	1.7
1.41-1.50	3.3	1.6	1.0
1.51-1.60	2.4	1.2	0.6
1.61-1.70	2.0	0.9	0.3
1.71-1.80	1.7	0.8	0.1
1.81-1.90	1.6	0.7	
1.91-2.00	1.4	0.6	
2.1			0.7
2.01-2.20	2.4	1.1	
2.21-2.40	2.0	0.9	
2.5			0.3
2.41-2.60	1.7	0.8	
2.61-2.80	1.3	0.7	
2.81-3.00	0.9	0.5	
3.10		0.7	
3.20	0.5		
3.30		0.3	
3.40	0.1		
3.70	0.7		
4.20	0.3		
Total	192.0	111.0	101.0

Table A-4. ACTUAL S/G C BOBBIN VOLTAGE DISTRIBUTIONS AT EOC-9 AND BOC-10								
Volts	EOC-9 with UOAs		BOC-10 with UOAs		EOC-9 without UOAs		BOC-10 without UOAs	
	All Ind.	Ind. Repaired	Ind. Left In Service	Ind. RPC Conf/N.I.[1]	All Ind.	Ind. Repaired	Ind. Left In Service	Ind. RPC Conf/N.I.[1]
0.00-0.3	11		11	11	11		11	11
0.31-0.4	11		11	11	10		10	10
0.41-0.5	15		15	15	14		14	14
0.51-0.6	15		15	15	13		13	13
0.61-0.7	19	1	18	18	19	1	18	18
0.71-0.8	10		10	10	8		8	8
0.81-0.9	15	1	14	14	9	1	8	8
0.91-1.0	10		10	10	9		9	9
1.01-1.1	4	4	0	0	4	4	0	
1.11-1.2	6	2	4	2	4	2	2	
1.21-1.3	3	1	2	1	2	1	1	
1.31-1.4	3	2	1	0	2	1	1	
1.41-1.5	3	0	3	1	2	0	2	
1.51-1.6	0	0	0		0	0	0	
1.61-1.7	2	0	2	1	1	0	1	
1.71-1.8	2	1	1	1	1	1	0	
1.81-1.9	3	1	2	1	2	1	1	
1.91-2.0	0	0	0		0	0	0	
2.01-2.2	3	1	2	1	2	1	1	
2.21-2.4	0	0	0		0	0	0	
2.41-2.6	1	0	1	1	0	0	0	
2.61-2.8	2	1	1	1	1	1	0	
2.81-3.0	2	2	0		2	2	0	
4.11	1	1			1	1		
TOTALS	141	18	123	114	117	17	100	91
Note 1. Bobbin indications confirmed by RPC or not RPC inspected and left in service								

Table A-5. Projected S/G C Bobbin Voltage Distributions at EOC-10						
	EOC-10 with UOAs			EOC-10 without UOAs		
Voltage Range	All Ind. POD=0.6	All Ind.	Ind. RPC Conf. + N.I.	All Ind. PoD=0.6	All Ind.	Ind. RPC Conf. + N.I.
0.31-0.40	15.56	9.35	9.35	14.82	8.90	8.90
0.41-0.50	19.09	11.46	11.46	17.80	10.68	10.68
0.51-0.60	22.12	13.23	13.23	20.39	12.19	12.19
0.61-0.70	23.95	14.24	14.24	22.01	13.08	13.08
0.71-0.80	22.76	13.48	13.48	19.90	11.77	11.77
0.81-0.90	20.86	12.27	12.24	16.99	9.95	9.93
0.91-1.00	17.67	10.21	10.08	13.95	7.99	7.86
1.01-1.10	13.67	7.62	7.26	10.69	5.86	5.50
1.11-1.20	10.07	5.38	4.73	7.71	3.99	3.35
1.21-1.30	7.45	3.84	2.96	5.44	2.69	1.81
1.31-1.40	5.79	2.93	1.95	4.05	1.97	0.98
1.41-1.50	4.55	2.31	1.33	3.07	1.50	0.52
1.51-1.60	3.70	1.91	1.00	2.40	1.19	0.28
1.61-1.70	3.16	1.65	0.86	1.97	0.98	0.19
1.71-1.80	2.81	1.48	0.82	1.68	0.82	0.16
1.81-1.90	2.58	1.36	0.80	1.50	0.72	0.16
1.91-2.00	2.31	1.21	0.75	1.33	0.63	0.02
2.01-2.20	3.92	2.03	1.33	2.24	1.03	0.67
2.21-2.40	2.88	1.47	1.03	1.57	0.33	0.33
2.50					0.67	
2.41-2.60	2.08	1.01	0.78	1.00		
2.70					0.33	
2.61-2.80	1.64	0.72	0.55	0.71		
2.81-3.00	1.23	0.07		0.55		
3.1		0.67	0.7			
3.2	0.87			0.43		
3.3		0.33	0.3			
3.4	0.53			0.07		
3.6	0.11					
3.9	0.67			0.67		
4.4				0.33		
4.5	0.33					
Total	217.00	123.02	114.00	177.84	100.00	91.09

Table A-6. Projected EOC-9 and EOC-10 S/G C Bobbin Voltage Distributions for Alternate Methodology		
Voltage Range	EOC-9	EOC-10
≤0.3	1.0	1.0
0.31-0.40	10.0	4.3
0.41-0.50	27.2	10.4
0.51-0.60	31.6	14.8
0.61-0.70	31.9	16.8
0.71-0.80	29.7	17.8
0.81-0.90	25.2	16.3
0.91-1.00	20.8	14.3
1.01-1.10	16.3	11.8
1.11-1.20	11.7	8.7
1.21-1.30	7.6	5.7
1.31-1.40	4.8	3.8
1.41-1.50	3.1	2.7
1.51-1.60	2.2	1.9
1.61-1.70	1.5	1.6
1.71-1.80	1.3	1.3
1.81-1.90	1.0	1.1
1.91-2.00	0.8	1.1
2.01-2.20	1.4	1.8
2.21-2.40	1.0	1.2
2.7	0.9	1.1
2.8	0.7	0.7
3.1	0.3	0.3
Total	232.0	140.5