SG-96-01-003

FARLEY UNIT 1

1995 INTERIM PLUGGING CRITERIA 90 DAY REPORT

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WESTINGHOUSE ELECTRIC CORPORATION
ENERGY SYSTEMS BUSINESS UNIT
NUCLEAR SERVICES DIVISION
P.O. BOX 355
PITTSBURGH, PENNSYLVANIA 15230

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GLOSSARY

APC	Alternate Plugging Criteria
BOC	Beginning of Cycle
CPDF	Cumulative Probability Distribution Function
DI	Distorted Indication
EFPD	Effective Full Power Day
EFPY	Effective Full Power Year
ECT	Eddy Current Test
EOC	End of Cycle
FF	Fracture Face
FS	Free Span
GPM	Gallons per Minute
ICC	Intergranular Cellular Corrosion
IGSCC	Intergranular Stress Corrosion Cracking
INR	Indication Not Reportable
IPC	Interim Plugging Criteria
MAI	Multiple Axial Indication
NDD	No Detectable Defect
NDE	Non Destructive Examination
NRC	Nuclear Regulatory Commision
ODSCC	Outside Diameter Stress Corrosion Cracking
PI	Potential Indication
POD	Probability of Detection
POPCD	Probability of Prior Cycle Detection
PWSCC	Primary Water Stress Corrosion Cracking
R_C_	Tube Location by Row, Column
RTS	Return to Service
SG	Steam Generator
SER	Safety Evaluation Report
RPC	Rotating Pancake Coil
SLB	Steam Line Break
TSP	Tube Support Plate
TTS	Top of Tube Sheet

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1.0 INTRODUCTION

This report provides the Farley Unit 1 steam generator tube support plate (TSP) eddy current inspection summary, together with postulated Steam Line Break (SLB) leak rate and tube burst probability analysis results, in support of the implementation of a 2.0 volt Interim Plugging Criteria (IPC) at End Of Cycle 13 (EOC-13) as outlined in the NRC Draft Generic Letter, Reference 10.1. Calculations of leak rates and probability of tube burst (PoB) are reported, based on actual EOC-13 bobbin voltage distributions. Also provided are projections of bobbin voltage distributions, leak rates and burst probabilities for Cycle 14 operation. The methodology used in these evaluations is in accordance with the Westinghouse technical report of Reference 10.2.

The application of the TSP Interim Plugging Criteria (IPC) at Farley-1 involves bobbin coil inspection of the tube bundle and plugging of > 2.0 volt TSP indications which are confirmed by Rotating Pancake Coil (RPC). Plugging of > 5.6 volt TSP bobbin indications is required regardless of RPC inspection results. Results of calculations to predict SG tube leak rate and probability of burst during a postulated SLB are within regulatory requirements as outlined in the NRC SER, Reference 10.3.

2.0 SUMMARY AND CONCLUSIONS

SLB leak rate and tube burst probability analyses were performed for the actual EOC-13 bobbin voltage distributions and are projected for EOC-14 at Farley-1. SG C was found to be the limiting SG at EOC-13 and is projected to be the limiting SG for Cycle 14. The calculations demonstrate that IPC application at EOC-13 (actual distribution) and EOC-14 (predicted distribution) will satisfy NRC criteria for allowable leakage and burst probability.

A total of 2571 indications were reported during the EOC-13 inspection. Of these 2571, 167 were RPC inspected, in accordance with the IPC criteria, of which 104 were confirmed. The RPC confirmed indications included 97 above 1.0 volt, of which 34 were above the 2.0 volt IPC repair limit. A total of 155 indications were removed from service, including 35 which exceeded the 2.0 volts repair limit and the remainder in tubes plugged for indications at other SG locations. Accordingly, 2416 of the 2571 indications were returned to service for Cycle 14. SG C had 973 indications reported at EOC-13, of which 132 were RPC inspected with 76 confirmations. Four hundred ninety two indications were reported as greater than 1.0 volt, with 21 indications exceeding the 2.0 volt IPC repair limit. Of the 21 >1.0 volt indications, 17 were RPC confirmed and were removed from service.

For the actual EOC-13 bobbin voltage distribution, the postulated SLB tube leak rate is calculated to be 5.3 gpm and the corresponding tube burst probability is 8.1 E-04 for SG C. These results are below the Farley-1 Cycle 13 allowable SLB leakage limit of 22.6 gpm and the NRC reporting guideline of 1.0 E-02 for the burst probability. The predicted SLB tube burst probability of 4.3 E-04 is slightly below that based on the actual EOC-13 voltage distribution. The actual EOC indications for SG C have three indications at higher voltages (3.6, 5.6 and 7.1 volts) than the projected EOC maximum voltage of 3.3 volts. These differences in maximum EOC-13 voltages are the primary contributor to the slightly higher burst probability for the actual distribution. The predicted EOC-13 SLB leakrate using updated GL-95-05 analysis methods would be 5.72 gpm which compares to 5.3 gpm calculated from the actual distribution. In this case, the larger number of indications (1153 vs actual 973) for POD = 0.6 in the projected distribution causes the projected leak rate to be higher than obtained for the actual distribution. Both analyses are based on leak rates independent of voltage. When the projections used draft NUREG-1477 methodology, as required in 1994, rather than GL-95-05 methods, the projected leak rate was 0.61 gpm. These results indicate that the NRC GL-95-05 methods are considerably more conservative for Farley-1 than the draft NUREG-1477 methods.

Using the NRC requirement for POD = 0.6 to calculate the performance of the limiting SG C during the next Farley-1 operating cycle, the SLB tube leak rate is projected to be 10.2 gpm and the burst probability is projected to be 1.4 E-03 at EOC-14. These results are within the Farley-1 Cycle 14 IPC allowable leakage (11.4 gpm) and the NRC guideline of 1.0 E-02 for the burst probability; accordingly, NRC requirements are satisfied.

One tube was pulled during the EOC-13 outage and two TSP intersections were destructively examined to obtain data to support the EPRI ARC database. The dominant OD origin corrosion morphology, axial IGSCC, was observed at both intersections. At TSP1, the tube had a field bobbin indication of 4.03 volts, which increased to 12.2 V upon reevaluation in the lab. This intersection contained multiple axial indications, with a maximum depth of 96% throughwall and length of 0.696 inch. The tube pull aggravated the conditions at this intersection. At TSP3, the indication was called a bobbin NDD, both in the field and in the lab, although some short, shallow indications were indicated in the UT test. This indication had a maximum corrosion depth of 45%. Crack morphology and corrosion of the pulled tube indications were consistent with the EPRI ARC database. The TSP 1 indication was leak-tested and 2.19 l/hr leakage occurred at 2560 psid, reference SLB conditions. The burst pressure for the TSP 1 indication was 5361 psi, below the mean of the EPRI burst correlation for a 4.03 volts indication. These Farley-1 pulled tube results do not significantly change the EPRI ARC burst or probability of leakage correlations.

To assist development of a voltage dependent probability of detection (POD) to more accurately project bobbin indication distributions for IPC analyses, analyses were performed for the probability of prior cycle detection (POPCD) which includes indications that were missed during the previous inspection, indications below the detectability threshold of the previous inspection, and new indications appearing since the previous inspection. POPCD was evaluated for the EOC-12 inspection based on both RPC confirmed indications and indications RPC confirmed plus not RPC inspected at EOC-13 in 1995. The inclusion of indications not RPC inspected leads to a lower bound POD assessment, since it can be expected that many of these low voltage (< 1.0 volt) indications would not be confirmed by RPC. POPCD evaluations for eleven inspections in seven plants, including the EOC-12 Farley-1 inspection, have been evaluated and are compared in this report. Comparisons of the combined POPCD evaluation for all eleven inspections with that for the seven inspections performed since 1992 show an overall improvement in POD. The POPCD for the seven inspections since 1992 is in excellent agreement with the EPRI POD. It is concluded that the POD applied for IPC leak and burst projections needs to be upgraded from the POD = 0.6 to a voltage dependent POD. The POPCD for the most recent seven inspections strongly supports the EPRI POD, without further adjustments for new indications, as an acceptable POD. POPCD exceeds 0.85 above 1.0 volt and approaches unity above 2.5 volts.

Of the 268 RPC NDD indications left in service at BOC-13, 84 were RPC tested during the EOC-13 inspection and 37 were confirmed. This RPC confirmation rate for prior RPC NDD indications (44%) is higher than that found for other plants during recent inspections. Consequently, it is recommended that future Farley-1 APC applications include only the largest fraction for the last two cycles (currently 44%) of the RPC NDD indications in the BOC voltage distribution used for EOC projections and leak/burst analyses.

3.0 FARLEY-1 1995 PULLED TUBE DATA AT TSP LOCATIONS

3.1 FARLEY-1 PULLED TUBE DESTRUCTIVE EXAMINATION RESULTS

During the EOC-13 outage in 1995, steam generator Tube R28C35 was removed from the hot leg side of SG B at Farley Unit 1 and, subsequently, was examined at the Westinghouse Science and Technology Center, in support of alternative repair criteria (ARC) applications. The examination was conducted to characterize tube corrosion at steam generator hot leg tube support plate (TSP) crevice locations (TSP1, a location with an original field eddy current call of an OD indication, and TSP3, a location with no detectable degradation).

After nondestructive laboratory examination by eddy current, ultrasonic testing, radiography, dimensional characterization and visual examination, the TSP1 region was leak tested at elevated temperature. Subsequently, room temperature burst testing was conducted on both TSP regions, as well as several free span locations. The burst tested specimens were destructively examined using SEM fractography and metallographic techniques to characterize corrosion.

3.1.1 Non Destructive (NDE) Results

Table 3-1 presents a summary of the more important field and laboratory NDE results. The eddy current data were reviewed, including reevaluation of the field data, to finalize the voltages assigned to the indications and to assess the field no detectable degradation (NDD) calls for detectability under laboratory analysis conditions. A single analyst performed this work to minimize data variability. In general, there was more noise in the laboratory eddy current data making comparisons between the field and laboratory eddy current inspections difficult. The tube had local plastic deformation and a number of deep axial scratches caused by the tube pull that were responsible for the noise. For the indication at TSP1, there was a significant difference in the eddy current bobbin voltage call between the reevaluated field and laboratory results. The voltage increased from 4.03 volts for the reevaluated field bobbin data (4.21V was the original call from the field data) to 12.2 volts in the laboratory data. This increase suggests a noticeable increase in effective crack size from an eddy current viewpoint, usually caused by a tearing of ductile ligaments separating microcracks, or, as suspected in this case, by the creation of a crack shear lip at the front of a nearly throughwall crack. Shearing of the nearly throughwall crack (96% depth found) is supported by the fact that Argon leakage was found at about 200 psi prior to the water leak test. In addition, the TSP1 region field dent signal increased from 3.0 volts at the TSP top edge location to 12 volts in the laboratory, also showing the distortion caused by the tube pull. (The field TSP bottom edge dent signal disappeared in the laboratory data within the larger laboratory indication signal.) Other probes (RPC in the field; RPC, + Point, DIP & Cecco probes in the laboratory) showed the presence of multiple axial indications (MAI) at many locations within the TSP1 crevice region. Laboratory UT data also resulted in a call of MAI for the TSP1 region.

The field bobbin data for the TSP3, the original field NDD call, was reevaluated to derive the most appropriate amplitude measurements, where possible, for any very small signals. The reevaluated field data for this NDD call continued to be NDD with no discernible flaw separable from the background level. In the laboratory, the TSP3 region was also called NDD. In addition, NDD was observed by all of the other field or laboratory eddy current probes for the TSP3 region. Laboratory UT data, however, resulted in a call of a number of short, shallow OD indications in the TSP1 region.

3.1.2 Leak, Burst and Tensile Testing

The TSP1 crevice region, which had an original field eddy current indication, was leak tested at elevated temperature and pressure at conditions ranging from a simulated normal operating condition to a simulated steam line break condition. For the six conditions tested, leak rates ranged from 0.172 liters/hour to 3.26 liters/hour. Table 3-2 presents the individual test conditions and measured leak rates.

Both TSP crevice regions were burst tested at room temperature at a pressurization rate of 2000 psi per second. The burst tests were performed simulating free span conditions with no TSP enveloping the indications. In addition, the TSP1 region with a field indication was tested using a bladder and foil for the burst tests in a "semi-constraint" condition which simulated the lateral constraint provided by the TSP located above the crack indication at prototypical spacing between TSPs. Results of the burst tests are presented in Table 3-3. All burst specimen developed axial burst openings. The openings for the two TSP crevice region specimens were centered within the crevice regions. The circumferential position of the burst opening in the TSP1 specimen was close to the location of the deepest laboratory UT indication. The eddy current RPC data does not provide an absolute circumferential position. Both TSP specimens burst at pressures below that of the free span locations. The lowest burst pressure for a TSP crevice region (TSP1, the 4.03 volt field bobbin indication) was 5,361 psi, 44% below the burst pressure of the free span region with the least subsequently found free span corrosion. Table 3-3 also presents room temperature tensile data obtained from a freespan (FS) section of the pulled tube. The tensile and burst strengths for the free span section is typical for Westinghouse tubing of this vintage.

Following burst testing, a visual inspection showed the presence of wide-spread intergranular corrosion at both TSP regions, that was confined to the crevice region.

3.1.3 Destructive Examination Results

From post-burst test visual inspections, corrosion cracks were observed on both of the TSP specimens. They were given a destructive examination that included SEM fractography of the burst openings and metallography of secondary corrosion.

The burst fracture faces (FF) of the two TSP crevice region specimens were opened for SEM fractographic examinations. In addition, a second large crack network, located approximately 180^0 around the TSP1 crevice region from the burst opening, was opened in the laboratory and SEM fractography was performed on it. Table 3-4 presents the results of the fractographic data in the form of macrocrack length versus depth, macrocrack length/average and maximum depth, and the number/location/width of ductile or uncorroded ligaments found on the TSP fracture faces. The TSP burst openings occurred in axial macrocracks that were composed of numerous axially oriented intergranular microcracks of OD origin. Ductile ligaments separating the microcracks were present in all three of TSP FF from the two TSP region specimens. These two TSP regions had a typical number of remaining uncorroded ligaments between microcracks comprising the burst macrocracks. All intergranular corrosion was confined to and centered within the crevice regions.

The burst opening corrosion macrocracks for the TSP crevice regions had maximum depths ranging from 45% to 96% throughwall, with average depths ranging from 31% to 61% throughwall and with macrocrack lengths ranging from 0.375 to 0.696 inch. The shallowest and shortest corrosion macrocrack was for the TSP3 burst opening. The deepest and longest was for the burst opening from the TSP1 region. Three separate locations near the center of the TSP1 burst macrocrack were close to throughwall (96% deep) and each of these locations had a narrow shear lip angled 45^0 to the FF plane. Based on contrasting eddy current bobbin data from the field and laboratory and also on a pre-leak test, low pressure gas test of the specimen fittings (which showed gas bubble leakage from the crevice region), it is believed that this shear lip was created during the tube pull.

The TSP3 region was called bobbin NDD in the field and laboratory. The maximum crack depth for this location was 45% with a corresponding average macrocrack depth of 31%.

Figures 3-1 and 3-2 present sketches of the TSP region crack distributions found by visual (30X stereoscope) examination and subsequent destructive examinations. The sketches show the locations where cracks were found and their overall appearance, not the exact number of cracks or their detailed morphology. All TSP regions had their corrosion centered within and confined to the crevice regions.

Due to the complexities of the crack networks observed in the TSP regions, radial metallography was utilized, in addition to transverse metallography, to provide an overall understanding of the intergranular corrosion morphology for the two TSP regions. In radial metallography, small sections of the tube (typically 0.5 by 0.5 inch) are flattened, mounted with the OD surface facing upwards and then progressively ground, polished, etched and viewed from the OD surface towards the ID surface. Table 3-5 provides a summary of the metallographic data. It can be noted that the maximum and average depths found by metallography for the TSP crevice region corrosion was less than observed by SEM fractography for their burst openings.

From the metallographic examinations conducted on the TSP1 region, it was concluded that the dominant OD origin corrosion morphology was axial intergranular stress corrosion cracking (IGSCC). In addition, there was some minor intergranular cellular corrosion (ICC) components found in association with the axial IGSCC. With an ICC morphology, a complex mixture of short axial and oblique angled cracks interact to form cell-like structures. Figure 3-3 provides an example of the corrosion morphology found at the TSP1 by radial metallography at a depth 4% below the OD surface. With progressive radial grinding, it was shown that the axial IGSCC became even more dominant with depth while the ICC tended to disappear. Radial metallography conducted on the TSP3 region showed only axial IGSCC with no ICC. Figure 3-4 provides an example of the corrosion morphology found at the TSP3 by radial metallography at a depth 4% below the OD surface. Finally, in the TSP crevice areas, especially where the cracking occurred at very high densities, shallow IGA also was sporadically present. The IGA always was significantly less deep than the intergranular corrosion.

IGSCC morphology can be characterized by depth/width (D/W) ratios where the extent of IGA associated with a given crack is measured by the ratio of crack depth to the width of the crack at its mid-depth. D/W ratios greater than 20 are defined as minor and ratios less than 3 are defined as significant. Crack density is also considered an important parameter in characterizing corrosion. Crack densities greater than 100 cracks in 360 degrees are defined as high while values less than 25 are defined as low. The OD origin axial intergranular corrosion observed by metallography in the TSP crevice regions had little variation in crack densities or in crack morphologies. The crack density was close to the defined boundary between low to medium (~25 cracks around the circumference) and the crack morphology was close to the defined boundary between minor to moderate (D/W ratios ~20), as measured by D/W ratios.

3.1.4 Conclusions

Both TSP crevice regions had OD origin corrosion present. Metallographic data showed that the corroded TSP crevice regions either had only axially oriented IGSCC (TSP3) or combinations of axially oriented IGSCC and ICC with the axial IGSCC strongly predominating (TSP1). All TSP region corrosion was confined to the crevice regions. The corrosion morphology was typical of pulled tubes within the EPRI database.

Eddy current bobbin and other (RPC, + point, gimbaled + point, Cecco) probe data correlated well with the corrosion distribution for the deeper cracks present in the TSP1 region. The TSP3 crevice region was called bobbin and RPC NDD in the field and by all probes in the laboratory. Of the NDE techniques, laboratory UT provided the most accurate description of the TSP region corrosion, both in numbers of the TSP regions with corrosion (2 out of 2) and in the area extent and orientation of the corrosion. The field NDD TSP3 region had corrosion 45% throughwall, maximum depth, with an average depth of 31%. Consequently, these location had corrosion below the eddy current detection threshold, but above the UT detection threshold.

The TSP crevice region burst pressures ranged from 5,361 to 10,620 psi. All burst pressures were well above safety limitations required by R.G. 1.121. The burst pressure data were consistent with expectations, but below mean predictions for the ARC burst pressure versus bobbin voltage correlation for the TSP1 region.

3.2 COMPARISON OF RPC DEPTH PROFILES WITH DESTRUCTIVE EXAMINATION RESULTS

Although not a part of the ARC for ODSCC at TSP intersections, industry efforts are being applied to develop software and procedures for obtaining length versus depth profiles from RPC and + Point data. Eddy current analyses for the Farley-1 indications were performed prior to the destructive examination of the tubes. The predicted depth profiles are compared with the destructive examination results in this section.

Figure 3-5 shows the comparison of the eddy current depth profiles with the destructive exam data for the burst opening crack (crack #1) of R28C35, TSP 1. The destructive exam length of 0.696" is slightly longer than the 3-coil RPC probe, 80 mil coil length of 0.52". The difference in length is due to eddy current not seeing the 30% deep crack segment near the bottom of the TSP. The destructive exam maximum and average depths of 96% and 61.8% (73.7% without the segment at the bottom of the TSP) are in good agreement with the RPC 80 mil coil values of 100% and 78.6%. RPC has overestimated the average depth for the indications although the agreement is very good when the short segment of the actual crack is ignored. Similar results are found for the axial coil as shown in Figure 3-5.

Comparisons of eddy current and destructive exam data for the second large crack in R28C35 are shown in Figure 3-6. The agreement between eddy current and the actual depth profile is comparable to that found for Crack 1 in Figure 3-5. The RPC lengths are short in that the short and shallow crack segments at the top and bottom of the crack are not seen by RPC. The structurally significant parts of both cracks are seen and well sized by RPC.

Overall, these comparisons provide strong support for the depth sizing capabilities in support of structural integrity assessments. Depth sizing can be applicable to assessing tube integrity of large voltage indications. Bobbin voltage responds as an integral of all indications around the circumference of the tube and thus can be high compared to the equivalent voltage for a structurally limiting indication. Depth sizing can be used to more directly assess the structural integrity of the limiting crack. In addition, depth sizing permits structural assessment of indications found at dented intersections with > 5.0 volt dents for which the bobbin voltage cannot be assigned.

3.3 FARLEY-1 PULLED TUBE EVALUATION FOR ARC APPLICATIONS

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

3.3.1 Eddy Current Data Review

Table 3-6 provides a summary of the eddy current data evaluations for the Farley-1 pulled tubes. These NDE data results have been discussed in the above Section 3.1.2. As noted above, the field and laboratory reevaluations of the field bobbin data are in good agreement for the field call at TSP 1 and 3 (both NDD at TSP 3). The reevaluated field bobbin voltages, including the adjustment for cross calibration of the field ASME standard to the laboratory standard, are used for the EPRI ARC database. The reevaluation was performed by the same analyst that performed a large part of the EPRI pulled tube database and the use of these voltages minimizes analyst variability in the database, which is separately accounted for in ARC applications as an NDE uncertainty.

The TSP 3 indication wes found to be bobbin NDD in the field data. This indication is associated with a maximum crack depth of 45% with an average depth of 31%. As previously discussed, this indication was detectable in the post-pull laboratory inspection only by UT.

3.3.2 Farley-1 Data for ARC Applications

The pulled tube leak test, burst test and destructive examination results are summarized in Table 3-6. The Farley-1 pulled tube results were evaluated against the EPRI data exclusion criteria for potential exclusions from the database. Criteria 1a to 1e apply primarily to unacceptable voltage, burst or leak rate measurements and indications without leak test measurements. Criterion 1d applies to unacceptable leak rate data due to tube pull damage and requires analyses to demonstrate that the uncorroded ligament would not have torn at accident conditions. As discussed in Section 3.1, it is clear that the 96% maximum depth corrosion crack was torn to throughwall during the tube pull since the indication leaked Argon at 200 psi pressure differential. However, it is very doubtful that any analyses could confidently establish that the indication would not have torn throughwall at accident conditions. Therefore, there is no basis to exclude the indication from the EPRI database for Criterion 1d. None of the others of Criteria 1 are applicable to the Farley-1 indications. Criterion 3 applies to potential errors in the leakage measurements and is not applicable to the Farley-1 indications with no leakage.

EPRI Criterion 2a applies to atypical ligament morphology for indications having high burst pressures relative to the burst/voltage correlation and states that high burst pressure indications with ≤ 2 uncorroded ligaments in shallow cracks < 60% deep shall be excluded from the database. The R28C35, TSP 1 indication has a maximum depth of 96% and the criterion is not applicable to this indication.

The TSP 1 indication leaked at SLB conditions. The measured leak rate given in Table 3-2 of 3.26 l/hr was adjusted to 2.19 l/hr at the reference SLB conditions using the EPRI leak rate adjustment procedure given in EPRI Report NP-7480-L. The adjustment is significant due to the high primary pressure and lower temperature (both of which tend to increase the effective pressure drop between the primary pressure and saturation pressure and increase the leak rate) for the test conditions given in Table 3-2. Since the TSP 3 indication is field bobbin NDD, this indications cannot be used in the EPRI ARC database for the voltage correlations.

As shown in Section 3.4, the TSP 1 leak rate tends to be high on the leak rate correlation and low on the burst pressure correlation. Part or all of these effects may be due to damage during the tube pull although, as noted above, the indication cannot be excluded from the EPRI database based on application of the EPRI data exclusion criteria.

As shown in the last column of Table 3-6, the TSP 1 indication of R28C35 is to be included in the probability of leakage, leak rate and burst correlations. This is further discussed in Section 3.4.

3.4 COMPARISON OF FARLEY 1 DATA WITH EXISTING APC CORRELATIONS

This section reports on the evaluations performed which utilized the results of leak rate and burst testing of the tube section which was removed from Farley Unit 1 in 1995. The results of the destructive examination of the tube is recorded in Section 3.1 of this report. The Farley 1 pulled tube data germane to the APC correlations, and the bobbin amplitudes for APC applications, are given in Table 3-7. The results of the destructive examinations, e.g., leak and burst tests, are compared to the database[1] of similar test results for 7/8" outside diameter steam generator tubes. In addition, the effect of including the new test data in the reference database was evaluated. In summary, the test data are consistent with the database relative to the burst pressures, the probability of leak as a function of the bobbin amplitude, and the leak rate as function of bobbin amplitude. The comparisons and evaluations are discussed below.

3.4.1 Suitability for Inclusion in the Database

The report information on the destructive examinations of the tube sections was reviewed in Section 3.3 relative to the EPRI guidelines for inclusion/exclusion of tube specimen data in the alternate plugging criteria (APC) database. This review revealed no information that would lead to a conclusion that the data should not be included in the database. Therefore, the resulting correlations should be considered applicable to the use of APC for indications in 7/8" diameter tubes in Westinghouse SGs.

3.4.2 Burst Pressure vs. Bobbin Amplitude

The result from a burst test, performed on a tube specimen which exhibited a non-zero bobbin amplitude at a TSP elevation location, was considered for evaluation. A

[1] The database consisted of the EPRI recommended database, plus test results from pulled tube sections removed from Beaver Valley 1 (SG-95-06-006, May 1995) and Farley 2 (SG-95-07-010, July 1995) in the Spring of 1995, and Sequoyah 1 (SG-96-01-007, January 1996).

plot of the burst pressure of the Farley 1 specimen is depicted on Figure 3-5 relative to the burst pressure correlation developed using the reference database.[2]

1. A visual examination of the data relative to the EPRI database indicates that the burst pressure measured falls within the scatter band of the reference data.

2. The data point falls just outside the 90% two-sided prediction band about the regression line (the one-sided 95% prediction curve depicted is the lower bound of the two-sided 90% prediction band). It is within a two-sided 95% prediction band, hence no significant statistical anomaly is indicated.

In summary, the visual examination doesn't indicate any significant departures from the reference database, although the burst pressure is less than would have been expected from such an indication. This could have been the influenced by mechanical deformation from the tube removal activities since the bobbin amplitude increased from 4 volts before removal to 12 volts after.

Since the Farley 1 burst pressure data was not indicated to be from a separate population from the reference data, the regression analysis of the burst pressure on the common logarithm of the bobbin amplitude was repeated with the additional data included. A comparison of the regression results obtained by including these data in the regression analysis is provided in Table 3-8. Regression predictions obtained by including these data in the regression analysis are also shown on Figure 3-5. A summary of the changes is as follows:

1. The intercept of the burst pressure, P_B, as a linear function of the common logarithm of the bobbin amplitude regression line is decreased by 0.26%. This has the effect of decreasing the predicted burst pressure as a function of the bobbin amplitude.

2. The absolute slope of the regression line is increased by 0.45%, i.e., the slope is more steep. This has the effect of decreasing the burst pressure as a function of bobbin amplitude for large indications.

3. There is an increase in the standard error of the residuals of 2.85%. The effect of this change would be reflected in a slightly larger deviation of the 95% prediction line from the regression line.

The net effect of the changes on the SLB structural limit, using 95%/95% lower tolerance limit material properties, is to decrease it by 0.6 volts, i.e., from 9.2 volts to 8.6 volts. The decrease in the intercept and the increase in the standard error coupled with the fact that the structural limit is also decreased indicates that the probability of burst would also increase for bobbin indications over the structural range of

[2] The database is not shown since it is proprietary to the Electric Power Research Institute.

interest. Based on the relatively small change in the structural limit, the change in the probability of burst would also be expected to be small.

3.4.3 Probability of Leak

The data of Table 3-7 were examined relative to the reference correlation for the PoL as a function of the common logarithm of the bobbin amplitude. Figure 3-6 illustrates the Farley 1 data relative to the reference correlation. The specimen exhibited PoL behavior somewhat commensurate with expectations indicated by the reference database and regression curve. The predicted PoL for a 4.03 volt indication is 0.133, thus, roughly 1 in 7 indications with an amplitude of 4.03 volts would be expected to leak. Had the expectation been 1 in 20, statistically anomalous behavior might have been suspected. So, based on the data examination, there is no significant evidence of irregular results, i.e., outlying behavior is not indicated. It is again noted that this indication had ligament tearing during the tube pull as indicatied by the maximum 96% corrosion depth resulting in post-pull Argon leakage at 200 psid and the increase in bobbin amplitude from 4.03 to 12.2 volts. However, since it is difficult to prove that the wall thickness ligament would not have torn during postulated SLB conditions, the indication is retained in the EPRI database although the measured leak rate is expected to be conservatively high as discussed in Section 3.3.

In order to assess the quantitative effect of the new data on the correlation curve, the database was expanded to include the Farley 1 data point and a *Generalized Linear Model* regression of the PoL on the common logarithm of the bobbin amplitude was repeated. A comparison of the correlation parameters with those for the reference database is shown in Table 3-9. These results indicate:

1. A 10.9% increase (smaller negative value) in the *logistic* intercept parameter.

2. A 8.0% decrease in the *logistic* slope parameter.

3. The absolute values of the parameters' covariance matrix changed by 27.5% to 33.6%. These changes may have a significant impact on the PoL values used during the Monte Carlo Simulations, but may not have a significant impact on the 95% confidence bound on the total estimated leak rate from a single SG.

4. The Pearson standard error decreased by 4.4% from 0.622 to 0.594. This is a negative indicator since the ideal value would be 1.0, but is not judged to be significant.

In order to assess whether or not these changes are significant, the reference correlation and the new correlation were also plotted on Figure 3-6. An examination of Figure 3-6 reveals a moderate change in the correlation up to about 5 volts. A tabular summary of PoL predictions before and after including the Farley 1 data point is provided as Table 3-10. For indications with amplitudes less than 1.0 volt, the PoL increases by a factor of 2 to 4. The PoL for indications of 3 volts increases by about 50%, and for indications of 8 volts and greater the change in the PoL is not significant. It is noted that when the total leak rate is determined using the leak rate to bobbin volts correlation, the resulting value can be quite insensitive to the form of the PoL function. So, the effect of the changes in the parameter values and variances would be expected to be small or insignificant relative to the calculation of the 95% confidence bound of the total leak rate from a SG. However, when the leak rate is considered as independent of the voltage (current APC database), the increase in PoL would most directly affect the estimated total leak rate.

3.4.4 Leak Rate vs. Bobbin Amplitude

The specimen exhibited leak rate corresponding to 2.19 lph at the SLB temperature and pressure difference conditions. The correlation of leak rate to bobbin voltage exhibits a *p*-value of 6.5% for the slope parameter using the reference database. With the addition of the Farley 1 data point the correlation exhibits a *p* value of 6.4%. Therefore, based on the requirements stipulated in the NRC Generic Letter for voltage based plugging criteria, the use of the correlation in performing Monte Carlo simulations to estimate the total leak rate is not considered to be justified. Figure 3-7 illustrates the new data point relative to the distribution predicted mean using the reference database and relative to a lower 95% confidence limit for a predicted leak rate from the distribution. Also illustrated is the relation of the data point to the regression fit and to the expected leak rate (mean of the log-normal distribution) based on the regression analysis of the leak rate on the bobbin amplitude. The common logarithm (log) of the test leak rate, 0.340, is lower than the mean of the log of the leak rates for the reference database, 0.576, but is well within one standard deviation of that value. The effects of including the data point in the database on the estimated parameters of the leak rate distribution are tabulated in Table 3-11. The estimated mean and standard deviation of the population of log leak rates are decreased, hence, predicted leak rates from Monte Carlo simulations and the 95% confidence bound on the total leak rate from a single SG will be reduced.

3.4.5 General Conclusions

The review of the effect of the Farley 1 data indicates that the burst pressure and the probability of leak correlations to the common logarithm of the bobbin amplitude would not be substantially changed by the inclusion of the data. Therefore, it is likely that the conclusions relative to EOC probability of burst and EOC total leak rate based on correlations obtained using the reference database would not be significantly affected. The increase in the PoL would be at least partially offset by decreases in the leak rate.

Table 3-1
Comparison of NDE Indications Observed at Farley Unit 1 on Pulled S/G Tube R28C35

Location	Field E/C	Lab E/C	Lab UT Data	Lab X-Ray
TSP1	<u>Bobbin</u>: 4.09V OD Ind (4.03V, 78% deep OD Ind with 3.0V dent at TSP top edge & 1.5V dent at TSP bottom edge)* <u>RPC</u>: 0.44" MAI (3 major MAI, one 0.51" long & 96% deep, one 0.46" long & 96% deep, one 0.29" long & 93% deep)*	<u>Bobbin</u>: 12.2V, 90% deep OD Ind with 12V dent at TSP top edge <u>RPC</u>: 5 major MAI, all more than 90% deep & up to 0.6" long, plus many more MAI; only 100^0 without MAI <u>+ Point</u>: similar to RPC data <u>DIP</u>: similar to RPC data <u>Cecco</u>: Inds in 18 channels (270^0 involvement)	Extensive network of OD axial indications throughout crevice region in radial, circumferential & axial MAI data, concentrated from 330^0 through 0^0 to 200^0	Clear, 0.65" long axial crack network in center of crevice near 0^0
TSP3	<u>Bobbin</u>: NDD <u>RPC</u>: NDD	<u>Bobbin</u>: NDD <u>RPC</u>: NDD <u>+ Point</u>: NDD <u>DIP</u>: NDD <u>Cecco</u>: NDD	Short, shallow, OD axial Inds in circumferential aim data	possible axial indication in crevice near 200^0

()* = Eddy current reevaluation value, given if additional or different information was produced. Bobbin voltages use cross calibration of ASME standard to reference lab standard.

<u>Legend of Abbreviations:</u>

Ind = Indication
RPC = Rotating Pancake Coil
DI = distorted indication
TSP = tube support plate
V = volts
SAI = single axial indication
MAI = multiple axial indications
NDD = no detectable degradation
TTS = top of tubesheet

Table 3-2

Leak Test Data for the TSP1 Region of Tube R28C35

Differential Pressure, psi	Leak Rate, liters/hr	Primary Pressure, psig	Secondary Pressure, psig	Primary Temperature, ^{0}F	Secondary Temperature, ^{0}F
1302	0.172	2058	756	579	597
1558	0.290	2074	517	574	590
1906	0.625	2430	524	560	572
2165	1.04	2536	370	550	524
2341	1.35	2706	365	534	490
2544	3.26	2774	230	454	402*

* Secondary side was at T_{SAT} conditions. The larger cooling coil collection system was used for the 2544 psi differential pressure test. The larger cooling coil intake line reaches to the bottom of the secondary side autoclave.

Table 3-3

Room Temperature Burst and Tensile Test Data for Farley Unit 1 S/G Tube R28C35

Location	Burst Pressure, psig	Burst Ductility %	Burst Length, inches	Burst Width, inches	0.2% Offset Tensile Yield Strength, psi	Tensile Ultimate Strength, psi	Tensile Elongation, %
TSP1*	5,361	6.7	0.720	0.149			
TSP3	10,620	14.0	1.262	0.335			
Control, NX8161	11,528	32.3	1.900	0.343	53,125	108,593	29.2

Legend:

TSP = tube support plate; FS = free span, TTS = top of tubesheet; S/G = steam generator
* = Burst with foil and bladder in a semi-restraint condition, all others burst without restraint, bladder, or foil.

Table 3-4

Farley Unit 1 S/G Tube R28C35 Intergranular Macrocrack Profiles for OD Origin Corrosion

Specimen, location	Length vs. Depth & Ductile Ligament Data (inches/% throughwall)	Positional Information	Comments
TSP1 (Axial Burst Crack at 0°)	0.00/00 0.04/67 0.08/67 0.12/75<--Ligament 1/0.006" wide 0.17/83 0.21/96<--(Max. depth = 96% over 0.04" from 0.19 to 0.23") 0.25/88 0.29/83 (0.31/96)<--(Max. depth = 96% over 0.009" from 0.305 to 0.314") 0.33/88 (0.35/96)<--(Max. depth = 96% over 0.008" from 0.345 to 0.353") 0.37/79 0.42/83 0.46/79 0.50/75 0.54/19 0.58/00<--Ligament 2/0.054" wide 0.62/33 0.67/27 (0.696/00) (Ave. depth = 61%, Macrocrack Length = 0.696 inch)	Crack Top (located 0.038" below TSP top) Crack Bottom (Located 0.734" below TSP top)	The axially oriented burst macrocrack had two ductile ligaments with dimple rupture features occurring over more than 50% of their lengths.

Table 3-4 (Continued)

Farley Unit 1 S/G Tube R28C35 Intergranular Macrocrack Profiles for OD Origin Corrosion

Specimen, location	Length vs. Depth & Ductile Ligament Data (inches/% throughwall)	Positional Information	Comments
TSP1 (Second Network at 200^0 Behind Axial Burst Crack)	0.00/00 0.04/12 <---Ligaments 1 & 2/0.004 & 0.006" wide 0.08/20 0.12/56 0.16/58 0.20/58 0.24/76 0.28/78 0.32/70 0.36/84<--(Max. depth = 84%) 0.40/74 0.44/61 0.48/58 <---Ligament 3/0.005" wide 0.52/60 0.56/50 <---Ligament 4/0.006" wide 0.60/38 (0.632/00) (Ave. depth = 53%, Macrocrack Length = 0.632 inch)	Crack Top (located at TSP top) Crack Bottom (Located 0.632" below TSP top)	
TSP3 (Axial Burst Crack at 210^0)	0.00/00 0.04/44 0.08/45<--(Max. depth = 45%) <---Ligaments 1& 2/0.002 & 0.006" wide 0.12/38 0.17/38 0.21/42 0.25/40 0.29/38 0.33/29 0.375/00 (Ave. depth = 31%, Macrocrack Length = 0.375 inch)	Crack Top (located 0.246" below TSP top) Crack Bottom (Located 0.621" below TSP top)	The axially oriented burst macrocrack had two ductile ligaments with dimple rupture features occurring over more than 50% of their lengths.

Table 3-5

Metallographic Data of Farley Unit 1 Steam Generator Tube R28C35

Specimen Location	Section Type	Number of Cracks	Section Length (Inch)	Cracks per Inch	Estimated Maximum Number of Cracks at Mid-crevice Location	Max./Avg.* Depth (% Throughwall)	Max. Depth of ICC Transverse and Axial Components (% Throughwall in Radial Section)	Avg. D/W Ratio from Transverse Section
TSP1	Transverse Radial Radial Radial Radial Radial	20 5 6 5 ≤1 0	2.0 0.32 0.32 0.32 0.32 0.32	10 16 19 16 3 0	~25	96/55 depth = 4% depth = 24% depth = 44% depth = 64% depth = 84%	24% < Oblique < 44% 44% < Axial ≤ 64%	~24
TSP3	Transverse Radial Radial Radial Radial	19 11 7 ≤1 0	2.5 0.52 0.52 0.52 0.52	8 21 13 2 0	~25	44/22 depth = 4% depth = 24% depth = 44% depth = 64%	Only axial IGSCC 24% < Axial ≤ 44%	~15

* = Average depth is the average of the depths of separated microcracks found around the circumference in the transverse section and does not represent a macrocrack average.

Table 3-6. Summary of Farley-1 Pulled Tube Eddy Current Results

Tube	TSP	Field Call		Lab. Reevaluation of Field Data					Post Pull Data				
		Bobbin Volts[1]	RPC Volts	Bobbin Volts	ASME Cal.[2]	Bobbin Volts[2]	Depth	RPC Volts	Bobbin Volts	RPC 3-Coil	+ Point	Cecco	UT
R28C35	1	4.09 v	3.1 v MAI	3.71 v 3.0 v Dent	1.087	4.03	78%	2.3 v MAI	12.2 v 12 v Dent	4.9 v MAI	MAI	18 Coils	MAI
	3	NDD	NDD	NDD				NDD	NDD	NDD	NDD	NDD	MAI

Notes: 1. Field data include cross calibration of ASME standard to the reference laboratory standard
2. ASME calibration represents the cross calibration factor for the field ASME standard to the reference laboratory standard and is applied to the laboratory reevaluation to obtain the corrected APC volts

Table 3-7. Farley-1 Pulled Tube Data for ARC Applications

Tube	TSP [1]	Bobbin Data		RPC Volts	Destructive Exam Results				Leak Rate-l/hr [6]		Burst Pressure Data - ksi				Use in Corr. Note 5
		Volts	Depth		Max. Depth	Avg. Depth	Crack Length	No. Lig. [2]	N. O. 1300 psid	SLB 2560 psid	Meas. Burst Press.	σ_y	σ_u	Adj. [4] Burst Press.	
R28C35	1	4.03	78%	0.5	96%	61%	0.696"	2	0.23	2.19	5.361			4.666	B, LR, POL
	3	NDD		NDD	45%	31%	0.375"	2	0.0[3]	0.0[3]	10.620			9.243	None
	FS										12.173	61.74	110.61	10.595	None

Notes:
1. FS is freespan section of tubing with no tube degradation to obtain tensile properties and undegraded tubing burst pressure
2. Number of uncorroded ligaments with > 50% of ligament length remaining in burst crack face.
3. Inferred from destructive exam depth, leak test not performed. Corrosion depth too shallow for leakage at SLB conditions.
4. Burst pressures adjusted to 150 ksi for $\sigma_y + \sigma_u$.
5. B = data to be used in burst correlation, POL = data to be used in probability of leakage correlation, L = data to be used in leak rate correlation.
6. Measured leak rates adjusted to reference conditions using EPRI leak rate adjustment procedure.

Table 3-8: Effect of Farley 1 Data on the Burst Pressure vs. Bobbin Amplitude Correlation

$$P_B = \alpha_1 + \alpha_2 \log(Volts)$$

Parameter	Reference[1] Database Value	Database with Farley 1	New / Old Ratio
α_1	7.6119	7.5920	0.9974
α_2	-2.3594	-2.3700	1.0045
r^2	82.70%	81.84%	0.9896
σ_{Error}	0.805	0.828	1.0285
N (data pairs)	79	80	
p Value for α_2	$5 \cdot 10^{-31}$	$1 \cdot 10^{-30}$	2.75
Reference σ_f	68.78 ksi[2]		

Notes: (1) The reference database includes the results of data obtained from tubes removed from Beaver Valley 1 and Farley 2 (Spring 1995), and Sequoyah 1 (Fall 1995).

(2) This is the flow stress value to which all data was normalized prior to performing the regression analysis. This affects the coefficient and standard error values. The corresponding values for a flow stress of 75.0 ksi can be obtained from the above values by multiplying by 1.0904.

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

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

Parameter	Reference[1] Database	Database with Farley 1	Change
β_1	-6.9901	-6.2269	-10.9%
β_2	8.4470	7.7739	-8.0%
V_{11}[2]	3.4522	2.2911	-33.6%
V_{12}	-3.8019	-2.6004	-31.6%
V_{22}	4.5456	3.2955	-27.5%
DoF[3]	106	107	
Deviance	25.18	28.90	14.7%
Pearson SD	62.2%	59.4%	-4.4%

Notes: (1) The reference database includes results obtained from tube sections removed from Beaver Valley 1 and Farley 2 in the Spring of 1995, and Sequoyah in the Fall of 1995.

(2) Parameters V_{ij} are elements of the covariance matrix of the coefficients, β_i, of the regression equation.

(3) Degrees of freedom.

Table 3-10: Effect of Farley 1 Data on Probability of Leak Predictions			
Bobbin Amplitude (Volts)	EPRI/NRC Database PoL	w/ Farley 1 Database PoL	New / Old Ratio
0.100	1.98E-07	8.31E-07	4.21
0.200	2.51E-06	8.63E-06	3.43
0.300	1.11E-05	3.39E-05	3.05
0.500	7.24E-05	1.90E-04	2.63
0.600	1.41E-04	3.52E-04	2.49
0.800	4.06E-04	9.29E-04	2.29
1.000	9.20E-04	1.97E-03	2.14
2.000	0.0116	0.0201	1.74
3.000	0.0493	0.0746	1.51
5.000	0.2524	0.3115	1.23
8.000	0.6544	0.6886	1.05
10.000	0.8111	0.8245	1.02
15.000	0.9500	0.9486	1.00
20.000	0.9820	0.9799	1.00
30.000	0.9959	0.9948	1.00
40.000	0.9986	0.9980	1.00
50.000	0.9994	0.9991	1.00

Table 3-11: Effect of Inclusion of the Farley 1 Data on the Reference Leak Rate Database for 7/8" Tube APC Applications				
Parameter	Leak Rate (lph)		Log(Leak Rate)[1]	
	Reference Database	w/ Farley 1 Database	Reference Database	w/ Farley 1 Database
Sample Size	26	27	26	27
Sample μ	13.74	13.32	0.5764	0.5696
Sample σ	21.13	20.84	0.8338	0.8188
Population μ	[redacted]	[redacted]	23.92 lph	21.96 lph
Upper 95% Pred.	[redacted]	[redacted]	100.6 lph	92.5 lph
Lower 95% Pred.	[redacted]	[redacted]	0.143 lph	0.149 lph
p Value	[redacted]	[redacted]	6.5%	6.4%

Notes: 1. The database of leak rates has been previously shown to follow a log-normal distribution with a high level of confidence.

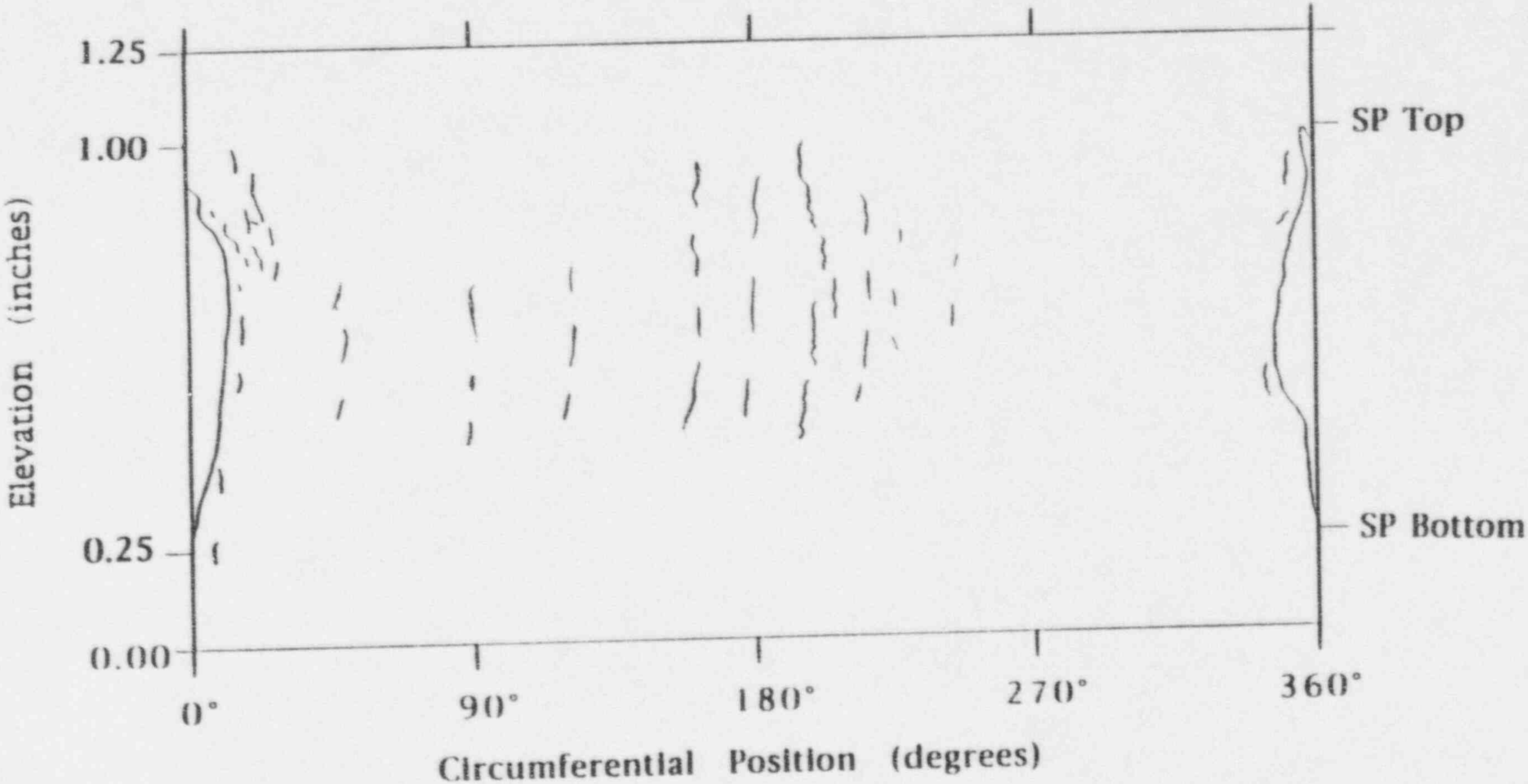


Figure 3-1 Sketch of the OD surface crack distribution found at the TSP1 region of Tube R28C35. Also shown is the location of the burst fracture opening. The burst opening extended beyond the TSP crevice region, but the corrosion cracking was confined to the crevice region.

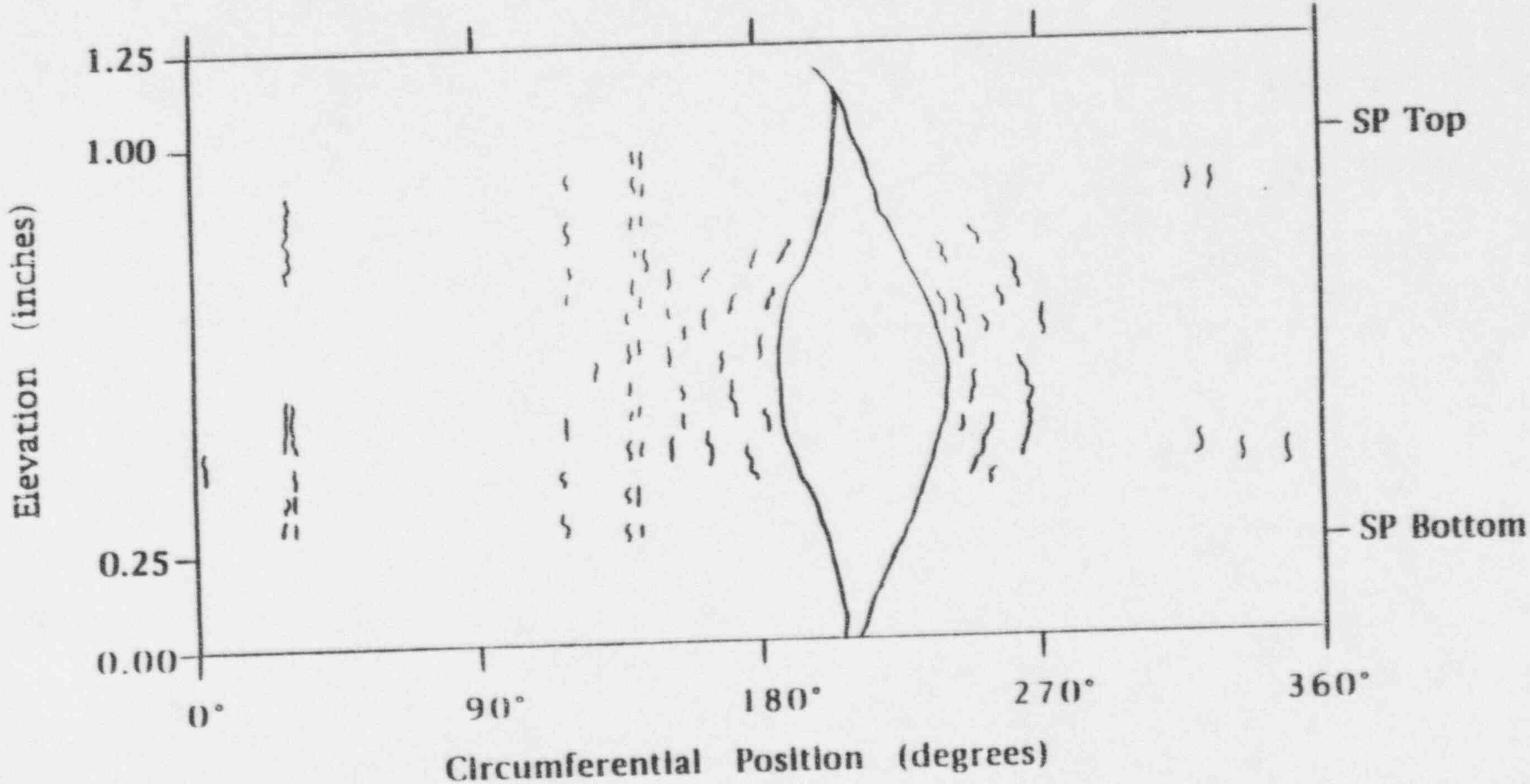


Figure 3-2 Sketch of the OD surface crack distribution found at the TSP3 region of Tube R28C35. Also shown is the location of the burst fracture opening. The burst opening extended beyond the TSP crevice region, but the corrosion cracking was confined to the crevice region.

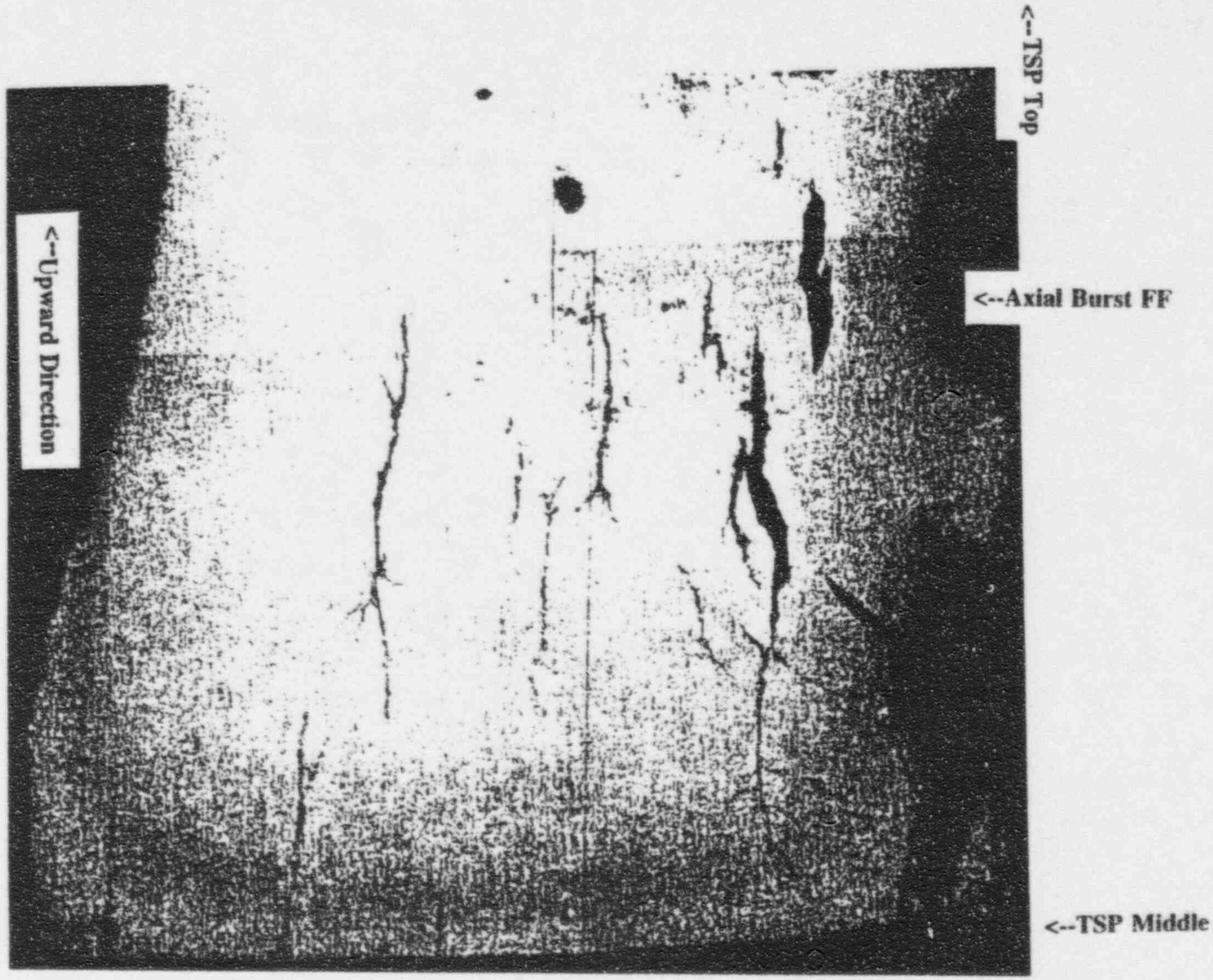


Figure 3-3 OD radial metallography showing minor intergranular cellular corrosion (ICC) present along with the more dominant axial intergranular stress corrosion (IGSCC) at the TSP1 region of Tube R28C35. (16X Mag. 4% Depth)

Figure 3-4 OD radial metallography showing axial intergranular stress corrosion (IGSCC) at the TSP3 region of Tube R28C35. (16X Mag. 4% Depth)

Figure 3-5: Burst Pressure vs Volts for 7/8" OD Alloy 600 SG Tubes

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

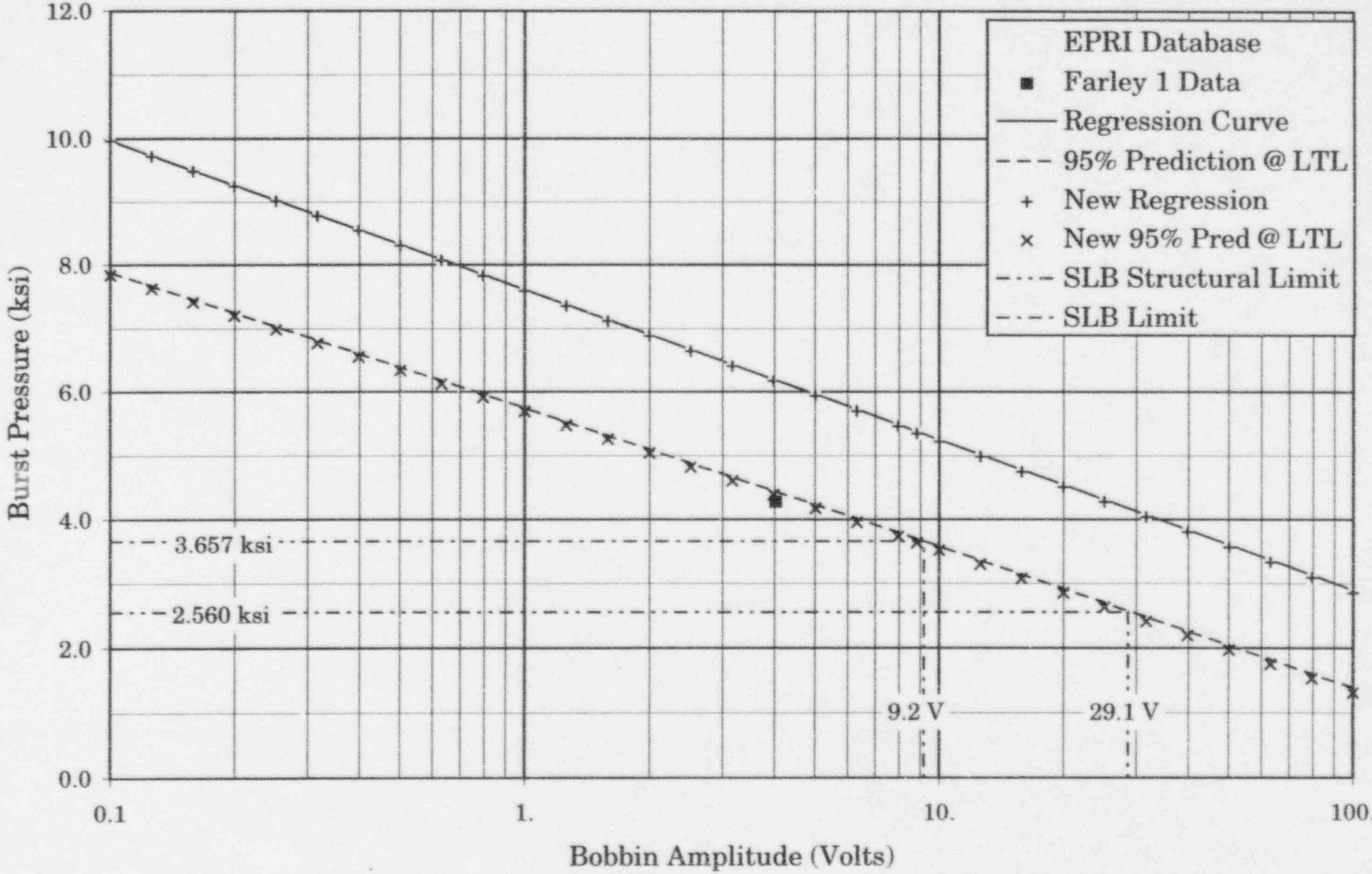
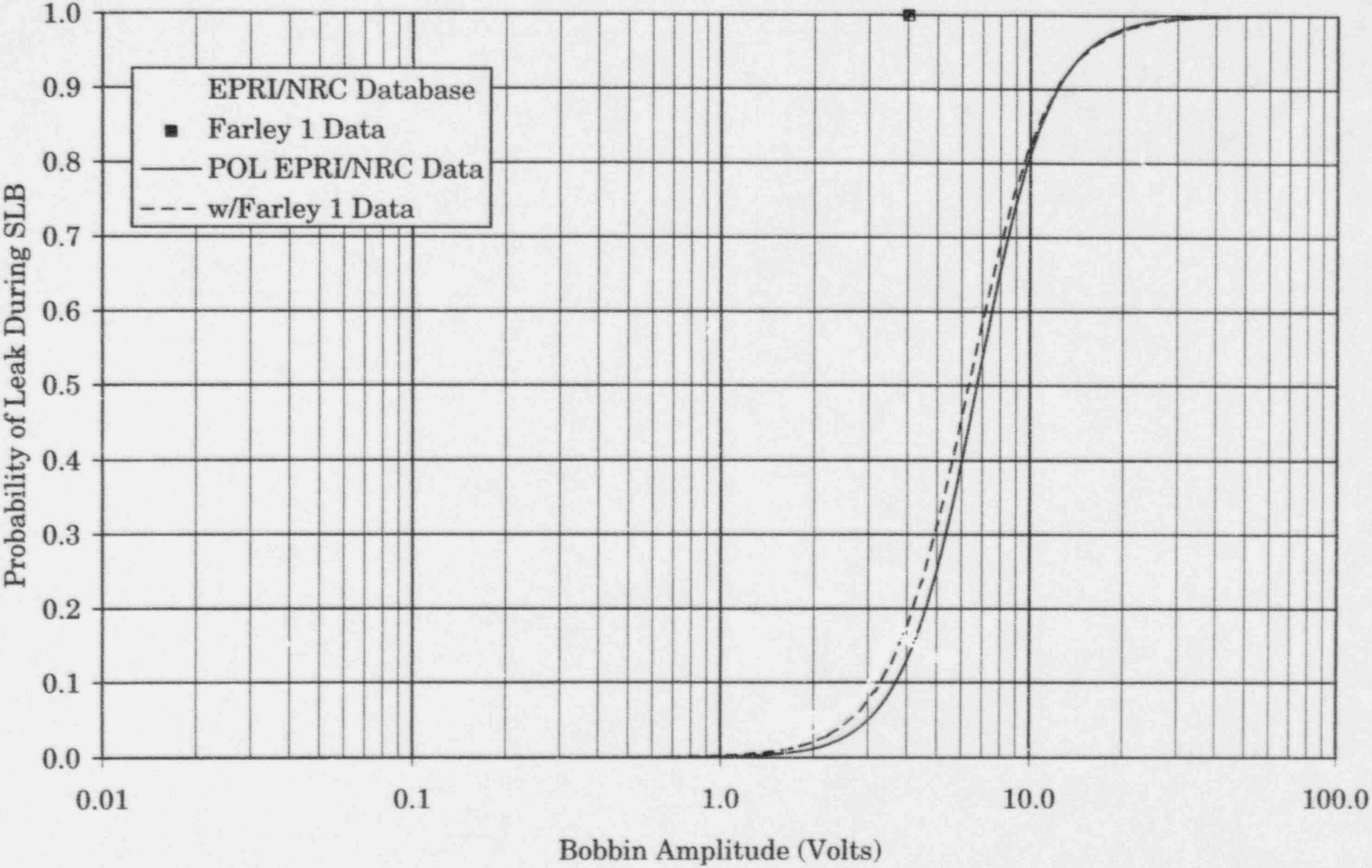


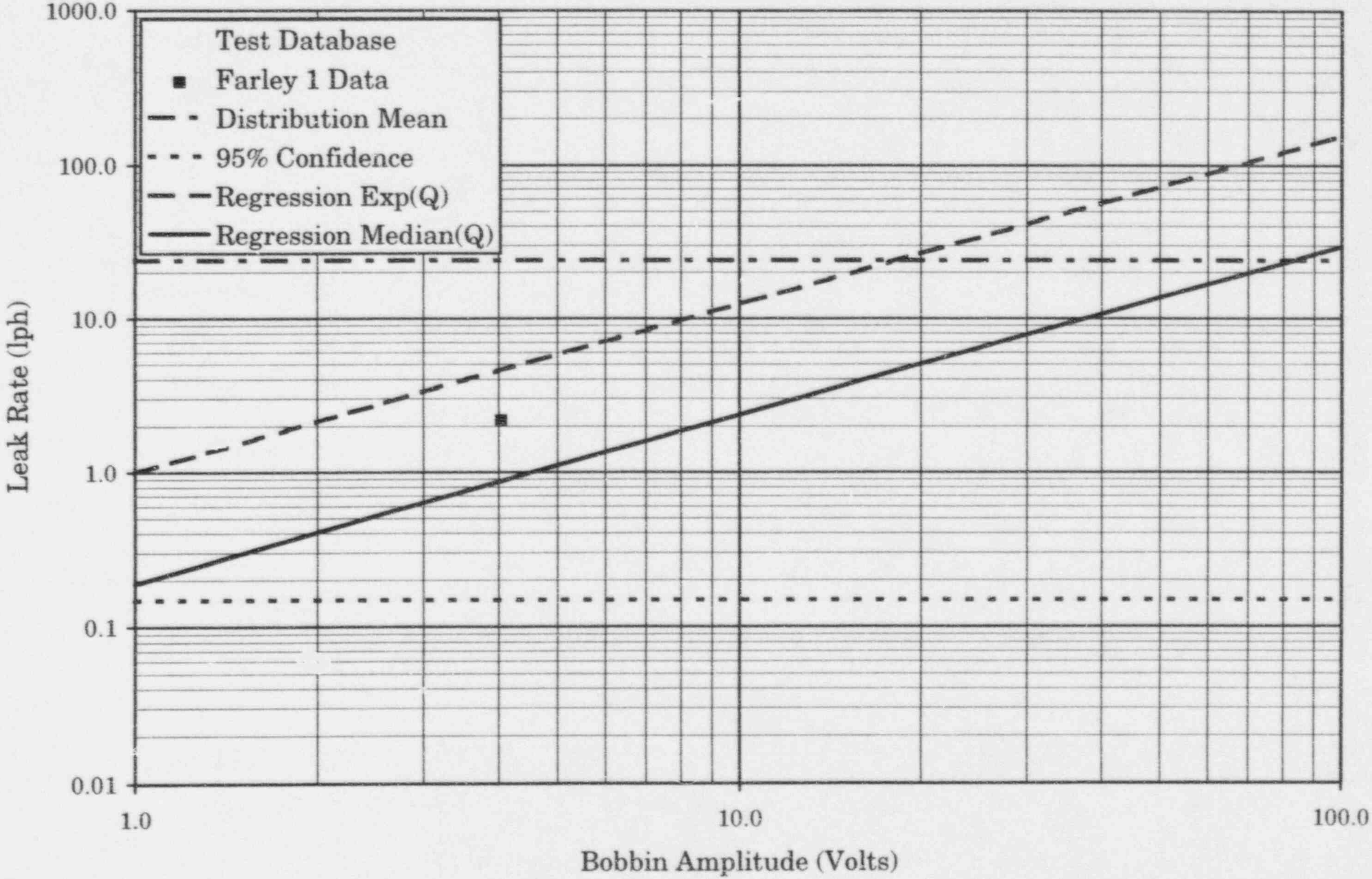
Figure 3-6: Probability of Leak for 7/8" SG Tubes Effect of Inclusion of Additional Data



[78pol_6.xls] PoL.log(V) RFK: 1/26/96, 11:14 AM

Figure 3-7: Leak Rate vs Bobbin Amplitude

7/8" Tube Data, All Data, NRC Correlation



4.0 EOC-13 INSPECTION RESULTS AND VOLTAGE GROWTH RATES

4.1 EOC-13 INSPECTION RESULTS

In accordance with the IPC guidance provided by the NRC draft generic letter (Reference 9.1), the end of Cycle 13 (EOC-13) inspection of the Farley-1 steam generators (SG) consisted of a complete 100% bobbin probe full length examination of all TSP intersections in the tube bundles of each SG. RPC examination was performed for all bobbin indications with amplitudes > 2.0 V and RPC confirmed indications of > 2.0 V bobbin amplitude were plugged.

A summary of the steam generator ECT indication voltage distributions is shown on Table 4-1. For those tubes that were in service for Cycle 13, Table 4-1 provides the number of field bobbin indications, the number of these field bobbin indications that were RPC inspected, the number of RPC confirmed indications, the number of indications in plugged tubes, and the subsequent total indication population being returned to service (RTS) for Cycle 14 (BOC-14). Overall, the combined data for the three steam generators of Farley-1 shows that:

- Out of a total of 2571 indications which were in-service during Cycle 13 and were identified during the EOC-13 inspection, 155 were removed from service (including indications in tubes plugged for other causes), leaving 2416 which were returned to service for Cycle 14. A total of 34 indications, > 2.0 volts and confirmed by RPC, were repaired for ODSCC at TSP intersections. Any RPC confirmed but not removed from service indications have bobbin amplitudes of < 2.0 volts.

- Of the 2571 indications, a total of 167 were RPC inspected.

- Of the 167 RPC inspected, a total of 104 were RPC confirmed.

Review of Table 4-1 indicates that steam generator C has more total as well as higher amplitude BOC-14 indications (a quantity of 896, with 446 indications >1.0 volt) than SG A or B, thereby it potentially will be the limiting SG at EOC-14.

Figure 4-1 shows the actual bobbin voltage distribution determined from the EOC-13 ECT inspection; note that SG C predominates above 0.8 V. The largest bobbin indication found in the EOC-13 inspection was 7.1 volts. This indication is less than the current structural limit (Section 3.4) of 9.2 volts without the latest Farley-1 pulled tube and 8.6 volts with the Farley-1 data. Figure 4-2 shows the population distribution of those EOC-13 indications which were plugged and taken out of service; 50% of these repairs were performed for SG C. Figure 4-3 shows the bobbin voltage distribution of indications in service during Cycle 13 continuing in service for BOC-14.

The distribution of EOC-13 indications as a function of support plate elevation, summarized in Table 4-2 and shown on Figure 4-4, shows the predisposition of ODSCC to occur in the first few hot leg TSPs (82% of the indications occurred in the first four hot leg TSPs) although the mechanism does extend higher and, to a much lesser extent (1.4%), to the cold leg.

4.2 VOLTAGE GROWTH RATES

Average growth rates for the Farley-1 steam generators, shown on Table 4-3, provide a comparison of recent operating cycles. Another comparison of voltage growth is shown by the Cumulative Probability Distribution Functions (CPDF) on Figure 4-5. The CPDF for Cycle 13 is between that of Cycle 11 and Cycle 12. Overall, these results generally tend to show a progressive reduction in average growth rates over the last ten years. Cycle 12 and Cycle 13 growth rates are clearly lower than previous experience, although Cycle 13 growth rates exceed those of Cycle 12. Average growth rates for individual Farley-1 steam generators during Cycle 13 are shown in Table 4-4 and the cumulative probability distributions are shown on Figure 4-6. The difference in average growth between SGs is small. The NRC guidelines require that the more conservative growth distribution from the prior two cycles be used for projecting the next cycle distributions; accordingly, the Cycle 13 growth rates shown in Table 4-5 will be used for Cycle 14 growth analyses and to predict EOC-14 voltage distributions.

The EOC-13 field bobbin data summarized on Table 4-1 (the basis for BOC-14 bobbin voltage and all tube leakage and burst probability calculations reported herein) does not include INR (Indication Not Reportable) field calls. Generally, growth estimates are calculated only for the cases where bobbin signal voltage is available for both inspections; i.e., no assumption about the signal voltage for prior year is made if a reliable flaw indication is not available. However, new indications which were called INRs in the EOC-12 inspection and reported as bobbin indications at EOC-13 were included in the growth analysis.

4.3 PROBABILITY OF PRIOR CYCLE DETECTION (POPCD)

The inspection results at EOC-13 permit an evaluation of the probability of detection at the prior EOC-12 inspection. For APC/IPC applications, the important indications are those that could significantly contribute to EOC leakage or burst probability. These significant indications can be expected to be detected by bobbin and confirmed by RPC inspection. Thus the population of interest for APC POD assessments is the EOC RPC confirmed indications that were detected or not detected at the prior inspection. The probability of prior cycle detection (POPCD) can then be defined as:

$$\text{POPCD(EOC-12)} = \frac{\begin{array}{c}\text{EOC-13 RPC Confirmed and Detected at EOC-12}\\ \text{+ EOC-12 RPC Confirmed and Plugged at EOC-12}\end{array}}{\begin{array}{c}\text{Numerator + New EOC-13 RPC Confirmed}\\ \text{Indications (i.e., not detected at EOC-12)}\end{array}}$$

POPCD is evaluated at the 1994 EOC-12 voltage values (from 1995 reevaluation for growth rate) since it is an EOC-12 POPCD assessment. The indications at EOC-12 that were RPC confirmed and plugged are included as it can be expected that these indications would also have been detected and confirmed at EOC-13. It is also appropriate to include the plugged tubes for APC applications since POD adjustments to define the BOC distribution are applied prior to reduction of the EOC indication distribution for plugged tubes.

It should be noted that the above POPCD definition includes all new EOC-13 indications not reported in the EOC-12 inspection. The new indications include EOC-12 indications present at detectable levels but not reported, indications present at EOC-12 below detectable levels and indications that initiated during Cycle 13. Thus, this definition, by including newly initiated indications, differs from the traditional POD definition. Since the newly initiated indications are appropriate for APC applications, POPCD is an acceptable definition and eliminates the need to adjust the traditional POD for new indications.

The above definition for POPCD would be entirely appropriate if all EOC-13 indications were RPC inspected. Since only a small fraction of bobbin indications < 2.0 volts were RPC inspected, POPCD could be distorted by using only a few indications in this voltage range. In this case, a more appropriate POPCD estimate can be made by assuming that all bobbin indications not RPC inspected would have been RPC confirmed. This definition is applied only for the 1995 EOC-13 indications not RPC inspected since inclusion for the EOC-12 inspection could increase POPCD by including indications on a tube plugged for non-ODSCC causes. This POPCD can be obtained by replacing the EOC-13 RPC confirmed by RPC confirmed plus not RPC inspected in the above definition of POPCD. Inclusion of the indications not RPC inspected in POPCD primarily influences detectability below two volts since indications > 2.0 volts which are not plugged for other causes are RPC inspected at Farley-1. For this report, both POPCD definitions are evaluated for Farley-1.

The POPCD evaluation for the 1994 EOC-12 inspection data is shown on Figure 4-7 and summarized in Table 4-6. Figure 4-7 shows POPCD evaluated for RPC confirmed plus not RPC inspected indications and the EPRI POD developed by analyses of field indications for 3/4 inch diameter tubing in Model D SGs. There is insufficient data to reliably predict a POD based on RPC confirmed indications only and POPCD based on RPC confirmed plus not RPC inspected is a more appropriate POD assessment. It is evident that the Farley-1 POPCD is slightly below the EPRI POD. It is likely that a more conservative bobbin call criteria was used in the EOC-13 inspection, resulting in more low voltage indications being reported as new indications. Of the 911 new indications found, 664 indications (in 1995 bobbin voltage, 755 in 1994 bobbin voltage) were less than or equal to one volt in amplitude. But for one missed indication (2.4 volts) in the 2 to 3 volt range, POPCD would be 1.0 above 2 volts (based on 12 indications).

In summary, the Farley-1 EOC-12 POPCD strongly supports a voltage dependent POD substantially higher than the NRC POD = 0.6 above about 0.6 volt and approaching unity at about 3 volts. The Farley-1 POPCD is slightly less than the EPRI proposed POD. It is concluded that the POD applied for IPC leak and burst projections needs to be upgraded from the POD = 0.6 to a voltage dependent POD.

4.4 ASSESSMENT OF RPC CONFIRMATION RATES

This section tracks the 1994 EOC-12 indications left in service at BOC-13 relative to RPC inspection results in 1995 at EOC-13. The composite results for all SGs are given in Table 4-7. For 1994 bobbin indications left in service, the indications are tracked relative to 1994 RPC confirmed, 1994 RPC NDD, 1994 bobbin indications not RPC inspected and 1994 bobbin indications with no indication found in 1995. Also included are new 1995 indications. The table shows, for each category of indications, the number of indications RPC inspected and RPC confirmed in 1995 as well as the percentage of RPC confirmed indications.

Of the 268 RPC NDD indications left in service at BOC-13, 84 were RPC tested during the EOC-13 inspection and 37 were confirmed. This RPC confirmation rate for prior RPC NDD indications (44%) is higher than that typically found for other plants during recent inspections. The Farley-1 RPC confirmation rate for prior RPC NDD indications evaluated at the latest EOC-12 inspection was 11%. It has been recommended by industry that the largest RPC NDD confirmation rates over the prior two cycles be used for projections. Consequently, it is recommended that future Farley-1 APC applications include only about 45% of the RPC NDD indications in the BOC voltage distribution used for EOC projections and leak/burst analyses.

4.5 NDE UNCERTAINTIES

The NDE uncertainties applied for the Cycle 14 voltage projections in this report are documented in References 10.2 and 10.3. The probe wear uncertainty has a standard deviation of 7.0% about a mean of zero and has a cutoff at 15% based on implementation of the probe wear standard. The analyst variability uncertainty has a standard deviation of 10.3% about a mean of zero with no cutoff. These NDE uncertainty distributions are included in the Monte Carlo analyses used to predict the EOC-14 voltage distributions.

Table 4 - 1
Farley Unit 1 1995 EOC-13
Summary of Inspection and Repair For Tubes in Service During Cycle 13

Voltage Bin	Steam Generator A					Steam Generator B				
	Field Bobbin Indications	RPC Inspected	RPC Confirmed	Indications Repaired	Returned to Service	Field Bobbin Indications	RPC Inspected	RPC Confirmed	Indications Repaired	Returned to Service
0.3	1	0	0	0	1	3	0	0	0	3
0.4	16	1	1	0	16	24	1	1	0	24
0.5	49	0	0	2	47	60	1	0	2	58
0.6	70	2	2	4	66	88	1	1	1	87
0.7	91	1	1	7	84	116	0	0	4	112
0.8	92	0	0	1	91	103	0	0	2	101
0.9	79	0	0	2	77	78	0	0	0	78
1	80	1	1	4	76	90	0	0	4	86
1.1	78	0	0	3	75	64	0	0	1	63
1.2	57	0	0	5	52	60	1	1	2	58
1.3	43	0	0	2	41	45	0	0	2	43
1.4	32	0	0	1	31	19	2	2	1	18
1.5	26	1	1	3	23	13	0	0	1	12
1.6	26	0	0	2	24	11	0	0	0	11
1.7	12	0	0	0	12	8	0	0	1	7
1.8	16	0	0	0	16	6	0	0	1	5
1.9	9	0	0	2	7	4	0	0	0	4
2	3	0	0	1	2	3	0	0	0	3
2.1	4	4	3	3	1	0	0	0	0	0
2.2	4	4	3	3	1	2	2	2	2	0
2.3	2	2	2	2	0	2	2	1	1	1
2.4	2	2	1	1	1	1	1	0	0	1
2.5	1	1	0	0	1	0	0	0	0	0
2.6	2	2	2	2	0	1	1	1	1	0
2.7	1	1	1	1	0	0	0	0	0	0
2.8	0	0	0	0	0	0	0	0	0	0
2.9	0	0	0	0	0	0	0	0	0	0
3.6	0	0	0	0	0	0	0	0	0	0
4.1	0	0	0	0	0	1	1	1	1	0
5.6	0	0	0	0	0	0	0	0	0	0
7.1	0	0	0	0	0	0	0	0	0	0
Total	796	22	18	51	745	802	13	10	27	775
> 1V	318	17	13	31	287	240	10	8	14	226
> 2V	16	16	12	12	4	7	7	5	5	2

Voltage Bin	Steam Generator C					Composite of All Three Steam Generators				
	Field Bobbin Indications	RPC Inspected	RPC Confirmed	Indications Repaired	Returned to Service	Field Bobbin Indications	RPC Inspected	RPC Confirmed	Indications Repaired	Returned to Service
0.3	1	0	0	0	1	5	0	0	0	5
0.4	6	0	0	0	6	46	2	2	0	46
0.5	38	0	0	4	34	147	1	0	8	139
0.6	64	0	0	4	60	222	3	3	9	213
0.7	85	0	0	2	83	292	1	1	13	279
0.8	101	1	0	13	88	296	1	0	16	280
0.9	108	0	0	5	103	265	0	0	7	258
1	78	0	0	3	75	248	1	1	11	237
1.1	110	1	1	4	106	252	1	1	8	244
1.2	93	1	1	5	88	210	2	2	12	198
1.3	63	0	0	2	61	151	0	0	6	145
1.4	57	0	0	3	54	108	2	2	5	103
1.5	41	1	0	8	33	80	2	1	12	68
1.6	40	40	23	4	36	77	40	23	6	71
1.7	25	25	14	0	25	45	25	14	1	44
1.8	20	20	9	2	18	42	20	9	3	39
1.9	10	10	4	0	10	23	10	4	2	21
2	12	12	7	0	12	18	12	7	1	17
2.1	2	2	2	2	0	6	6	5	5	1
2.2	3	3	2	2	1	9	9	7	7	2
2.3	5	5	3	4	1	9	9	6	7	2
2.4	3	3	3	3	0	6	6	4	4	2
2.5	0	0	0	0	0	1	1	0	0	1
2.6	1	1	1	1	0	4	4	4	4	0
2.7	1	1	0	0	1	2	2	1	1	1
2.8	2	2	2	2	0	2	2	2	2	0
2.9	1	1	1	1	0	1	1	1	1	0
3.6	1	1	1	1	0	1	1	1	1	0
4.1	0	0	0	0	0	1	1	1	1	0
5.6	1	1	1	1	0	1	1	1	1	0
7.1	1	1	1	1	0	1	1	1	1	0
Total	973	132	76	77	896	2571	167	104	155	2416
> 1V	492	131	76	46	446	1050	158	97	91	959
> 2V	21	21	17	18	3	44	44	34	35	9

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Table 4 - 2
Farley Unit 1 1995 Outage
TSP ODSCC Indication Distributions for Tubes in Service During Cycle 13

Tube Support Plate	Steam Generator A				Steam Generator B			
	Number of Indications	Maximum Voltage	Average Voltage	Average Growth	Number of Indications	Maximum Voltage	Average Voltage	Average Growth
1H	184	2.66	0.97	0.126	132	4.09	0.88	0.144
2H	117	2.03	0.93	0.063	171	1.83	0.82	0.074
3H	153	2.31	0.93	0.048	188	2.35	0.88	0.030
4H	182	2.22	0.98	0.092	179	2.25	0.91	0.025
5H	85	1.96	0.99	0.091	75	2.12	0.92	0.013
6H	47	2.46	1.12	0.203	35	1.59	0.94	0.064
7H	8	1.54	1.06	0.225	10	1.16	0.70	0.058
1C	2	0.76	0.55	-0.060	2	0.75	0.70	0.125
2C	1	0.87	0.87	0.000	0	-	-	-
3C	0	-	-	-	2	0.65	0.65	0.200
4C	6	1.03	0.87	0.045	1	0.39	0.39	-0.040
5C	8	1.12	0.87	0.095	4	0.73	0.53	-0.020
6C	2	0.56	0.55	-0.005	0	-	-	-
7C	1	1.12	1.12	0.310	3	1.18	0.93	0.033
Total	796				802			

Tube Support Plate	Steam Generator C				Composite of All Three SGs			
	Number of Indications	Maximum Voltage	Average Voltage	Average Growth	Number of Indications	Maximum Voltage	Average Voltage	Average Growth
1H	111	2.8	0.92	0.108	427	4.09	0.93	0.127
2H	241	7.04	1.12	0.125	529	7.04	0.98	0.095
3H	236	2.88	1.07	0.067	577	2.88	0.97	0.050
4H	224	2.55	1.08	0.089	585	2.55	1.00	0.070
5H	104	2.7	1.05	0.105	264	2.7	0.99	0.074
6H	45	3.57	1.04	0.169	127	3.57	1.04	0.153
7H	8	1.54	0.94	0.093	26	1.54	0.88	0.120
1C	0	-	-	-	4	0.76	0.62	0.033
2C	1	0.5	0.50	0.120	2	0.87	0.69	0.060
3C	0	-	-	-	2	0.65	0.65	0.200
4C	0	-	-	-	7	1.03	0.80	0.033
5C	0	-	-	-	12	1.12	0.76	0.057
6C	2	0.82	0.77	0.100	4	0.82	0.66	0.048
7C	1	0.46	0.46	0.050	5	1.18	0.88	0.092
Total	973				2571			

Table 4 - 3
Farley Unit1 1995 Outage
Average Voltage Growth History
Composite of All Steam Generator Data

Bobbin Voltage Range	Number of Indications	Average Voltage BOC	Average Voltage Growth	Average Percentage Growth	
				Per Cycle	Per EFPY
	Cycle 13 (1994 - 1995) - 489.4 EFPD				
Entire Voltage Range	2571	0.89	0.085	10%	7%
V_{BOC} < .75	1024	0.56	0.101	18%	14%
≥ .75	1547	1.10	0.074	7%	5%
	Cycle 12 (1992 - 1994) - 442 EFPD				
Entire Voltage Range	1681	0.98	-0.01	~0 %	~0 %
V_{BOC} < .75	466	0.60	0.04	7 %	6%
≥ .75	1215	1.13	-0.03	~0 %	~0 %
	Cycle 11 (1991 - 1992) - 471 EFPD				
Entire Voltage Range	1267	0.85	0.22	26%	20%
V_{BOC} < .75	546	0.57	0.21	37%	29%
≥ .75	721	1.08	0.23	21%	17%
	Cycle 10 (1989 - 1991)				
Entire Voltage Range	499	0.70	0.23	33%	N/A
V_{BOC} < .75	306	0.51	0.24	8%	N/A
≥ .75	193	1.01	0.08	8%	N/A
	Cycle 9 (1988 - 1989)				
Entire Voltage Range	431	0.62	0.22	35%	N/A
	Cycle 8 (1986 - 1988)				
Entire Voltage Range	274	0.48	0.28	58%	N/A
	Cycle 7 (1985 - 1986)				
Entire Voltage Range	123	0.45	0.20	44%	N/A

Table 4 - 4
Farley Unit - 1 1995 Outage
Average Voltage Growth During Cycle 13

	Number of Indications	Average Voltage BOC	Average Growth		Percent Growth	
			Entire Cycle	Per EFPY	Entire Cycle	Per EFPY
	Composite of All Steam Generator Data					
Entire Voltage Range	2571	0.89	0.085	0.063	9.6	7.1
$V_{BOC} < .75$	1024	0.56	0.101	0.075	17.9	13.4
$\geq .75$	1547	1.10	0.074	0.056	6.7	5.0
	Steam Generator A					
Entire Voltage Range	796	0.87	0.094	0.070	10.7	8.0
$V_{BOC} < .75$	326	0.56	0.116	0.087	20.7	15.5
$\geq .75$	470	1.09	0.078	0.059	7.2	5.4
	Steam Generator B					
Entire Voltage Range	802	0.82	0.058	0.043	7.1	5.3
$V_{BOC} < .75$	392	0.55	0.095	0.071	17.4	13.0
$\geq .75$	410	1.07	0.022	0.017	2.1	1.6
	Steam Generator C					
Entire Voltage Range	973	0.96	0.100	0.075	10.4	7.8
$V_{BOC} < .75$	306	0.59	0.093	0.069	15.7	11.7
$\geq .75$	667	1.13	0.104	0.077	9.2	6.8

[#] Based on Cycle 13 duration of 489.4 EFPD.

Table 4 - 5
Farley Unit 1
Signal Growth Statistics For Cycle 13 on an EFPY Basis

Delta Volts	Steam Generator A		Steam Generator B		Steam Generator C		Cumulative	
	1994 to 1995		1994 to 1995		1994 to 1995		1994 to 1995	
	No. of Obs	CPDF	No. of Obs	CPDF	No. of Obs	CPDF	No. of Obs	CPDF
-0.4	0	0	1	0.0012	1	0.0010	2	0.0008
-0.3	3	0.0038	6	0.0087	3	0.0041	12	0.0054
-0.2	16	0.0239	18	0.0312	5	0.0092	39	0.0206
-0.1	66	0.1068	61	0.1072	48	0.0586	175	0.0887
0	183	0.3367	224	0.3865	181	0.2446	588	0.3174
0.1	263	0.6671	295	0.7544	440	0.6968	998	0.7056
0.2	136	0.8379	132	0.9190	204	0.9065	472	0.8891
0.3	85	0.9447	42	0.9713	64	0.9723	191	0.9634
0.4	20	0.9698	15	0.9900	14	0.9866	49	0.9825
0.5	13	0.9862	3	0.9938	6	0.9928	22	0.9911
0.6	7	0.9950	2	0.9963	1	0.9938	10	0.9949
0.7	2	0.9975	0	0.9963	2	0.9959	4	0.9965
0.8	1	0.9987	0	0.9963	0	0.9959	1	0.9969
1.1	1	1	2	0.9988	0	0.9959	3	0.9981
1.4			0	0.9988	1	0.9969	1	0.9984
1.6			0	0.9988	1	0.9979	1	0.9988
2			1	1	0	0.9979	1	0.9992
2.3					1	0.9990	1	0.9996
3.9					1	1	1	1
Total	796		802		973		2571	

Table 4 - 6
Farley Unit - 1
1995 EOC-13 Evaluation for Probability of Prior Cycle Detection (EOC-12)
Composite of All Steam Generator Data

Voltage Bin	New Indications		1995 Bobbin, Field Call in 1994		1994 Bobbin	POPCD			
	1995 RPC Confirmed	1995 RPC Confirmed plus not Inspected	1995 RPC Confirmed	1995 RPC Confirmed plus not Inspected	1994 Confirmed and Plugged	RPC Confirmed		RPC Confirmed Plus Not Inspected	
						Frac.	Count	Frac.	Count
> 0 - 0.2	1	3	0	0	0	0	0 / 1	0.000	0 / 3
0.2 - 0.4	2	115	0	27	0	0	0 / 2	0.190	27 / 142
0.4 - 0.6	2	258	0	233	0	0	0 / 2	0.475	233 / 491
0.6 - 0.8	3	231	0	424	0	0	0 / 3	0.647	424 / 655
0.8 - 1.0	2	146	2	369	0	0.500	2 / 4	0.717	369 / 515
1.0 - 1.2	3	77	7	292	0	0.700	7 / 10	0.791	292 / 369
1.2 - 1.4	5	42	10	136	0	0.667	10 / 15	0.764	136 / 178
1.4 - 1.6	5	13	28	79	0	0.848	28 / 33	0.859	79 / 92
1.6 - 1.8	2	8	14	33	0	0.875	14 / 16	0.805	33 / 41
1.8 - 2.0	2	4	7	9	1	0.800	8 / 10	0.714	10 / 14
2.0 - 3	1	1	8	8	3	0.917	11 / 12	0.917	11 / 12
TOTAL	28	898	76	1610	4				
Total > 1	18	145	74	557	4				

Figure 4 - 1
Farley Unit -1 1995 Outage
Bobbin Voltage Distributions for Tubes in Service During Cycle 13

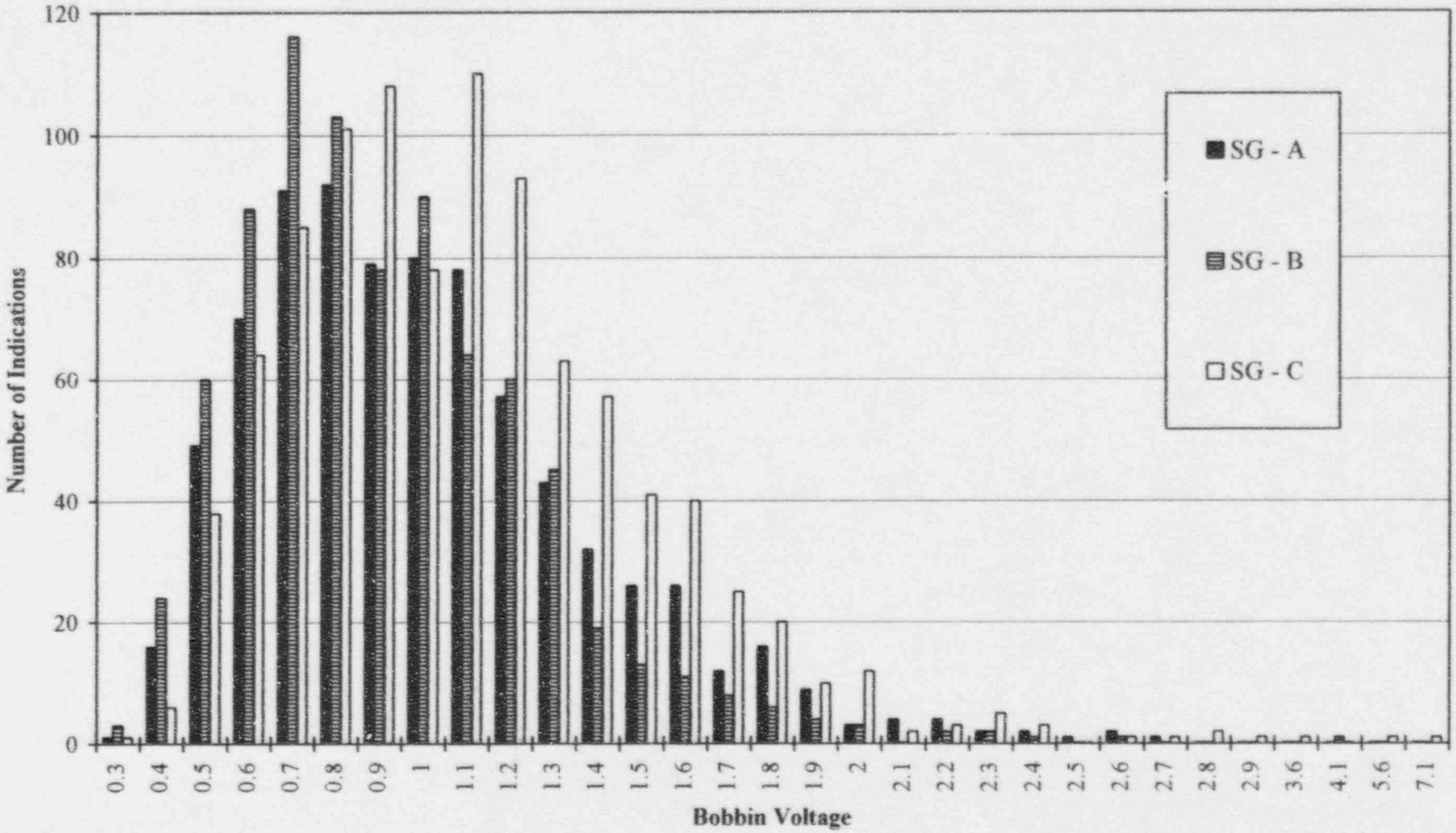

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Figure 4 - 2
Farley Unit -1 1995 Outage
Bobbin Voltage Distribution for Tubes Plugged After Cycle 13 Service

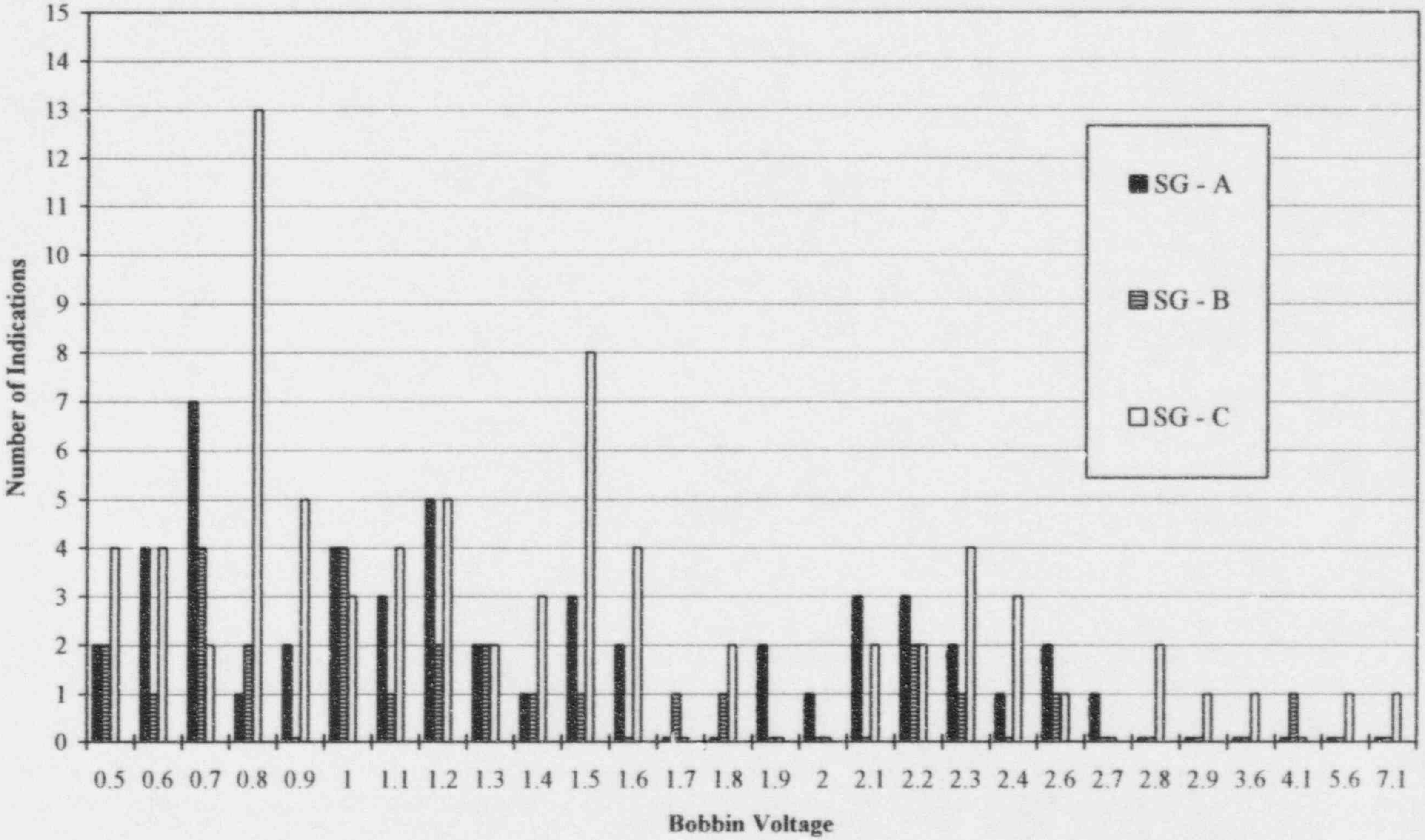

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Figure 4 - 3
Farley Unit -1 1995 Outage
Bobbin Voltage Distributions for TubesReturned to Service for Cycle 14

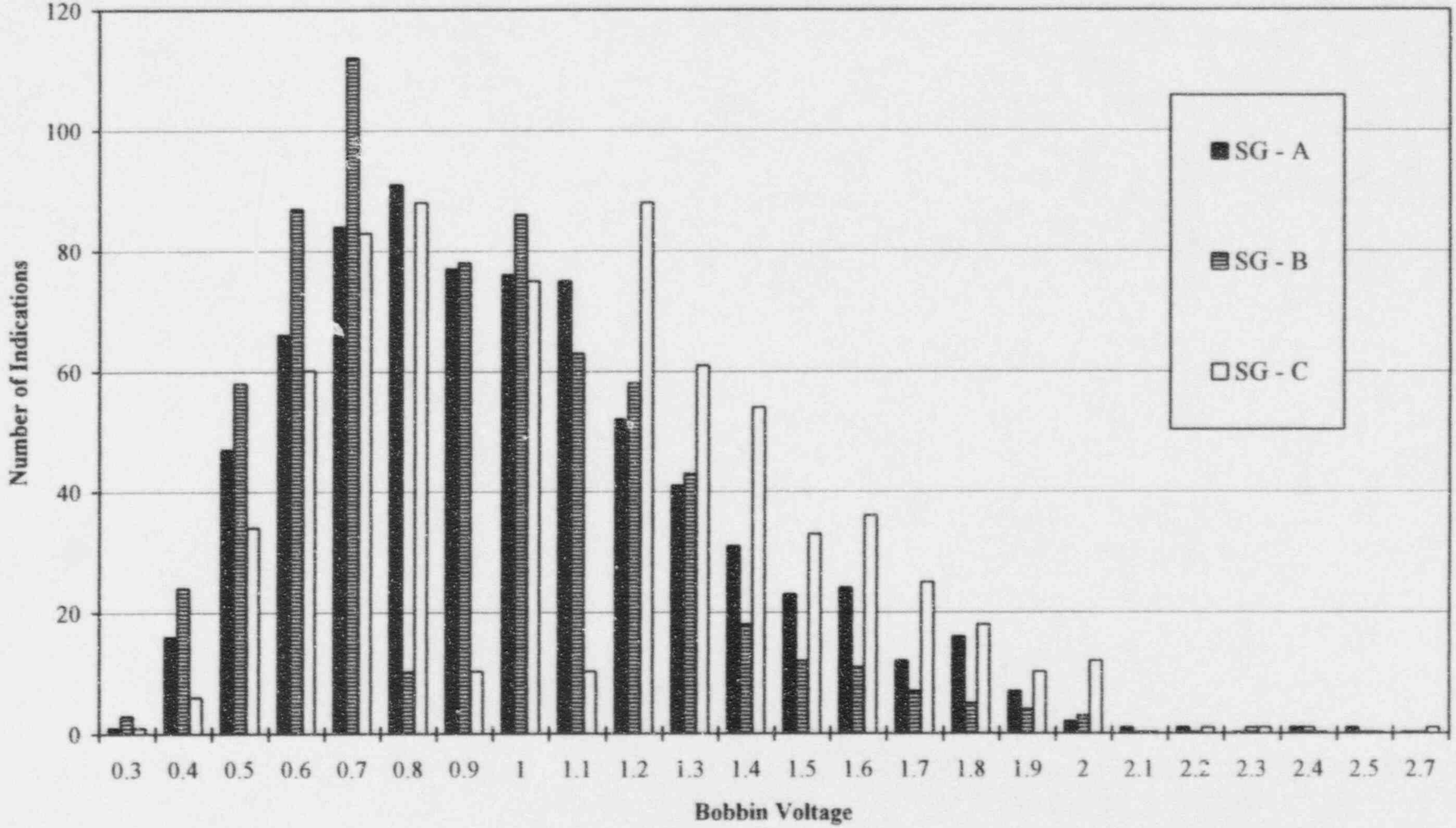

Figure 4 - 4
Farley Unit 1 1995 Outage
ODSCC Axial Distributions for Tubes in Service During Cycle 13

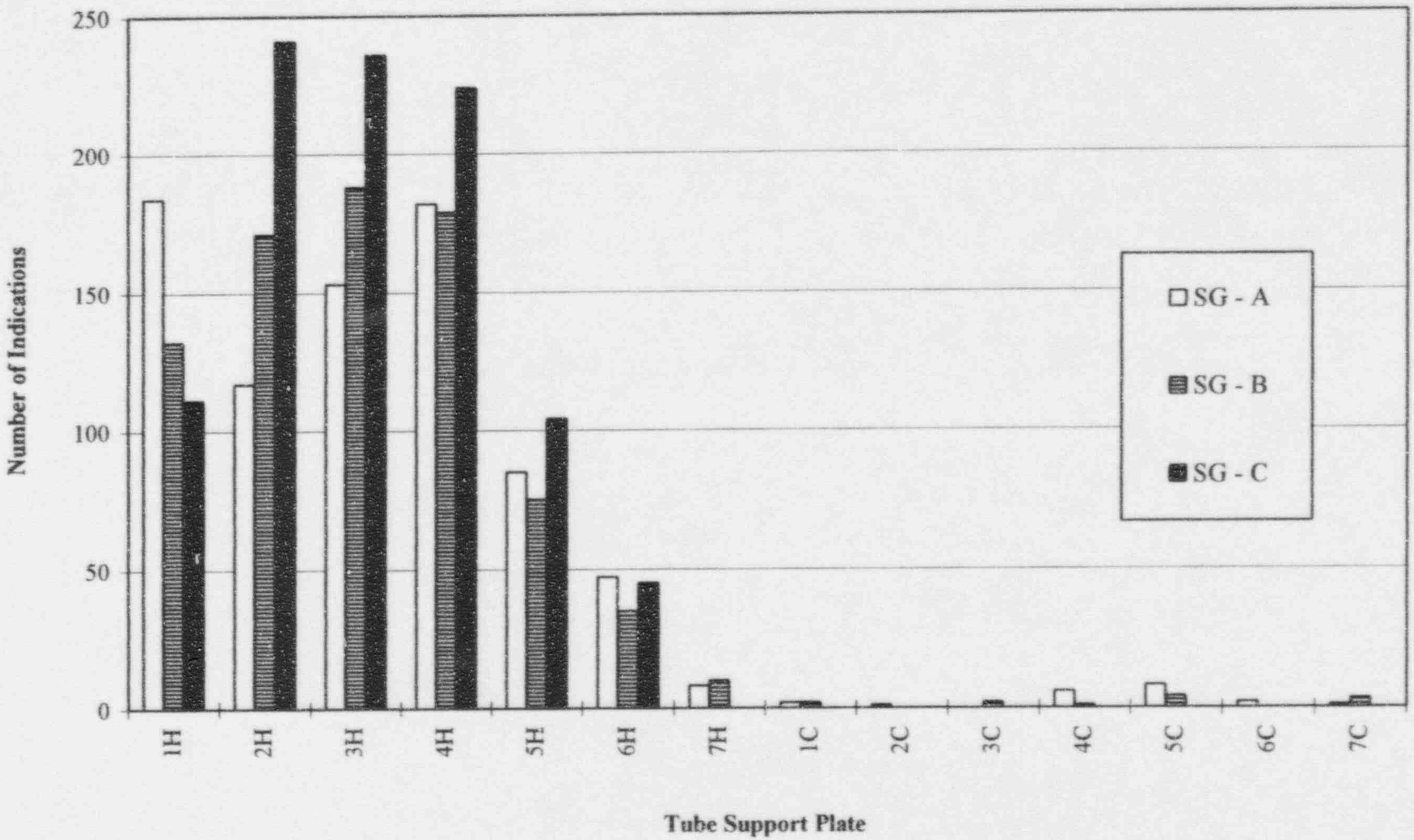

Figure 4 - 5
Farley Unit - 1 Growth History
Cumulative Probability Distributions for Voltage Growth on an EFPY Basis
Composite of All Four Steam Generators

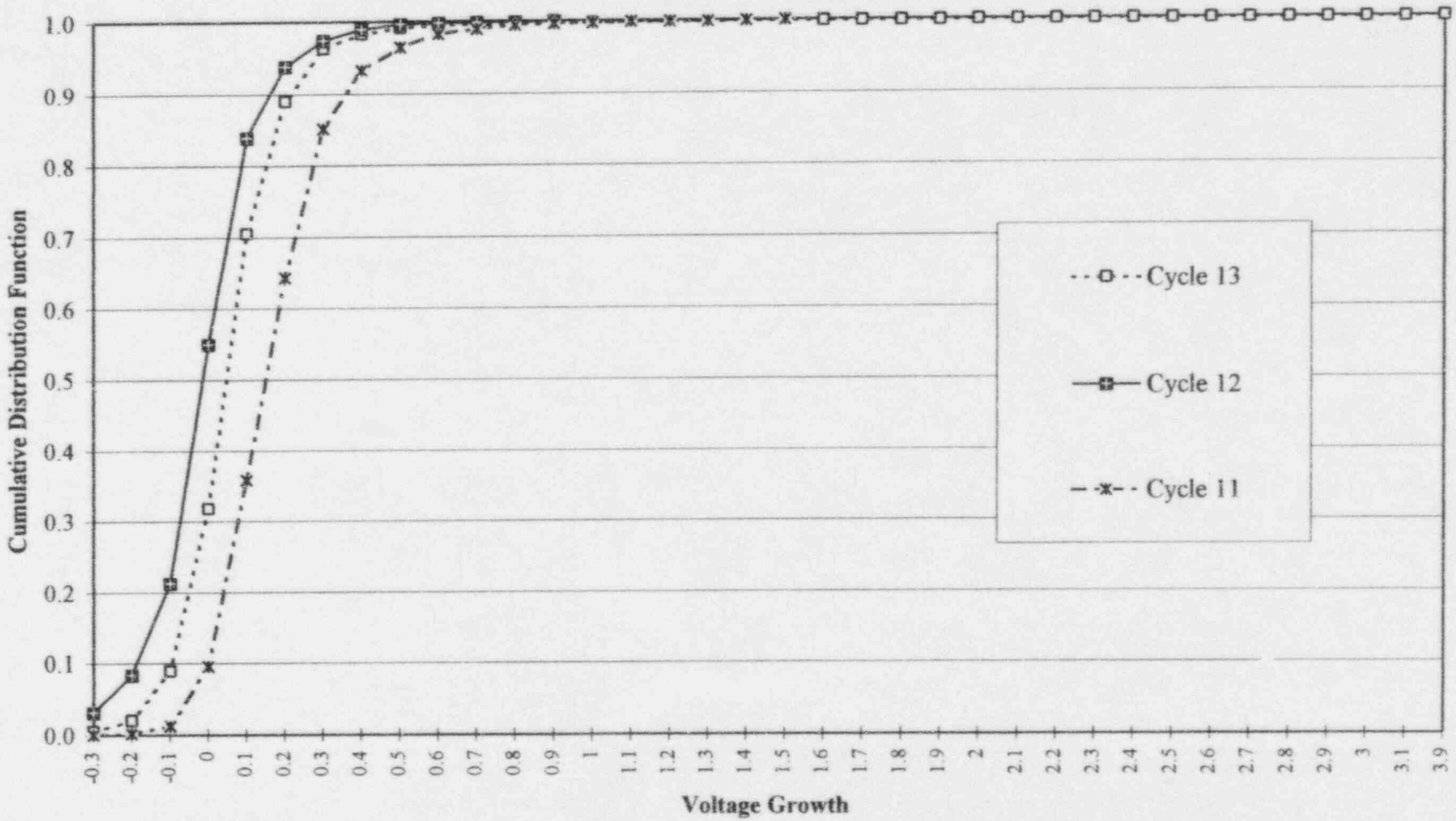

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Figure 4 - 6

Farley Unit -1 Cycle 13 (1994 to 1995)

Cumulative Probability Distributions for Voltage Growth on an EFPY Basis

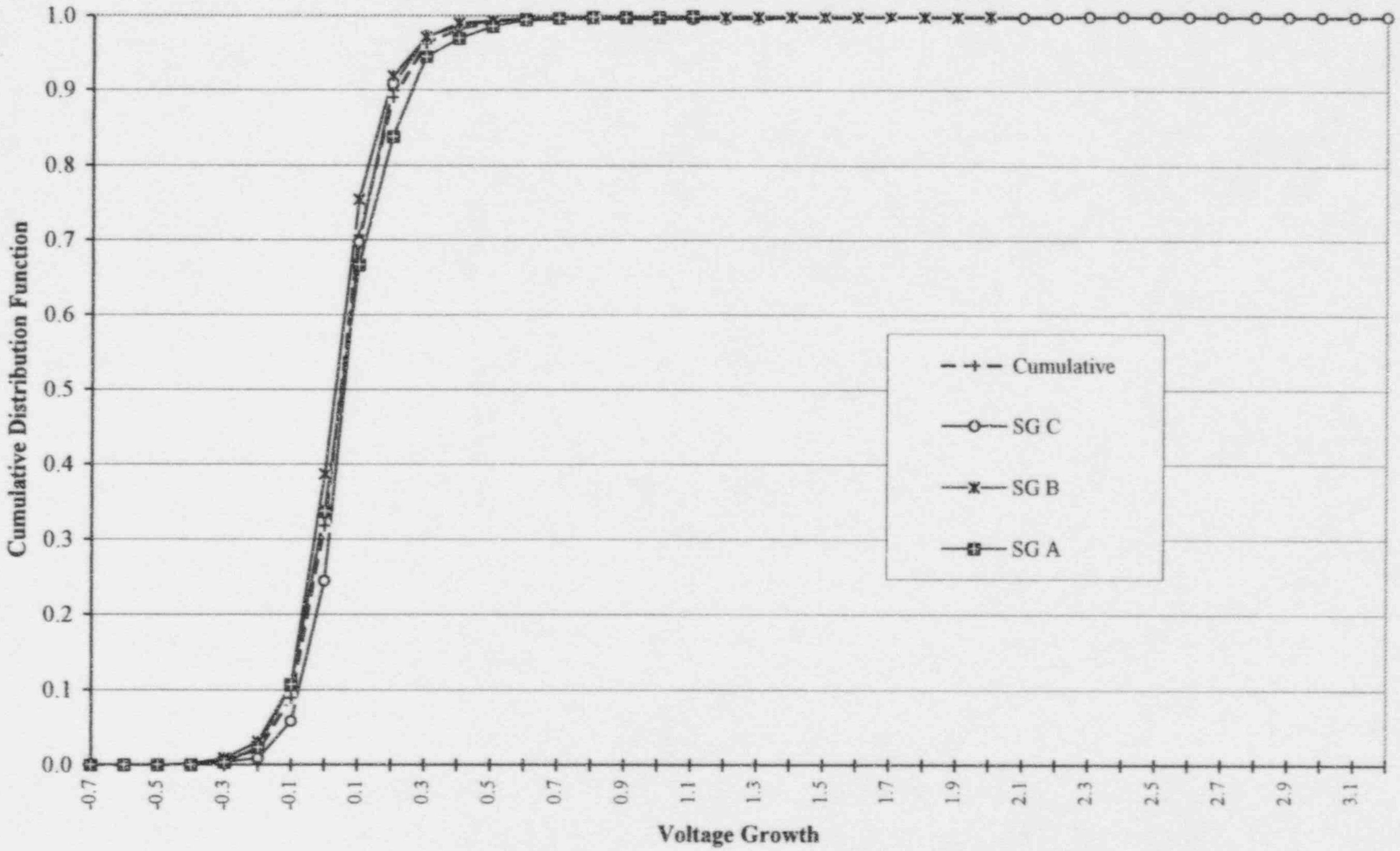

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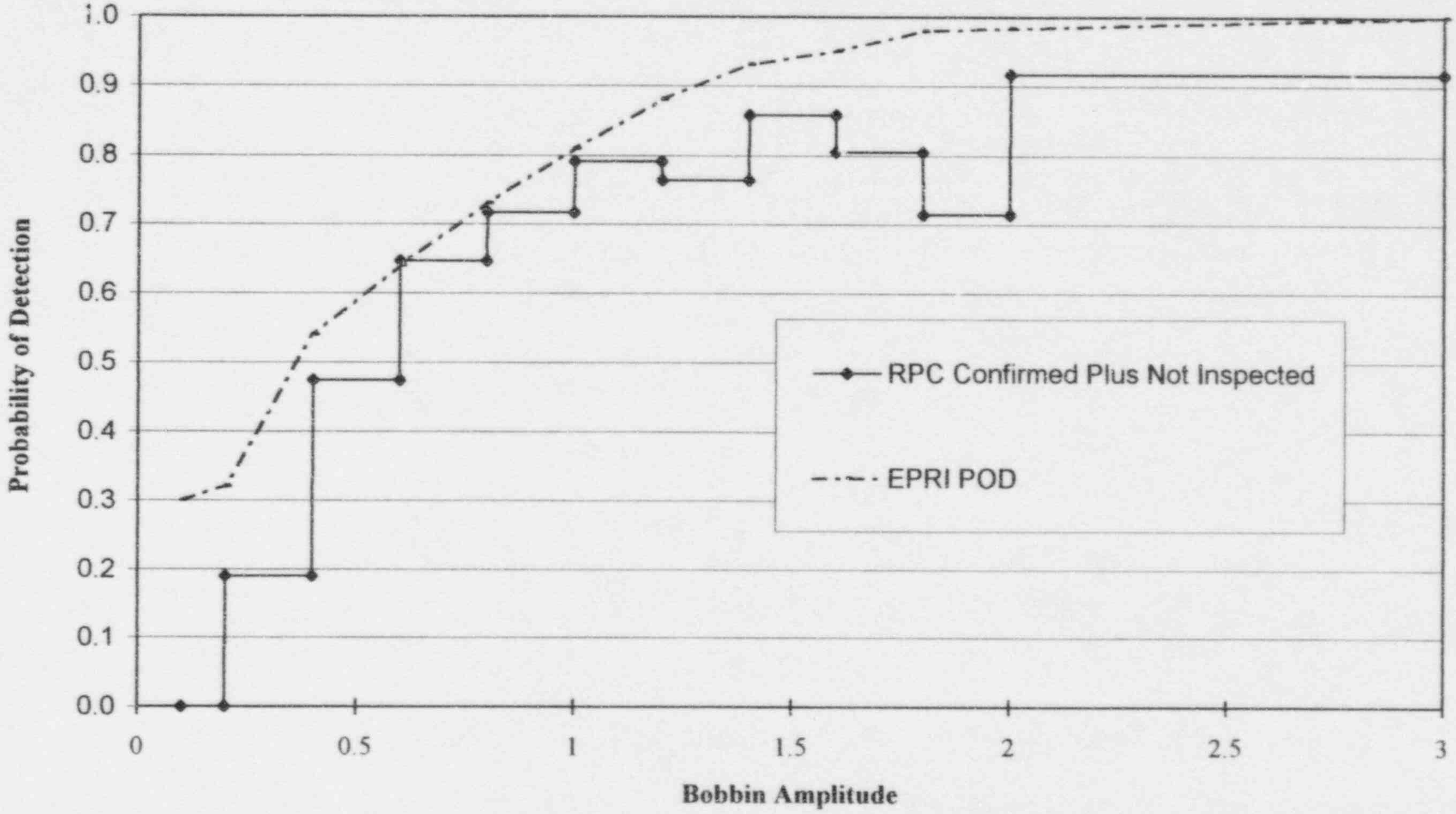
Figure 4 - 7
Farley Unit - 1
1995 EOC-13 Evaluation for POPCD at EOC-12



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5.0 DATA BASE APPLIED FOR IPC CORRELATIONS

The database used for the IPC correlations that are applied in the analyses of this report are consistent with the NRC SER applicable to the Farley-1 EOC-13 inspection (documented in Reference 10.3). The SER recommended data for the burst pressure correlation is the same as the EPRI recommended database described in Reference 10.2 and Reference 10.5, and is applied in the analyses of this report.

For the SLB leak rate correlation, the NRC recommends that Model Boiler specimen 542-4 and Plant J-1 pulled tube R8C74, TSP1 be included in the database. This database is referred to as the NRC database in Reference 10.5 and is applied for the leak rate analyses of this report. The probability of leakage correlation of Reference 10.5 is also accepted by the NRC SER and applied in this report. The SLB leak rate do not satisfy the NRC guidelines for a voltage dependent correlation and, consistent with GL-95-05, the leak rate correlation is developed independent of voltage, as discussed in Section 6.

Based on prior NRC requests for updating the EPRI database, the correlations have been updated to include 1995 pulled tube results from Beaver Valley-1 and Farley-2. This update resulted in very minor changes in the burst pressure and probability of leak correlations.

6.0 SLB ANALYSIS METHODS

Monte Carlo analyses are used to predict the EOC-14 voltage distributions and to calculate the SLB leak rates and tube burst probabilities for both the actual EOC-13 voltage distribution and the predicted EOC-14 voltage distribution. These methods are consistent with the requirements of the Farley-1 NRC SER and are described in the generic methods report of WCAP-14277 (Reference 10.2) and the IPC report of WCAP-14123 (Reference 10.5).

Based on the NRC SER recommended leak rate database, the leak rate data do not satisfy the requirement for applying the SLB leak rate versus bobbin voltage correlation. The NRC requirement is that the p value obtained from the regression for the slope parameter be less than or equal to 5%. For the NRC recommended data, the p value is about 6.5% and the leak rate versus voltage correlation is not applied. The SLB leak rate correlation applied is based on an average of all leak rate data independent of voltage. The analysis methods for applying this leak rate model are given in Section 4.6 of WCAP-14277.

A Monte Carlo analysis is applied to account for parameter uncertainties even though the leak rate is independent of voltage. This method of leak rate analysis is similar in concept to that of draft NUREG-1477 except for the uncertainty treatment and the use of mean and standard deviations derived from the log leak rates of the test data. However, it is found that the GL-95-05 and WCAP-14277 methods lead to considerably larger leak rates for Farley-1 than obtained with draft NUREG-1477 methodology (which was used to project the EOC-13 leak rates). Therefore, the SLB leak rate analysis results given in Section 8 are based on updates to the GL-95-05 methods in order to eliminate analysis methodology differences between projected and actual results.

7.0 BOBBIN VOLTAGE DISTRIBUTIONS

7.1 PROBABILITY OF DETECTION (POD)

The number of indications assumed in the analysis to predict tube leak rate and burst probability is obtained by adjusting the number of indications reported, to account for measurement uncertainty and birth of new indications over the projection period. This is accomplished by using a Probability of Detection (POD) factor. The calculation of projected bobbin voltage frequency distribution is based on a net total number of indications returned to service, defined as:

$$N_{Tot\ RTS} = \frac{N_i}{POD} - N_{Repaired} + N_{deplugged},$$

where:

- $N_{Tot\ RTS}$ = Number of bobbin indications returned to service for the next cycle.
- N_i = Number of in-service bobbin indications reported in this inspection.
- POD = Probability of Detection.
- $N_{repaired}$ = Number of N_i which are repaired (plugged) after the last cycle.
- $N_{deplugged}$ = Number of indications which are deplugged after the last cycle and are returned to service.

The NRC generic letter (Reference 10.1 is the draft of GL-95-05) requires the application of a POD = 0.6 to define the BOC distribution for the EOC voltage projections, unless an alternate POD is approved by the NRC.

There were no deplugged indications returned to service for BOC-14.

7.2 CYCLE OPERATING TIME

The operating periods used in the voltage projection calculations are:

Cycle 12 = 442 EFPD. Cycle 13 = 489.435 EFPD. Cycle 14 = 511.35 EFPD

7.3 CALCULATION OF VOLTAGE DISTRIBUTIONS

Bobbin voltage projections start with a cycle initial voltage distribution which is projected to the corresponding cycle final voltage distribution, based on an empirical growth rate adjusted for the anticipated cycle operating time. The overall growth rates of the Farley-1 steam generators during the previous three operating periods, as represented by their cumulative probability distribution functions, are shown on Figure 4-5. The 1994 - 1995 operation (Cycle 13) growth rates exceed those of the 1992 - 1994 (Cycle 12) operation and are used to predict the EOC-14 bobbin voltage distributions. The growth in SG C exceeds that of the other two SGs. To conservatively predict the IPC voltage for EOC-14, the growth projections are based on rates of steam generator C during Cycle 13. The methodology used in the calculation of EOC bobbin voltage distributions is described in References 10.2 and 10.5.

For each SG, the initial bobbin voltage distribution of indications being returned to service for the next cycle (BOC-14) is derived from the actual EOC-13 inspection results adjusted for tubes that are taken out of service by plugging. The Cycle 14 bobbin voltage population, summarized on Table 7-1, shows EOC-13 bobbin voltage indications; the subsequent plugged indications (which were in service for Cycle 13 and then taken out of service); and also shows the BOC-14 indications corresponding to PODs of 0.6, 1.0, and the EPRI lower 95% confidence limit.

7.4 PREDICTED EOC-14 VOLTAGE DISTRIBUTIONS

Calculation of the predicted EOC-14 bobbin voltage distributions is performed for all SGs with three different detection uncertainty factors represented by:

POD = 0.6, in accordance with NRC direction.

POD = EPRI, a voltage based uncertainty developed by EPRI.

POD = 1.0, a nominal value with no uncertainty considered.

Using the methodology previously described, analyses were performed to predict the performance of the Farley-1 steam generators at EOC-14, based on the BOC-14 summarized in Table 7-1 and the Cycle 13, SG C growth distribution summarized in Table 4-5 (in accordance with NRC guidelines, Cycle 13 growth is used since it is the higher of the last two cycles). The EPRI developed voltage dependent POD is based on expert opinion and multiple analysts' evaluations for plants with 3/4" diameter tubes. It is of interest to apply the EPRI POD for sensitivity analysis and for comparison with POD = 0.6 and POD = 1.0. The BOC-14 IPC voltage distributions are summarized on Table 7-1 for POD = 0.6, for the EPRI POD and for POD = 1.0, which is the order of decreasing detection uncertainty. The EOC-14 predicted IPC voltage distributions are summarized on Table 7-2. As anticipated, the limiting steam generator is SG C with 1547 indications predicted for POD = 0.6. For each steam generator, the BOC-14 actual and the EOC-14 predicted bobbin voltage frequency distributions are shown on Figure 7-1, 7-2, and 7-3, respectively, for all three PODs. The maximum bobbin voltage predicted for EOC-14 is 7.6 V for POD = 0.6, in SG C.

7.5 COMPARISON OF PREDICTED AND ACTUAL EOC-13 VOLTAGE DISTRIBUTIONS

The methodology used in the projection of bobbin voltage frequency indications is described in References 10.2 and 10.4. Calculations of the predicted EOC-13 bobbin voltage distributions were performed for SG C, based on the BOC-13 conditions and Cycle 11 growth rates. The actual EOC-13 bobbin voltage distributions and the corresponding predictions, summarized on Table 7-3 and shown on Figure 7-4, provide a comparison of three different detection uncertainty factors represented by:

POD = 0.6, in accordance with the NRC direction of Reference 10.1.

POD = EPRI, a voltage based uncertainty developed by EPRI.

POD = 1.0, a nominal value with no uncertainty considered.

As reported in Reference 10.4, SG C was predicted to be limiting for EOC-13. As shown on Figure 7-4, the POD = 0.6 calculation underpredicted up to 0.7 volt and generally overpredicted above 0.7 volt, except for the three highest outliers (3.6, 5.6, 7.1 volt bins). The New Indication Method (N.I.M.) prediction, which is a predecessor to the POPCD method, did predict outliers, although below the actuals. In summary:

- o The projection based on POD = 0.6 underpredicts for < 0.7 V and overpredicts thereafter, resulting in a conservative forecast of number of indications, but did not predict the three highest bobbin voltage calls.
- o The projection based on POD = 1.0 generally underpredicted the number of indications and the three highest bobbin voltage calls.
- o The projection with the N.I.M. gave the most accurate prediction of the three PODs, but it also did not predict the two largest indications.

TABLE 7-1
Farley Unit 1 1995 Outage
Summary of Inspection and Repair of Tubes

Voltage Bin	STEAM GENERATOR A					STEAM GENERATOR B					STEAM GENERATOR C				
	EOC-13		BOC-14			EOC-13		BOC-14			EOC-13		BOC-14		
	Field Ind.	Plugged	POD = 0.6	POD = EPRI	POD = 1.0	Field Ind.	Plugged	POD = 0.6	POD = EPRI	POD = 1.0	Field Ind.	Plugged	POD = 0.6	POD = EPRI	POD = 1.0
0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.3	1.0	0.0	1.7	2.3	1.0	3.0	0.0	5.0	7.0	3.0	1.0	0.0	1.7	2.3	1.0
0.4	16.0	0.0	26.7	29.6	16.0	24.0	0.0	40.0	44.4	24.0	6.0	0.0	10.0	11.1	6.0
0.5	49.0	2.0	79.7	81.5	47.0	60.0	2.0	98.0	100.3	58.0	38.0	4.0	59.3	60.8	34.0
0.6	70.0	4.0	112.7	106.5	66.0	88.0	1.0	145.7	137.9	87.0	64.0	4.0	102.7	97.1	60.0
0.7	91.0	7.0	144.7	126.8	84.0	116.0	4.0	189.3	166.6	112.0	85.0	2.0	139.7	123.0	83.0
0.8	92.0	1.0	152.3	125.0	91.0	103.0	2.0	169.7	139.1	101.0	101.0	13.0	155.3	125.4	88.0
0.9	79.0	2.0	129.7	99.3	77.0	78.0	0.0	130.0	100.0	78.0	108.0	5.0	175.0	133.5	103.0
1.0	80.0	4.0	129.3	94.5	76.0	90.0	4.0	146.0	106.8	86.0	78.0	3.0	127.0	93.0	75.0
1.1	78.0	3.0	127.0	89.3	75.0	64.0	1.0	105.7	74.7	63.0	110.0	4.0	179.3	126.2	106.0
1.2	57.0	5.0	90.0	60.0	52.0	60.0	2.0	98.0	66.4	58.0	93.0	5.0	150.0	101.0	88.0
1.3	43.0	2.0	69.7	45.3	41.0	45.0	2.0	73.0	47.5	43.0	63.0	2.0	103.0	67.2	61.0
1.4	[illegible]	1.0	52.3	33.6	31.0	19.0	1.0	30.7	19.6	18.0	57.0	3.0	92.0	58.7	54.0
1.5	[illegible]	3.0	40.3	24.7	23.0	13.0	1.0	20.7	12.9	12.0	41.0	8.0	60.3	35.7	33.0
1.6	26.0	2.0	41.3	25.3	24.0	11.0	0.0	18.3	11.6	11.0	40.0	4.0	62.7	38.0	36.0
1.7	12.0	0.0	20.0	12.4	12.0	8.0	1.0	12.3	7.3	7.0	25.0	0.0	41.7	25.9	25.0
1.8	16.0	0.0	26.7	16.3	16.0	6.0	1.0	9.0	5.1	5.0	20.0	2.0	31.3	18.4	18.0
1.9	9.0	2.0	13.0	7.2	7.0	4.0	0.0	6.7	4.1	4.0	10.0	0.0	16.7	10.2	10.0
2.0	3.0	1.0	4.0	2.1	2.0	3.0	0.0	5.0	3.1	3.0	12.0	0.0	20.0	12.2	12.0
2.1	4.0	3.0	3.7	1.1	1.0	0.0	0.0	0.0	0.0	0.0	2.0	2.0	1.3	0.0	0.0
2.2	4.0	3.0	3.7	1.1	1.0	2.0	2.0	1.3	0.0	0.0	3.0	2.0	3.0	1.0	1.0
2.3	2.0	2.0	1.3	0.0	0.0	2.0	1.0	2.3	1.0	1.0	5.0	4.0	4.3	1.1	1.0
2.4	2.0	1.0	2.3	1.0	1.0	1.0	1.0	1.7	1.0	1.0	3.0	3.0	2.0	0.0	0.0
2.5	1.0	0.0	1.7	1.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2.6	2.0	2.0	1.3	0.0	0.0	1.0	1.0	0.7	0.0	0.0	1.0	1.0	0.7	0.0	0.0
2.7	1.0	1.0	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	1.7	1.0	1.0
2.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	2.0	1.3	0.0	0.0
2.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	1.0	0.7	0.0	0.0
3.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	1.0	0.7	0.0	0.0
4.1	0.0	0.0	0.0	0.0	0.0	1.0	1.0	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	1.0	0.7	0.0	0.0
7.1	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.7	0.0	0.0	1.0	1.0	0.7	0.0	0.0
TOTAL	796	51	1276	986	745	802	29	1310	1056	775	973	77	1545	1143	896
>1V	318	31	372	320	287	240	16	387	254	226	492	46	774	497	446

TABLE 7-2
Farley Unit 1 1995 Outage
Summary of Predicted Bobbin Voltage Distributions for EOC-14

Voltage Bin	STEAM GENERATOR A			STEAM GENERATOR B			STEAM GENERATOR C		
	POD=0.6	POD=EPRI	POD=1.0	POD=0.6	POD=EPRI	POD=1.0	POD=0.6	POD=EPRI	POD=1.0
0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.2	0.1	0.1	0.0	0.1	0.2	0.1	0.1	0.1	0.0
0.3	1.8	2.1	1.1	3.5	4.4	2.1	1.0	1.3	0.6
0.4	14.1	15.4	8.4	20.6	22.8	12.3	7.5	8.2	4.4
0.5	41.7	42.7	24.6	54.6	56.2	32.5	29.8	30.1	17.2
0.6	74.8	72.3	43.9	96.3	93.4	57.3	62.6	59.9	36.5
0.7	104.9	95.6	61.5	132.4	121.4	78.7	96.7	87.2	56.5
0.8	124.1	107.3	73.1	149.2	129.9	88.6	124.3	105.9	72.4
0.9	130.8	107.3	77.3	149.0	123.4	88.6	141.0	114.0	82.3
1.0	129.1	100.8	76.3	140.0	110.5	83.3	148.4	114.3	86.8
1.1	120.9	90.3	71.3	125.8	95.0	74.7	149.1	110.0	87.5
1.2	107.3	77.2	63.1	107.9	78.4	64.0	142.1	101.2	83.6
1.3	90.8	63.2	53.3	87.5	61.7	51.8	127.9	88.3	75.2
1.4	74.5	50.4	43.6	67.1	46.2	39.7	110.0	73.8	64.4
1.5	60.0	39.6	35.1	49.1	33.1	29.0	91.5	59.8	53.3
1.6	47.9	30.9	28.0	35.1	23.1	20.6	74.3	47.5	43.2
1.7	37.9	24.0	22.1	24.8	16.0	14.5	59.2	37.2	34.3
1.8	29.4	18.3	17.1	17.5	11.1	10.2	46.2	28.6	26.7
1.9	22.4	13.6	12.9	12.5	7.8	7.2	35.1	21.5	20.3
2.0	16.6	9.8	9.3	8.9	5.4	5.1	26.1	15.7	15.0
2.1	12.0	6.9	6.5	6.3	3.8	3.6	18.9	11.1	10.7
2.2	8.5	4.7	4.5	4.5	2.6	2.5	13.3	7.6	7.4
2.3	6.1	3.1	3.0	3.2	1.8	1.7	9.3	5.1	4.9
2.4	4.3	2.1	2.0	2.3	1.3	1.2	6.4	3.3	3.2
2.5	3.1	1.4	1.4	1.7	0.9	0.9	4.5	2.2	2.1
2.6	2.3	1.0	0.9	1.3	0.7	0.6	3.2	1.4	1.4
2.7	1.7	0.7	0.7	1.0	0.5	0.5	2.3	1.0	0.9
2.8	1.3	0.6	0.5	0.8	0.4	0.4	1.8	0.7	0.7
2.9	1.0	0.4	0.4	0.6	0.4	0.3	1.4	0.5	0.5
3.0	0.8	0.3	0.3	0.5	0.3	0.2	1.1	0.4	0.4
3.1	0.6	0.3	0.2	0.4	0.2	0.2	0.9	0.3	0.3
3.2	0.5	0.2	0.2	0.3	0.2	0.2	0.7	0.3	0.3
3.3	0.4	0.2	0.2	0.3	0.2	0.1	0.6	0.3	0.2
3.4	0.3	0.2	0.1	0.2	0.2	0.1	0.5	0.2	0.2
3.5	0.2	0.1	0.1	0.2	0.1	0.1	0.4	0.2	0.2
3.6	0.2	0.1	0.1	0.2	0.1	0.1	0.4	0.2	0.1
3.7	0.2	0.1	0.1	0.2	0.1	0.1	0.3	0.2	0.1
3.8	0.2	0.1	0.1	0.2	0.1	0.1	0.3	0.1	0.1
3.9	0.1	0.1	0.1	0.2	0.1	0.1	0.3	0.1	0.1
4.0	0.1	0.1	0.1	0.2	0.1	0.1	0.2	0.1	0.1
4.1	0.1	0.1	0.1	0.2	0.1	0.1	0.2	0.1	0.1
4.2	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.1	0.1
4.3	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.1	0.1
4.4	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
4.5	0.1	0.1	0.1	0.1	0.1	0.0	0.1	0.1	0.1
4.6	0.1	0.1	0.0	0.1	0.1	0.0	0.1	0.1	0.1
4.7	0.1	0.1	0.0	0.1	0.1	0.0	0.1	0.1	0.1
4.8	0.1	0.1	0.0	0.1	0.1	0.0	0.1	0.1	0.1
4.9	0.1	0.1	0.0	0.1	0.1	0.0	0.1	0.1	0.1
5.0	0.1	0.1	0.0	0.1	0.1	0.0	0.1	0.1	0.1
5.1	0.1	0.1	0.0	0.1	0.1	0.0	0.1	0.1	0.1
5.2	0.1	0.1	0.0	0.1	0.1	0.0	0.1	0.1	0.1
5.3	0.1	0.1	0.0	0.1	0.1	0.0	0.1	0.1	0.0
5.4	0.1	0.1	0.0	0.1	0.1	0.0	0.1	0.1	0.0
5.5	0.1	0.1	0.0	0.1	0.1	0.0	0.1	0.1	0.0
5.6	0.1	0.1	0.0	0.1	0.1	0.0	0.3	0.1	0.0
5.7	0.1	0.1	0.0	0.1	0.1	0.0	0.2	0.1	0.0
5.8	0.1	0.1	0.0	0.1	0.1	0.0	0.2	0.1	0.1
5.9	0.1	0.1	0.0	0.1	0.1	0.0	0.2	0.1	0.1
6.0	0.2	0.1	0.0	0.2	0.2	0.0	0.2	0.1	0.1
6.1	0.2	0.0	0.0	0.2	0.0	0.0	0.2	0.2	0.1
6.2	0.2	0.0	0.0	0.1	0.0	0.7	0.2	0.1	0.0
6.3	0.0	0.0	0.7	0.0	0.7	0.0	0.2	0.0	0.0
6.4	0.0	0.7	0.0	0.0	0.0	0.0	0.2	0.0	0.0
6.5	0.7	0.0	0.0	0.7	0.0	0.0	0.2	0.7	0.7
6.6	0.0	0.0	0.0	0.0	0.3	0.3	0.2	0.0	0.0
6.7	0.0	0.3	0.3	0.3	0.0	0.0	0.2	0.0	0.0
6.8	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.3
6.9	0.3	0.0	0.0	0.0	0.0	0.0	0.1	0.3	0.0
7.2	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.0	0.0
7.6	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0
TOTAL	1276	986	745	1310	1056	775	1545	1143	896
>1V	654	442	379	564	394	332	933	622	539

Table 7-3
J.M.Farley-1: Projected EOC 13 Distributions (Limiting SG)

Volt Bin	SG C Prediction			SG C Actual
	POD=0.6	POD=1.0	N.I.M	
0.3	0	0	0	1
0.4	3	2	7	6
0.5	16	10	25	38
0.6	43	25	52	64
0.7	77	47	83	85
0.8	106	63	100	101
0.9	120	72	113	108
1.0	128	76	111	78
1.1	125	76	96	110
1.2	111	66	76	93
1.3	95	57	54	63
1.4	78	47	39	57
1.5	63	38	28	41
1.6	50	29	20	40
1.7	38	23	16	25
1.8	28	17	10	20
1.9	21	12	8	10
2.0	14	9	6	12
2.1	11	7	3	2
2.2	8	4	3	3
2.3	5	3	2	5
2.4	4	2	1	3
2.5	2	2	1	0
2.6	2	1	1	1
2.7	2	1	0	1
2.8	1	1	1	2
2.9	1	0	0	1
3.0	0	0	0	0
3.1	0	0.7	0	0
3.2	0.7	0.3	0	0
3.3	0.3	0	0	0
3.4	0	0	0.7	0
3.6	0	0	0	1
4.5	0	0	0.3	0
5.6	0	0	0	1
7.1	0	0	0	1
Total	1153	691	857	973

Figure 7-1
Farley Unit 1 Steam Generator A
Bobbin Voltage Distributions for Cycle 14

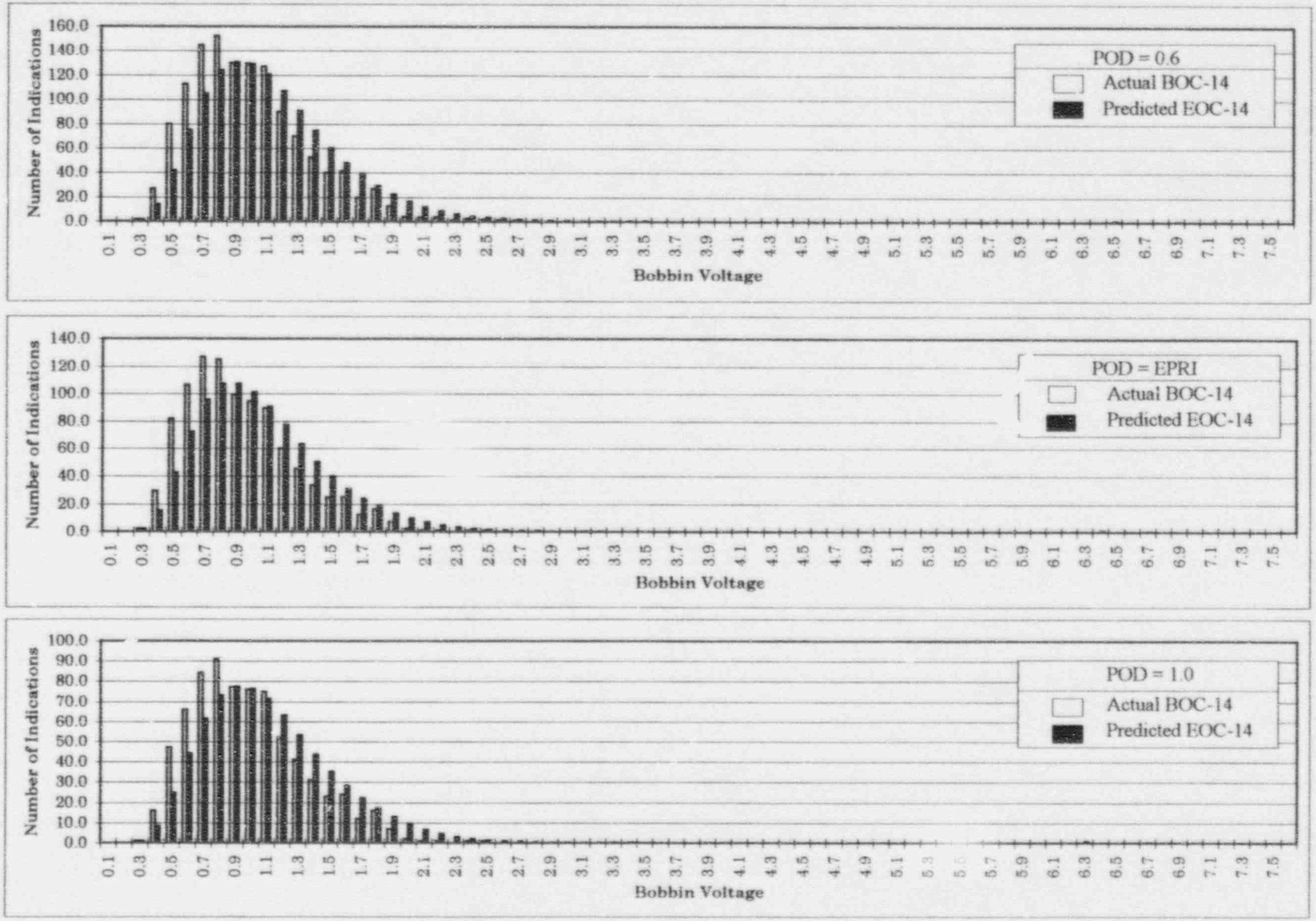


Figure 7-2
Farley Unit 1 Steam Generator B
Bobbin Voltage Distributions for Cycle 14

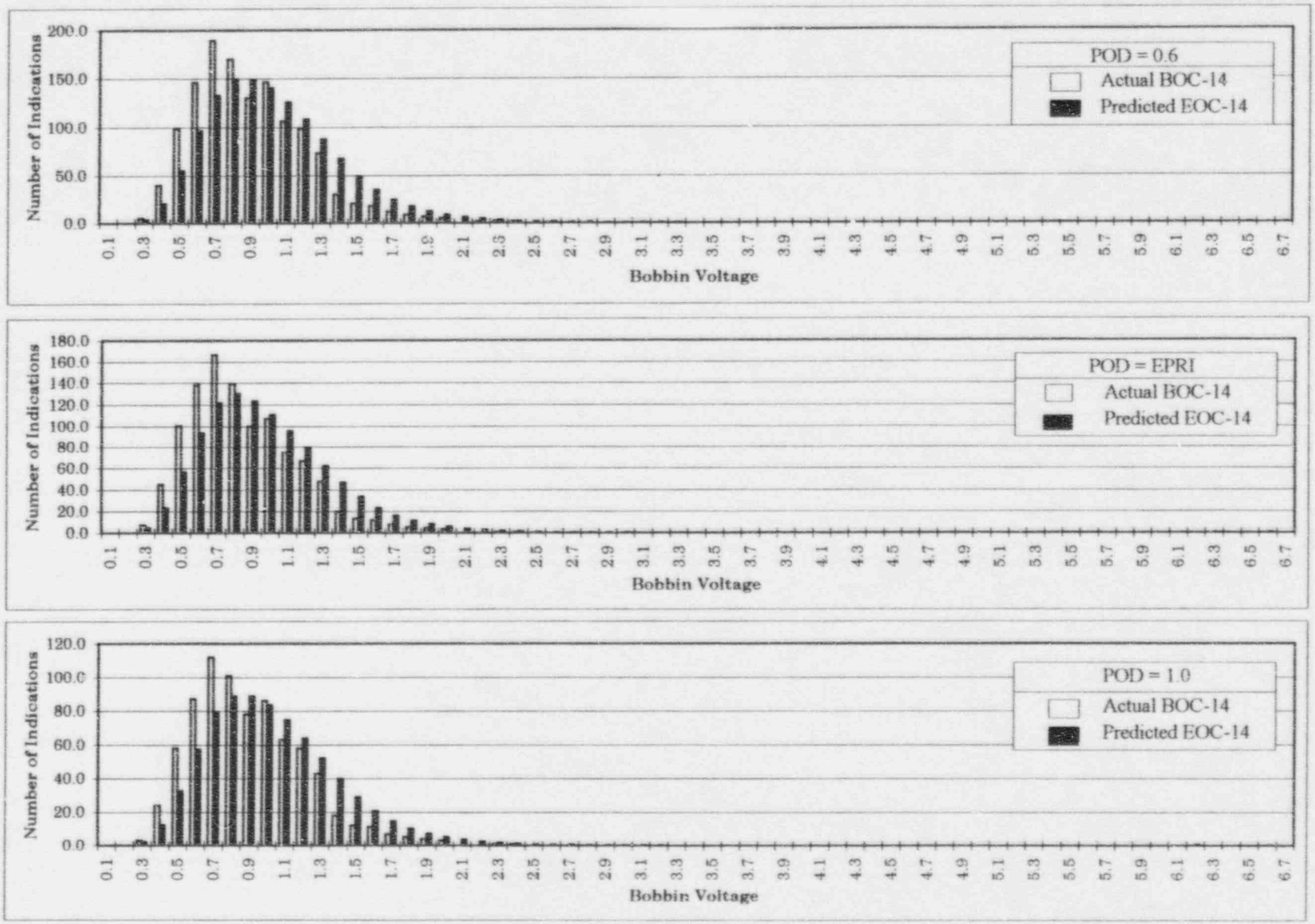


Figure 7-3
Farley Unit 1 Steam Generator C
Bobbin Voltage Distributions for Cycle 14

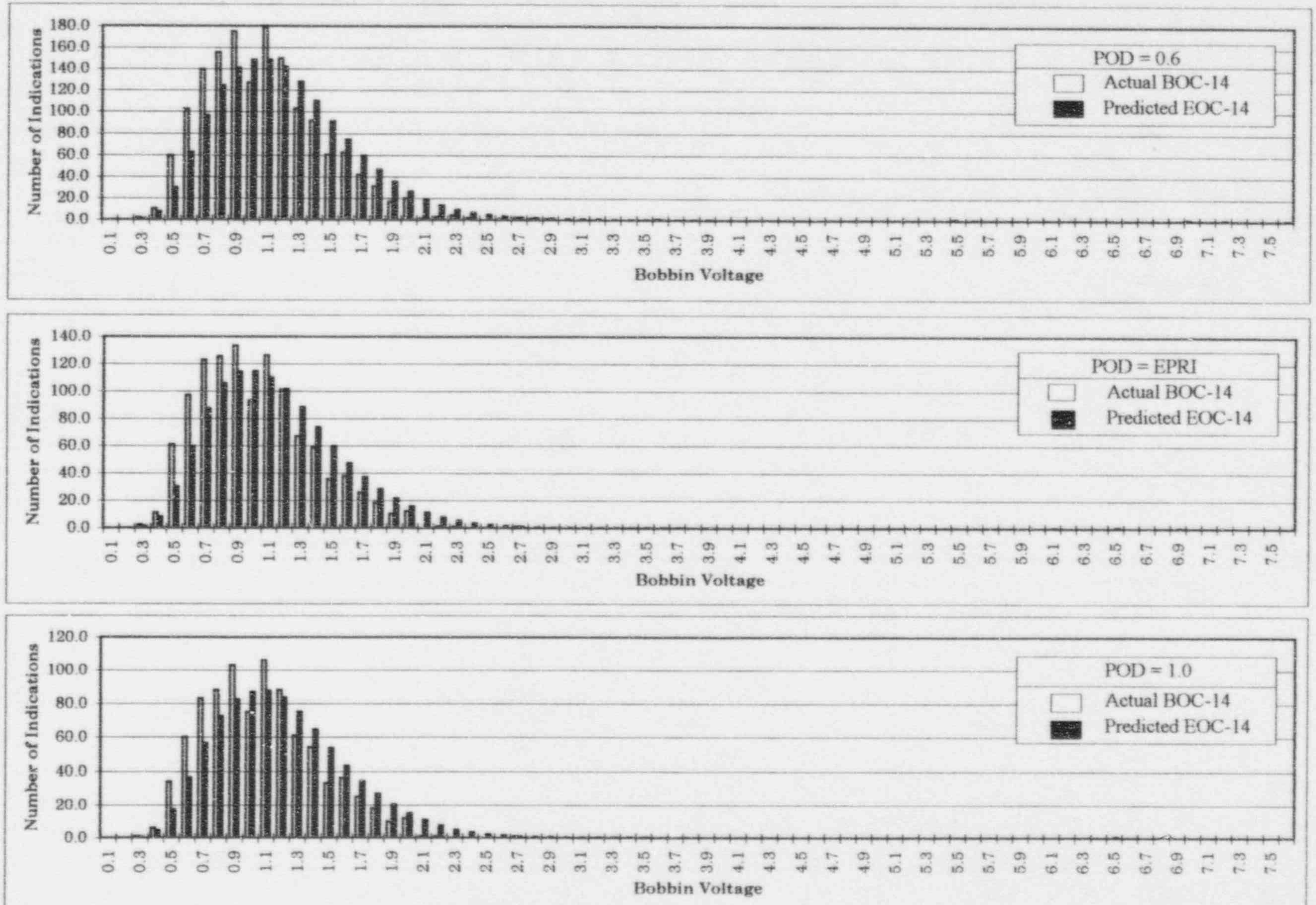
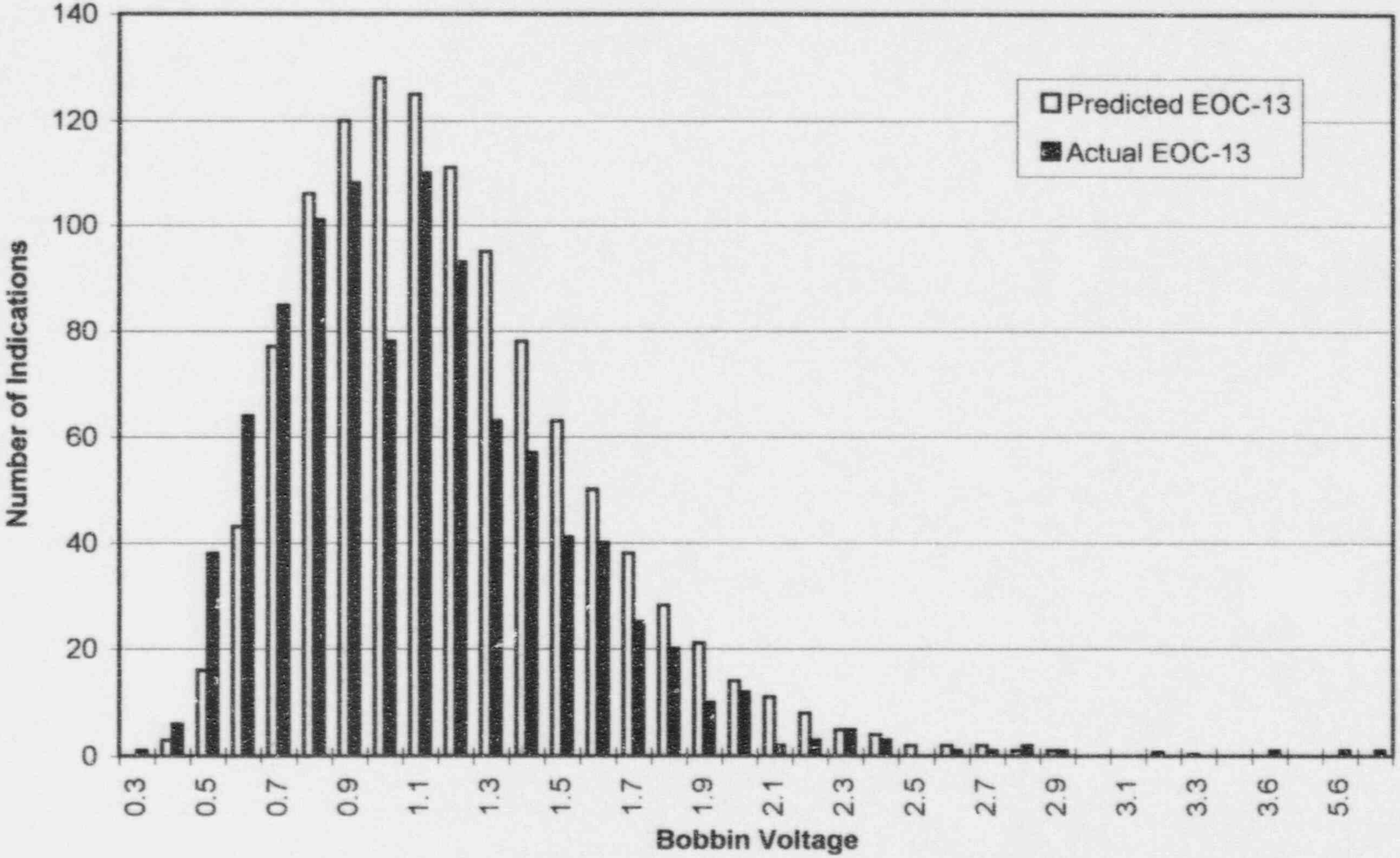


Figure 7-4
J.M.Farley Unit-1 SG C
Bobbin Voltage Distributions for Cycle 13



8.0 TUBE LEAK RATE AND TUBE BURST PROBABILITIES

8.1 CALCULATION OF LEAK RATE AND TUBE BURST PROBABILITIES

Correlations have been developed for the evaluation of ODSCC indications at TSP locations in steam generators of nuclear power plants which relate bobbin voltage amplitudes, free span burst pressure, probability of leakage and associated leak rates. The Westinghouse methodology used in the calculation of these parameters, documented in References 10.2 and 10.4, is consistent with NRC criteria and guidelines of References 10.1 and 10.3.

8.2 PREDICTED AND ACTUAL LEAK RATE AND TUBE BURST PROBABILITY FOR EOC-13

Using the methodology previously described, analyses were performed to calculate EOC-13 SLB tube leak rate and probability of burst for the actual and predicted bobbin voltage distribution previously presented in this report. The results of Monte Carlo calculations performed for the predicted and the actual voltage distributions are summarized on Table 8-1. The EOC-13 predicted values given in Table 8-1 are based on updating the prior projections of Reference 10.4 to the GL-95-05 leak rate analysis methods and burst probability database. This permits a more direct comparison of prediction and actuals without changes in methods and database. The projected SLB leak rates of Reference 10.4 used NRC draft NUREG-1477 methods (versus updated GL-95-05 methods) and had projected leak rates of 0.61 and 0.45 gpm for SGs C and A, respectively, versus the corresponding GL-95-05 methodology results of 5.72 and 3.61 gpm. Reference 10.4 included projected burst probabilities for two databases - the EPRI ARC database which was later approved in GL-95-05 (and updated to later pulled tube data as discussed in Section 5) and an earlier NRC previously approved for Cycle 13 analyses. The Reference 10.4 projections for the EPRI database and Monte Carlo analyses are given in Table 8-1. The difference between the EPRI and updated (consistent with GL-95-05) databases are negligible for burst probability analyses.

Comparison of the EOC-13 actuals with the corresponding predictions indicates that:

a) SG C was predicted to be the most limiting steam generator for Cycle 13.

b) SG C was confirmed to have the highest tube leak and probability of burst values based on actual ECT bobbin measurements at EOC-13.

c) The leakage rate (based on projected indication population) predicted for a postulated SLB is conservative compared to SLB leakage rate based on actual ECT bobbin measurements for EOC-13, when the same leakage methods are used in both analyses.

d) The probability of burst (based on projected indication population) predicted for a postulated SLB is in reasonable agreement with the SLB probability of tube burst values based on actual ECT bobbin measurements for EOC-13. The predicted value of 4.3 E-04 compares to 8.1 E-04 for the actual distribution. The difference is due to the three larger than predicted actual indications at 3.6, 5.6 and 7.1 volts. With eddy current uncertainties included in the EOC-13 Monte Carlo analyses, the actual distribution leads to a 7.7 volts maximum, as shown on Table 8-1.

e) A voltage based POD incorporating previous prediction accuracy would most reliably predict ECT voltage distributions for tube leakage and probability of burst assessments.

The postulated SLB leak rate of 5.3 gpm calculated from the actual EOC-13 voltage distribution is below the Farley-1 Cycle 13 allowable limit of 22.6 gpm and the burst probability of 8.1 E-04 is well below the NRC reporting threshold of 1.0 E-2.

8.2 LEAK RATE AND TUBE BURST PROBABILITY FOR EOC-14

Calculations have been conducted to predict the performance of the limiting steam generator in Farley-1 at EOC-14. The methodology used in these predictions is the same as previously described. Results of the EOC-14 predictions, summarized on Table 8-1, indicate that the limiting steam generator for Cycle 14 at Farley-1 is expected to be SG C. With the NRC endorsed POD = 0.6, the predicted EOC-14 SLB leak rate for S/G C is calculated as 10.2 gpm and the EOC-14 SLB tube burst probability is calculated as 1.4 E-03; these results are below the Farley-1 Cycle 14 allowable SLB leak rate limit of 11.4 gpm and the NRC reporting guideline for tube burst probability of 1.0 E-02. Accordingly, the performance of Farley-1 steam generators during Cycle 14 is predicted to be in compliance with the NRC GL-95-05 requirements.

Steam Generator	POD	No. of Indications	Max.[1] Volts	Burst Probability		SLB Leak Rate gpm
				1 Tube	≥ 1 Tube	
EOC-13 PREDICTED[3]						
A	0.6		5.0	~2.8 E-04	-	3.61
C	0.6	1153	3.3	4.3 E-04	-	5.72
EOC-13 ACTUAL[1]						
A	1.0	796	3.3	2.1 E-04	< 4.0 E-06	3.3
B	1.0	802	4.5	1.4 E-04	< 4.0 E-06	2.6
C	1.0	973	7.7	8.1 E-04	< 4.0 E-06	5.3
	1.0	973	7.7	7.5 E-04	< 4.0 E-06	0.8[2]
EOC-14 PREDICTED						
A	0.6	1276.	6.9	7.5 E-04	2.5 E-05	7.1
	EPRI	986.	6.7	5.4 E-04	1.9 E-05	4.7
	1.0	745.	6.7	4.6 E-04	< 4.0 E-06	3.9
B	0.6	1310.	6.7	7.1 E-04	1.9 E-05	6.0
	EPRI	1056.	6.6	4.9 E-04	< 4.0 E-06	4.2
	1.0	775.	6.6	4.2 E-04	< 4.0 E-06	3.4
C	0.6	1545.	7.6	1.4 E-03	1.9 E-05	10.2
	0.6	1545.	7.6	1.4 E-04	3.1 E-05	1.7[2]
	EPRI	1143.	6.9	7.0 E-04	1.9 E-05	6.5
	1.0	896.	6.8	5.7 E-04	1.9 E-05	5.5

Table 8-1
Farley-1 1995 Outage
Summary of SLB Tube Leak Rate and Burst Probability
NRC GL-95-05 Methodology

[1] Voltages include NDE uncertainties from Monte Carlo analyses and exceed measured voltages.

[2] Analysis with leakage correlated to voltage; all other results are without correlation.

[3] Leakage calculations were recalculated in accordance with NRC GL-95-05. Original EOC-13 predictions were based on draft NUREG-1477.

9.0 COMPARISON OF POPCD FOR 11 INSPECTIONS, 7 PLANTS WITH EPRI POD

The evaluation of the probability of prior cycle detection (POPCD) for Farley-1 is described in Section 4.3 At this time, POPCD evaluations are available for eleven inspections of seven plants, including the last two inspections at Farley-1. The available data include eight inspections of plants with 7/8" diameter tubing and three inspections of plants with 3/4" diameter tubing. This section summarizes these POPCD evaluations for comparison with the EPRI proposed POD.

The individual plant POPCD evaluations were combined for comparisons with the EPRI proposed POD. Data from two Farley-1 assessments (EOC-11 and EOC-12 results representing '92 inspection and '94 inspections) as well as data from two Farley-2 assessments are included. Figures 9-1 to 9-3 show the combined data for 7/8" tubing, for 3/4" tubing and for the combined 7/8" and 3/4" tubing plants. These results include RPC confirmed plus not inspected indications. The 3/4" POPCD is in very good agreement with the EPRI POD above 1.0 volt while the 7/8" POPCD is slightly lower than the EPRI POD above 1.0 volt. When all eleven POPCD assessments are combined (Figure 9-3), there is generally good agreement with the EPRI POD although the trend exists to be below the EPRI POD. The definition of POPCD includes indications which were not present at the prior inspection and thus would be expected to be somewhat lower than the EPRI POD which is based on "expert" evaluations of inspection results and does not include indications clearly below detectable levels.

The POPCD evaluations shown in Figures 9-1 to 9-3 are based on the definition of "truth" as RPC confirmed plus not RPC inspected indications. Since many of the indications not RPC inspected would be expected to be found to be NDD if inspected, this represents a lower bound POPCD evaluation. Figure 9-4 shows the POPCD evaluation for all eleven inspections based only on RPC confirmed indications. This results in a significant increase in POPCD below 1.0 volt and a modest increase between 1.0 and 1.5 volts. Above 2.0 volts, all indications are RPC inspected and there is no difference in the definitions. The data supporting Figures 9-3 and 9-4 are given in Table 9-1. The data of Table 9-1 show more than 200 indications in all voltage bins below 1.6 volts and at least 22 indications in the voltage bins up to 5 volts. Thus the collective data are a reasonable basis for defining a POD.

The POPCD evaluations performed since 1992 show significant improvement over the earlier assessments which represent the first IPC inspections. Bobbin data analysis guidelines (Appendix A) have been revised since the first inspections to reflect the initial IPC experience. Thus, it is appropriate to assess POPCD for inspections performed since 1992. Seven of the eleven inspections for which POPCD has been evaluated were performed since 1992. The data for these seven inspections are given in Table 9-2 and the POPCD evaluation is shown in Figure 9-5 for RPC confirmed plus not inspected indications. It is seen that the inspections since 1992 yield a

POPCD in good agreement with the EPRI POD which was a 1994 evaluation. Both POPCD and the EPRI POD support a POD approaching unity above 2.5 volts. Since the data analysis guidelines were revised since 1992 and significant experience has been gained in IPC inspections, the POPCD of Figure 9-5 is the appropriate data for assessing voltage dependent PODs for IPC applications. Figure 9-5 strongly supports the EPRI POD, without further adjustments for new indications, as an acceptable POD.

The results of Figure 9-5 clearly support an increase in the POD for IPC applications above the POD = 0.6, independent of voltage, required by the NRC GL-95-05. For indications above 1.0 volt, the POD exceeds 0.85 and is 0.98 to near unity above 2.0 volts. A POD of 0.6 is only applicable to indications below about 0.6 volts.

The POPCD evaluations for eleven inspections, including seven inspections since 1992, together with the EPRI POD evaluation provide a database for updating the NRC generic letter requirements on POD.

Table 9 - 1
Combined POPCD Evaluation (11 Assessments) for All Plants
POPCD Based on RPC Confirmed Plus Not Inspected Indications

Voltage Bin	New Indications		Bobbin Call in Both Inspections		First Inspection	POPCD			
						RPC Confirmed		RPC Confirmed Plus Not Inspected	
	RPC Confirmed	RPC Confirmed plus not Inspected	RPC Confirmed	RPC Confirmed plus not Inspected	RPC Confirmed and Plugged	Frac.	Count	Frac.	Count
> 0 - 0.2	8	502	0	445	6	0.429	6/14	0.473	451/953
0.2 - 0.4	84	2335	23	2247	82	0.556	105/189	0.499	2329/4664
0.4 - 0.6	101	3053	123	3121	188	0.755	311/412	0.520	3309/6362
0.6 -0.8	103	2423	257	2816	159	0.802	416/519	0.551	2975/5398
0.8 - 1.0	94	996	347	1689	185	0.850	532/626	0.653	1874/2870
1.0 - 1.2	88	219	149	618	435	0.869	584/672	0.828	1053/1272
1.2 - 1.4	43	105	61	244	265	0.883	326/369	0.829	509/614
1.4 - 1.6	24	39	61	122	100	0.870	161/185	0.851	222/261
1.6 - 1.8	11	18	26	45	84	0.909	110/121	0.878	129/147
1.8 - 2.0	6	8	14	16	50	0.914	64/70	0.892	66/74
2.0 - 2.2	1	1	9	9	40	0.980	49/50	0.980	49/50
2.2 - 2.5	1	1	2	2	24	0.963	26/27	0.963	26/27
2.5 - 3.0	1	1	4	4	25	0.967	29/30	0.967	29/30
3.0 - 4.0	0	0	0	0	22	1.0	22/22	1.0	22/22
4.0 - 5.0	0	0	0	0	4	1.0	4/4	1.0	4/4
TOTAL	565	9701	1076	11378	1669				
Total > 1V	175	392	326	1060	1049				

Table 9-2
Combined POPCD Evaluation for 7 Assessments Conducted After 1992
POPCD Based on RPC Confirmed Plus Not Inspected Indications

Voltage Bin	New Indications		Bobbin Call in Both Inspections		First Inspection	POPCD			
	RPC Confirmed	RPC Confirmed plus not Inspected	RPC Confirmed	RPC Confirmed plus not Inspected	RPC Confirmed and Plugged	RPC Confirmed		RPC Confirmed Plus Not Inspected	
						Frac.	Count	Frac.	Count
> 0 - 0.2	6	454	0	403	5	0.455	5 / 11	0.473	408 / 862
0.2 - 0.4	69	1701	18	1875	81	0.589	99 / 168	0.535	1956 / 3657
0.4 - 0.6	86	1359	99	2095	183	0.766	282 / 368	0.626	2278 / 3637
0.6 -0 .8	76	668	218	1601	150	0.829	368 / 444	0.724	1751 / 2419
0.8 - 1.0	62	273	263	915	112	0.858	375 / 437	0.790	1027 / 1300
1.0 - 1.2	44	122	79	417	339	0.905	418 / 462	0.861	756 / 878
1.2 - 1.4	20	59	31	174	195	0.919	226 / 246	0.862	369 / 428
1.4 - 1.6	12	22	42	97	73	0.906	115 / 127	0.8[illegible]5	170 / 192
1.6 - 1.8	5	11	23	42	55	0.940	78 / 83	0.898	97 / 108
1.8 - 2.0	4	6	10	12	34	0.917	44 / 48	0.885	46 / 52
2.0 - 2.2	0	0	9	9	26	1.0	35 / 35	1.000	35 / 35
2.2 - 2.5	1	1	2	2	15	0.944	17 / 18	0.944	17 / 18
2.5 - 3.0	0	0	4	4	20	1.0	24 / 24	1.0	24 / 24
3.0 - 4.0	0	0	0	0	18	1.0	18 / 18	1.0	18 / 18
4.0 - 5.0	0	0	0	0	4	1.0	4 / 4	1.0	4 / 4
TOTAL	385	4676	798	7646	1310				
Total > 1V	86	221	200	757	779				

Figure 9 - 1
Combined POPCD Evaluation (8 Assessments) for Plants with 7/8" Dia. Tubes
POPCD Based on RPC Confirmed Plus Not Inspected Indications

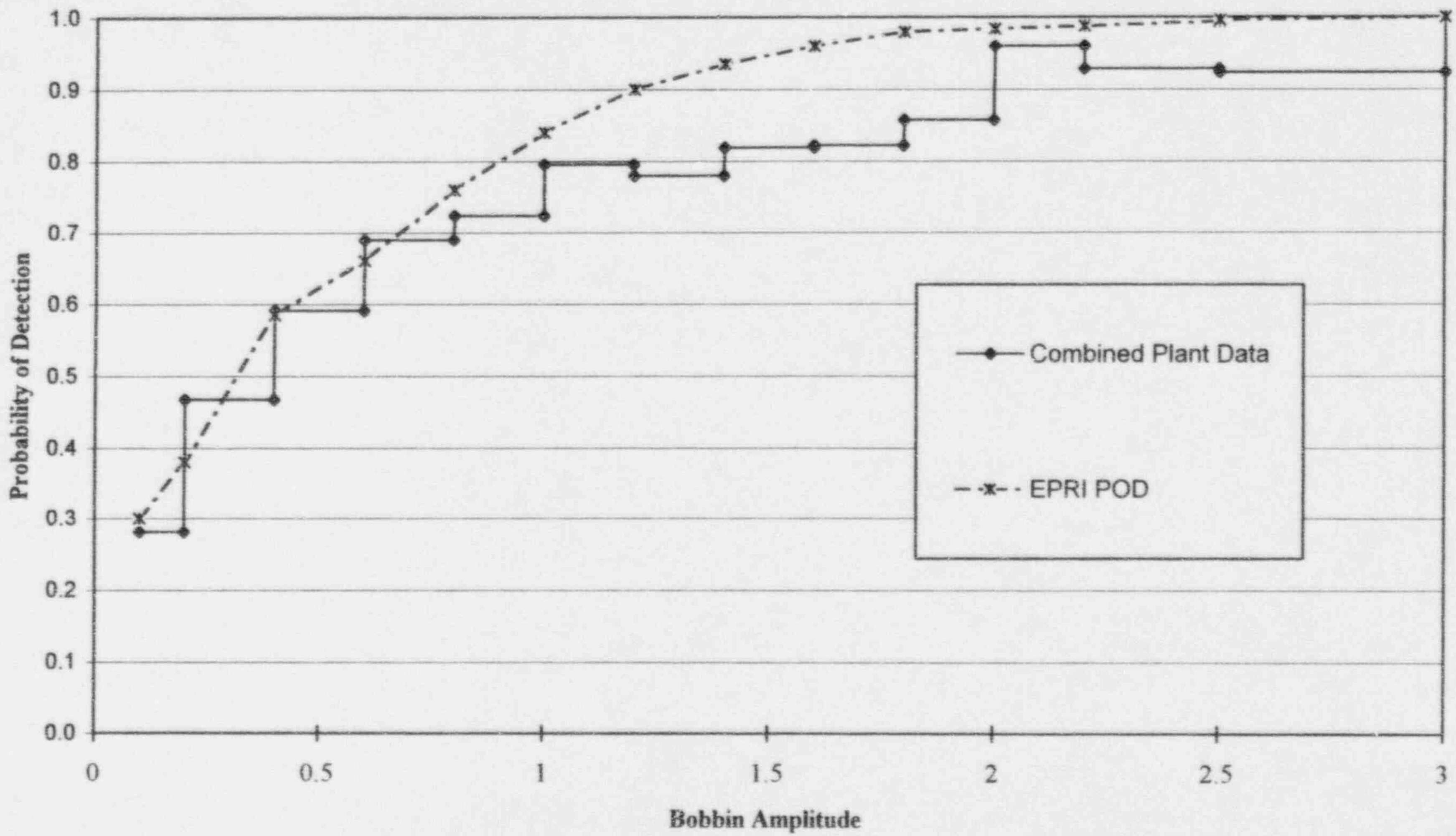


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Figure 9 - 2

Combined POPCD Evaluation (3 Assessments) for Plants with 3/4" Dia. Tubes

POPCD Based on RPC Confirmed Plus Not Inspected Indications

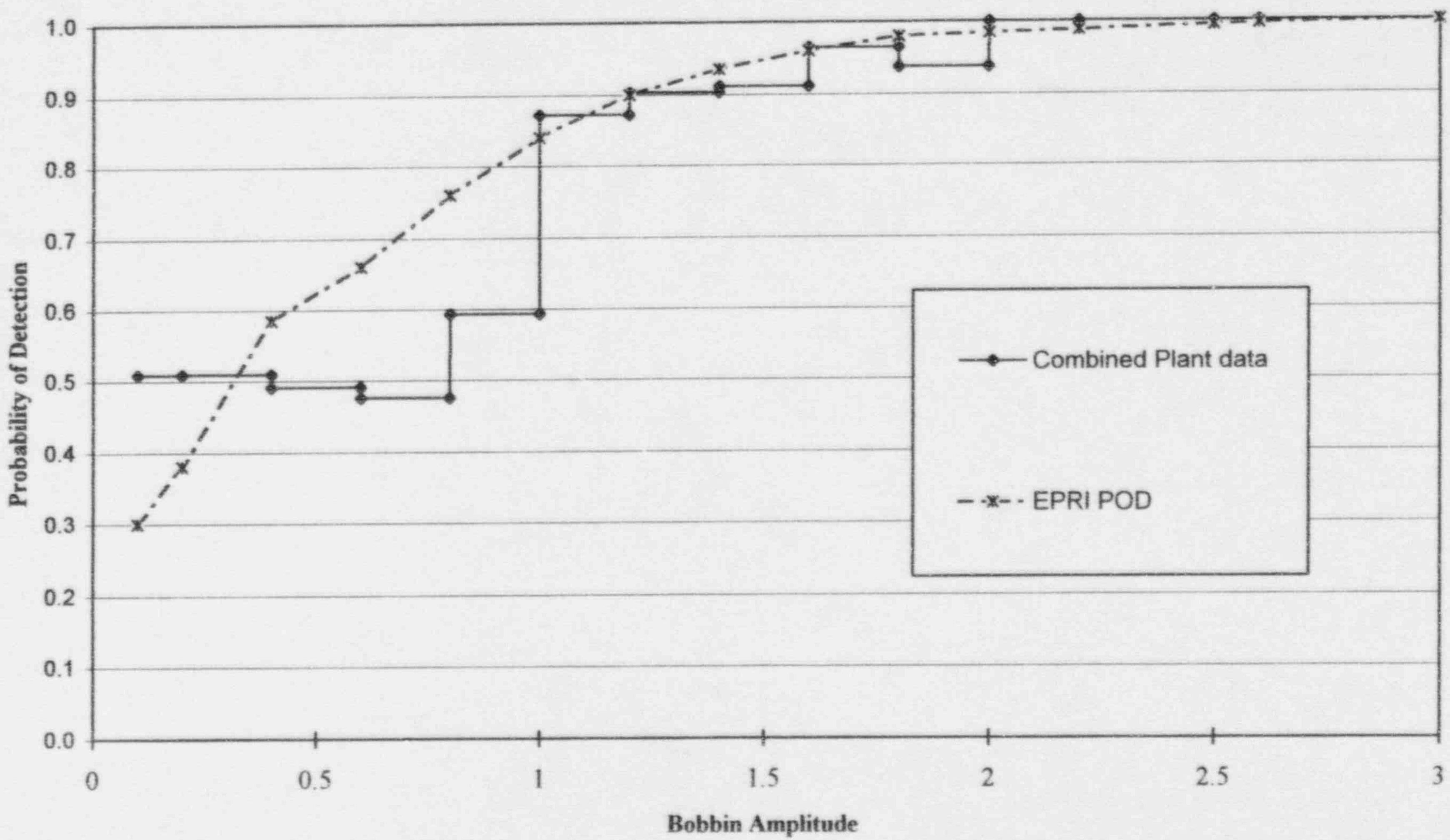

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Figure 9 - 3
Combined POPCD Evaluation (11 Assessments) for All Plants
POPCD Based on RPC Confirmed Plus Not Inspected Indications

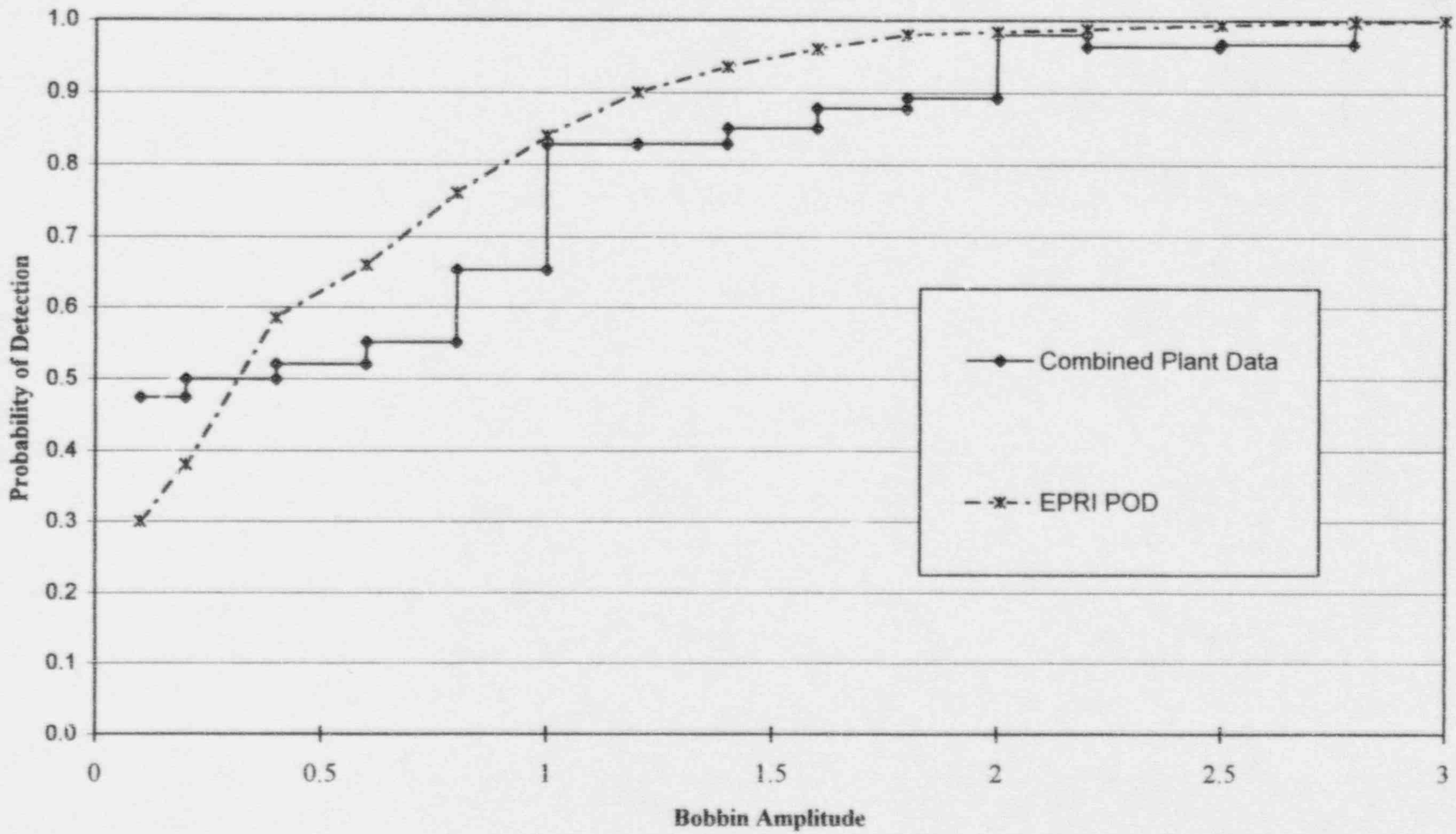

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Figure 9 - 4
Combined POPCD Evaluation (11 Assessments) for All Plants
POPCD Based on RPC Confirmed Indications Only

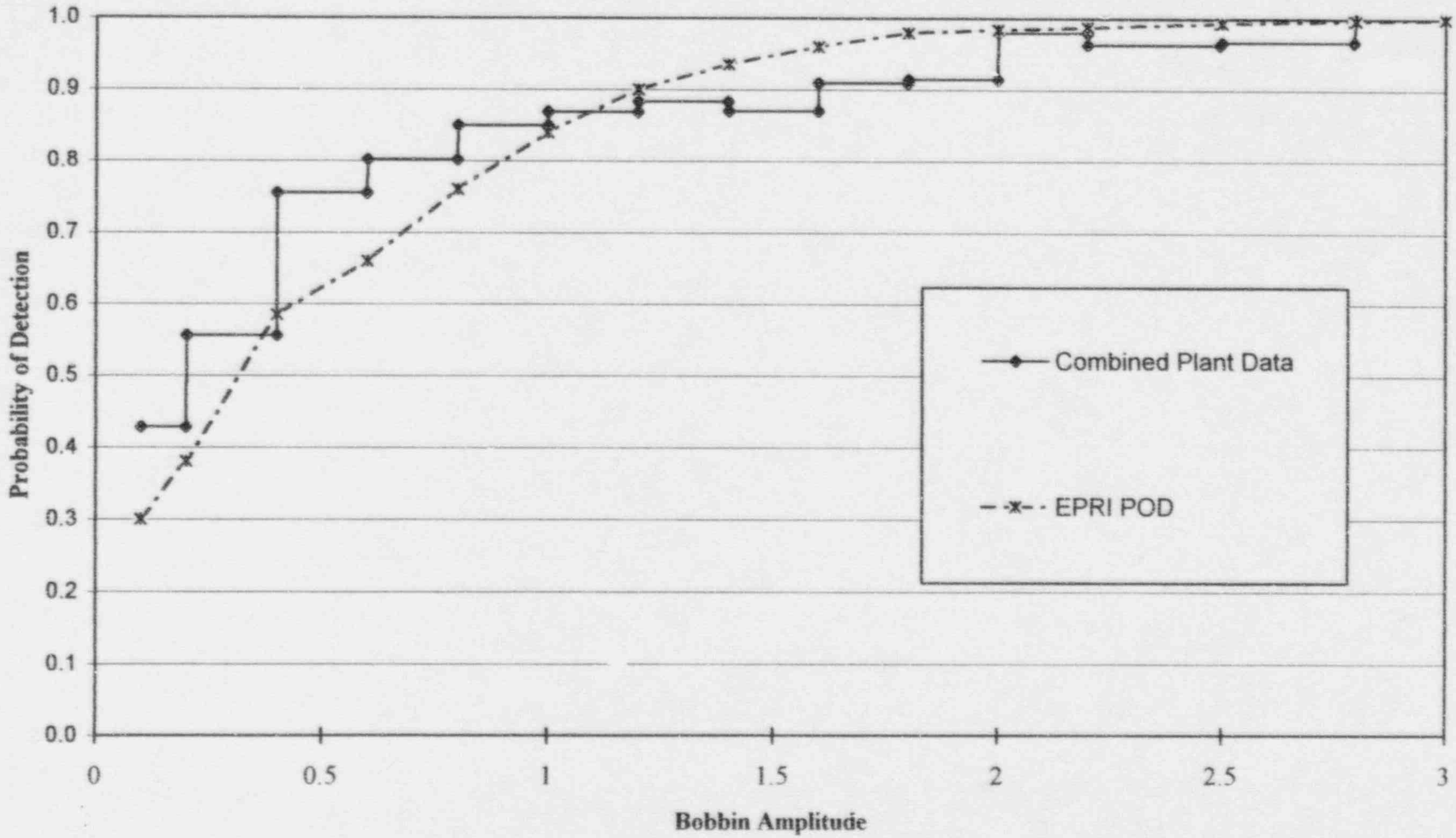
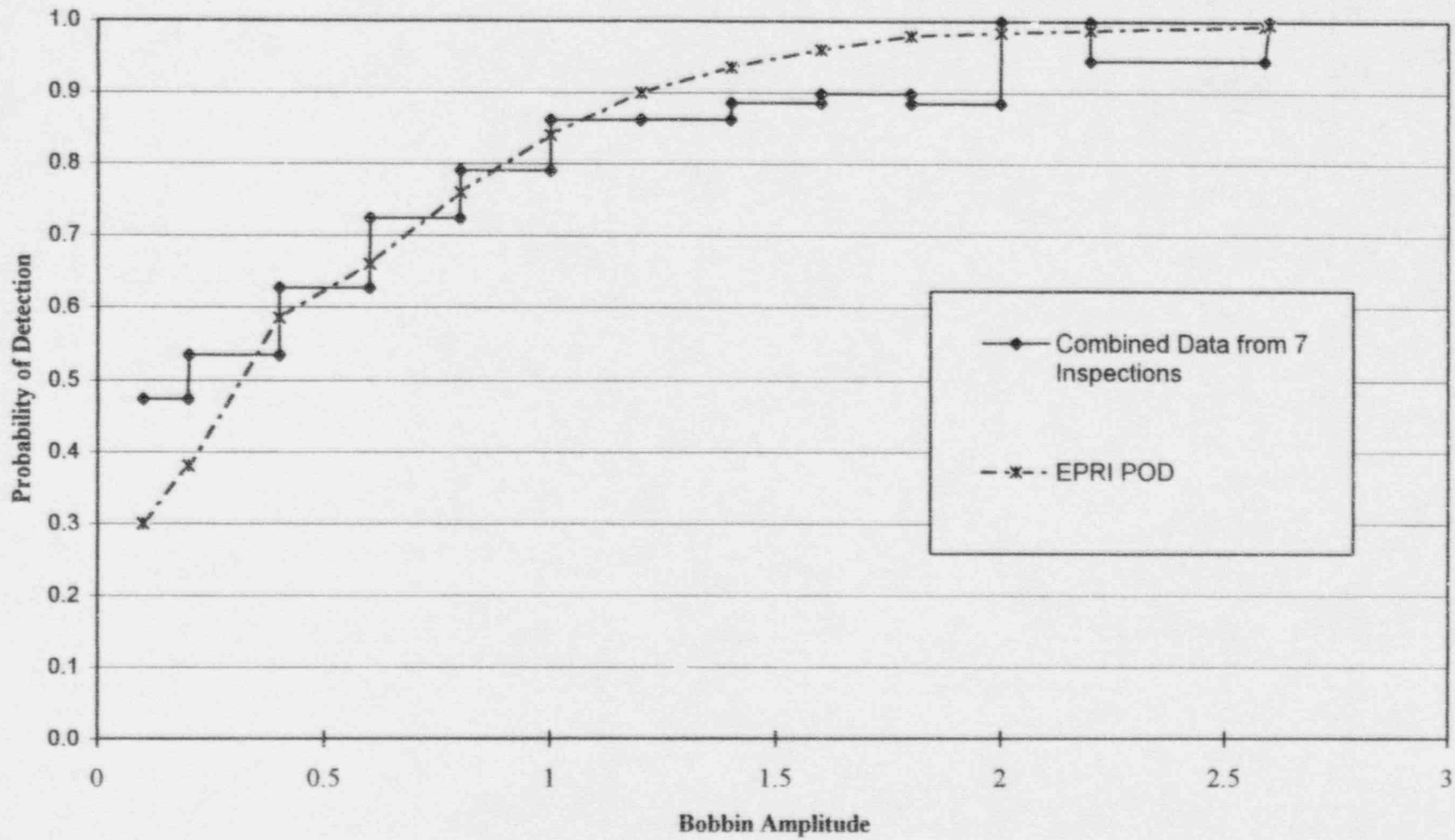


Figure 9 - 5
Combined POPCD Evaluation for 7 IPC Assessments Conducted After 1992
POPCD Based on RPC Confirmed Plus Not Inspected Indications



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10.0 REFERENCES

10.1 NRC Generic Letter 95-05, "Voltage-Based Repair Criteria for Westinghouse Steam Generator Tubes Affected by Outside Diameter Stress Corrosion Cracking", USNRC Office of Nuclear Reactor Regulation, August 3, 1995.

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

10.3 United States Nuclear Regulatory Commission, "Safety Evaluation by the Office of Nuclear Reactor Regulation Related to Amendment No. 117 to Facility Operating License NPF-2 Southern Nuclear Operating Company, Inc. Joseph M. Farley Nuclear Plant, Unit 1, Docket Nos. 50-348," September 28, 1995.

10.4 SG-94-08-006, "Farley-1 Cycle 12 IPC Assessment and Projected EOC-13 SLB Leakage", August 1994.

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

THE END

Discard this sheet.

That's all there is.