FENOC

FirstEnergy Nuclear Operating Company

Beaver Valley Power Station
Route 168
P.O. Box 4
Shippingport, PA 15077-0004

Lew W. Myers
Senior Vice President

724-682-5234
Fax: 724-643-8069

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U. S. Nuclear Regulatory Commission
Attention: Document Control Desk
Washington, DC 20555-0001

Subject: Beaver Valley Power Station, Unit No. 1
Docket No. 50-334, License No. DPR-66
Cycle 15 Steam Generator Tube Inspection 90 Day Report

Reference 1: NRC Generic Letter 95-05, "Voltage-Based Repair Criteria for the Repair of Westinghouse Steam Generator Tubes Affected by Outside Diameter Stress Corrosion Cracking," August 3, 1995.

Enclosed is a copy of the "Beaver Valley Unit 1, Cycle 15 Voltage-Based Repair Criteria 90 Day Report," which supports continued implementation of the 2.0 volt repair criteria as outlined in Reference 1. This report provides a summary of the steam generator inspections performed during the fourteenth refueling outage at tube support plate intersections along with postulated steam line break leak rate and tube burst probability analysis results.

The enclosed report includes data from testing of a steam generator tube pulled during the fourteenth refueing outage. The initial laboratory results for the pulled tube are detailed in the attached 90 day report. The data from the laboratory leak tests indicates a potential non-conservative impact to the current Industry database used for GL 95-05 evaluations. The NRC was notified of this potential non-conservative impact via telephone conference call on 12/06/01. NEI and other utilities were notified of the initial laboratory results and potential non-conservative impact to the Industry database due to the latest Beaver Valley 1 pulled tube data on 12/13/01. FENOC will work with NEI and other affected utilities to incorporate the Beaver Valley 1 pulled tube data into the Industry database in accordance with the NRC approved NEI protocol.

Report "Steam Generator Tubing ODSCC at TSPs Database, NP-7480-L, Addendum 4" was submitted by NEI to the NRC in September 2001. Addendum 4 details a new exclusion criterion (Data Exclusion Criterion 2c) regarding datasets with atypical deep crack morphology. This exclusion provides a technical basis for excluding datasets from the Industry database whose crack depths for indications >5 volts do not have near throughwall degradation consistent with domestic pulled tubes with indications >5 volts.

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This criterion provides a justification for addressing foreign datasets that force undue conservatism in the GL 95-05 EOC evaluations that result simply from the artifacts of statistics and not from true safety significant concerns. FENOC endorses this new exclusion criterion and urges the NRC to complete its review and approval of data exclusion criterion 2c as soon as possible.

If you have any questions concerning this matter, please contact Mr. Thomas S. Cosgrove, Manager, Regulatory Affairs at 724-682-5203.

Sincerely,

Robert E. Donnellan FOR

Lew W. Myers

c: Mr. L. J. Burkhart, Project Manager
Mr. D. M. Kern, Sr. Resident Inspector
Mr. H. J. Miller, NRC Region I Administrator

SG-SGDA-01-04

BEAVER VALLEY UNIT - 1

CYCLE 15 VOLTAGE-BASED REPAIR CRITERIA 90-DAY REPORT

December 2001

Westinghouse Electric Company

Nuclear Services Business Unit
P.O. Box 158
Madison, Pennsylvania 15663-0158

SG-SGDA-01-04

BEAVER VALLEY UNIT - 1

CYCLE 15 VOLTAGE-BASED REPAIR CRITERIA 90-DAY REPORT

December 2001

Authors: ____________________
(V. Srinivas)

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(W. K. Cullen)

Reviewer: ____________________
(R. F. Keating)

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Beaver Valley Unit - 1
Cycle 15 Voltage-Based Repair Criteria
90-Day Report

1.0 Introduction

This report provides a summary of the Beaver Valley Unit-1 steam generator (SG) bobbin and RPC (+Pt) probe inspections at tube support plate (TSP) intersections together with postulated Steam Line Break (SLB) leak rate and tube burst probability analysis results. These results support continued implementation of the 2.0 volt voltage-based repair criteria for Cycle 15 as outlined in the NRC Generic Letter 95-05 (Reference 9-1). Information required by the Generic Letter is provided in this report including SLB leak rates and tube burst probabilities calculated using the end of cycle (EOC) conditions for the recently completed cycle (EOC-14 condition monitoring analysis) and projection of bobbin voltage distributions, leak rates and burst probabilities for the ongoing cycle (Cycle 15 operational assessment).

Condition monitoring analysis at EOC-14 was carried out using the actual bobbin voltage distributions measured during the EOC-14 outage and the results compared with corresponding values from projections performed based on the last (EOC-13) bobbin voltage data (presented in Reference 9-2). These evaluations utilized the Westinghouse generic Monte Carlo methodology presented in Reference 9-3.

Operational assessment analysis was performed to project leak rates and tube burst probabilities for postulated SLB conditions at the end of the ongoing cycle (Cycle 15) based on the 2.0 volt repair criteria. These analyses utilized bobbin voltage distributions measured during the recent (EOC-14) inspection and a limiting growth rate distribution from the last two inspections (EOC-13 and EOC-14 inspections).

2.0 Summary and Conclusions

A total of 3533 axial outside diameter stress corrosion cracking (ODSCC) indications were found during the EOC-14 inspection in all three SGs combined, of which 469 were inspected with a RPC probe, and 436 were confirmed as flaws. The RPC confirmed indications included 363 indications above 1.0 volt. The largest number of bobbin indications, 1530 indications, was found in SG-A; 188 of those were inspected by RPC, and 182 were confirmed as flaws. A total of 20 indications were found above 2 volts in all SGs combined, all but 3 of those indications were inspected with a RPC probe; all RPC inspected bobbin indications > 2 volts were confirmed. The indications over 2 volts that could not be RPC inspected had sleeves installed at elevations below the elevation of the indication in questions. The sleeve prevented passage of the RPC probe. All indications over 2 volts were removed from service. No circumferential indications or axial indications extending outside TSP were identified by RPC inspection at TSP distorted signal indication locations. RPC inspection of dented intersections also did not show any degradation, either OD or ID initiated. Three single volumetric indications (SVIs) were found coincident with previously reported distorted signal indications in SG-A, and tubes containing those indications were removed from service. The source of the volumetric indications were determined to be related to foreign object signals.

SLB leak rate and tube burst probability analyses were performed for the actual EOC-14 bobbin voltage distributions (condition monitoring analysis) as well as the projected EOC-15 bobbin voltage distributions (operational assessment). The actual number of indications detected during the EOC-14 inspection for all SGs are below their corresponding projections based on both constant POD of 0.6 as well as voltage dependent POPCD. With the exception of a single indication in SG-C, EOC-14 measured voltages were bounded by voltage distributions projected using both POD=0.6 and POPCD. The SLB leak rate values based on the actual measured voltages show significant margins relative to their projected values. SG-A was predicted to be the limiting SG at EOC-14 as it had a slightly higher projected SLB leak rate and burst probability than other 2 SGs, and it was also found have the largest leak rate based on the EOC-14 voltages. However, SG-C was found to be limiting for tube burst probability as it contained the largest indication found in this inspection.

The largest SLB leak rate in the condition monitoring analysis is calculated for SG-A, and its magnitude is 2.2 gpm, which is substantially lower than the allowable SLB leakage limit in effect at EOC-14 of 5.5 gpm. It should be noted that RCS activity was administratively controlled during Cycle 14 to more conservative levels than used for the leak rate determination of 5.5 gpm. NRC approval of license amendment request 293 has effectively raised the permissible leak rate to 14.5 gpm. All leak rate values quoted are equivalent volumetric rates at room temperature. The limiting conditional tube burst probability based on the EOC-14 actual measured voltages, 2.1×10^{-4} predicted for SG-C, is well below the NRC reporting guideline of 10^{-2}. Both the projected and condition monitoring leak rate and burst probability values presented are calculated using the same ARC database, which is

documented in Reference 9-4. Thus, the condition monitoring results meet the allowable limits.

Reference calculations for the SLB leak rate and tube probability projections at the EOC-15 conditions were performed using the latest ARC database available (Addendum-4 update), which is documented in Reference 9-5. SG-A is again predicted to be the limiting SG. For a cycle duration of 545 EFPD, the EOC-15 leak rate projected for SG-A using the NRC mandated constant POD of 0.6 is 5.5 gpm (room temperature), which is well below the current licensing limit of 14.5 gpm. This leak rate projection utilized a leak rate versus bobbin voltage correlation since the p-value for the leak rate correlation slope parameter in Reference 9-5 meets the 5% limit specified in the Generic Letter 95-05. The limiting EOC-15 burst probability, however, is calculated for SG-C; its magnitude is 3.1×10^{-4}, which is more than a factor of 30 below the NRC reporting guideline of 10^{-2}.

A section of tube R15 C62 in SG C containing TSP intersections 1 and 2 on the hot leg side was pulled during this outage and examined in the laboratory. The TSP 01H intersection contained the largest indication found in this inspection (5.3 volts) and leakage from that indication under SLB conditions was measured in an elevated temperature (600° F) leak test. The TSP 02H intersection had a 1.29 volts indication that did not leak under SLB conditions. To examine the effect of including this new leak rate data in the ARC leak rate database and the impact on the projected EOC-15 leak rate, this data was added to the latest leak rate database for 7/8" tubes presented in Reference 9-5 and the correlations for probability of leakage and leak rate for 7/8" tubes were updated. Section 3.0 presents the results of the pulled tube testing, and preliminarily updates the Reference 9-5 database. Until such time that the Industry database is formally updated, approved and issued for use in accordance with the NRC approved NEI protocol, the leak rate results with the newest pulled tube data from Beaver Valley added to said database are provided for information only.

Probability of detection (POPCD) for the last (EOC-13) inspection was assessed using EOC-13 and EOC-14 inspection results, and the data strongly supports a voltage dependent POD substantially higher than the NRC mandated POD value of 0.6. POPCD exceeds 0.6 at about 0.6 volt and remains above 0.90 beyond 0.8 volt. The Beaver Valley-1 EOC-13 POPCD distribution is slightly better than the generic POPCD distribution presented in Reference 9-5.

The EOC-14 RPC confirmation rate for RPC NDD indications left in service during Cycle 14 is only about 36%, and the corresponding estimate for the EOC-13 inspection was 87%. Although Beaver Valley Unit-1 has the option considering a fraction of RPC NDD (with a minimum of 70%) for leak and burst projections, 100% of such indications were included in the EOC-15 projections presented in this report.

3.0 Pulled Tube Examination Evaluations and Results

3.1 Summary of Pulled Tube Examination Results

3.1.1 Introduction

A section of hot leg tube was removed from R15 C62, SG C. The tube cut was located approximately 6" below the 03H, thus the 02H TSP, 01H TSP, and top of tubesheet regions were removed for examination. Bobbin DSI indications and +Pt axial OD indications were reported at the 01H and 02H TSPs. No degradation was reported by NDE at the top of tubesheet. The tube was pulled after chemical cleaning of the SGs that included both a bulk removal process targeted at removal of OD deposits on the tube freespan sections and top of tubesheet region and an additional process targeted towards cleaning of the TSP crevices.

3.1.2 Non Destructive Examination

A summary of the field and laboratory eddy current results for this tube is provided in the below table. Similar probes were used in the laboratory as in the field, namely a 0.720" diameter bobbin probe and 0.720" diameter +Pt probe. A review of the field analysis results produced essentially equal results. The laboratory NDE of the as-received sections did however indicate substantial flaw amplitude response increases for both the bobbin and +Pt coils.

BVPS Unit 1, SG C, R15 C62 Field and Laboratory Eddy Current Results				
TSP →	01H		02H	
Technique	Bobbin (V / %TW)	+Pt (V / %TW)	Bobbin (V / %TW)	+Pt
Field	5.30 / 81%	2.94	1.29 V / 59%	0.15 V
Laboratory (post pull)	9.08 / 80%	4.55 / 94%	3.76 V	N/A
Post-Leak Test	26.4 / 80%	8.94 / 97%	No Data (1)	No Data (1)
(1): Apparent tube ID surface damage due to tube cutting tool produced interference at this location.				

Figure 3.1 presents the field +Pt terrain plot for the 01H intersection. The intersection is dominated by a substantial axial indication with a second smaller parallel axial indication in close proximity to the dominant flaw. Figure 3.2 presents the field and laboratory +Pt amplitude plot for the dominant 01H flaw, specified as Flaw 2. The +Pt profiles indicate that

a significant flaw amplitude increase occurred at the lower end of the flaw, possibly due to damage that occurred during pulling of the tube. The reported pre-pull and post pull +Pt amplitudes are 2.94 volts and 4.55 volts respectively. Figure 3.3 presents the field and laboratory depth plot for the dominant flaw, Flaw 2, including the corrosion depth profile from destructive examination. With regard to +Pt amplitude, the next largest amplitude was 1.71 volts, and only 9 distorted signal indications had +Pt amplitudes > 1 volt (other than R15 C62). At these +Pt amplitudes, it is likely that the 01H TSP intersection of R15 C62 in SG C represented the only TSP intersection in all 3 Beaver Valley Unit 1 SGs that represented a leakage potential at SLB conditions at EOC-14.

3.1.3 Elevated Temperature Leakage Testing

Following NDE of the as-received tube sections, elevated temperature (600°F) leakage testing was performed for the 01H and 02H intersections of R15 C62. The testing program included holds at the normal operating pressure differential, intermediate test pressure between normal operating pressure differential and SLB, and SLB pressure differential. For the 02H TSP, no leakage was reported for any test pressure. For the 01H intersection, leakage was reported at the normal operating pressure differential, although quite low, and for all test pressures beyond. Between about 2200 psi and 2480 psi, a ligament likely tore, thus producing an order of magnitude increase in leak rate for these two pressure differentials. Table 3.2 presents the leak rate test results for the elevated temperature leak rate testing of the 01H intersection.

Following elevated temperature leak testing, room temperature burst testing was conducted for the 01H TSP region, 02H TSP region, and freespan region of the tube. Pressurization rate was limited to 200 psi/second during the burst test. All burst testing was performed in a freespan mode, i.e., no TSP restraint was provided. Table 3.3 presents the burst test results for these locations. The lowest burst pressure was reported for the 01H TSP region, at 4741 psi. The 02H TSP region burst at 8640 psi. The freespan burst pressure was greater than 10,000 psi. All burst openings were axially oriented.

The yield and ultimate strength values were determined using a tensile test for a freespan section of the pulled tube. The yield strength was 48.463 ksi, ultimate strength was 104.997 ksi, for a flow stress (sum of yield + ultimate divided by 2) of 76.73 ksi. The mean room temperature flow stress for 7/8" OD x 0.050" nominal wall mill annealed Alloy 600 tubing is 75.47 ksi, thus the flow stress of the pulled tube R15 C62 is only 1.7% higher than the average flow stress for all 7/8" OD tubing.

Figure 3.4 presents a photograph of the burst opening of the 01H TSP region of R15 C62. The burst opening appears to be comprised principally of two offset axial cracks separated by a

ligament in the circumferential direction. The dominant crack appears to extend downward from the top of the TSP by about 0.5", with a second parallel axial crack extending up from the bottom the TSP, and with a ligament separating the two cracks by about 25 mils. The ligament appears to be located at about 0.15" below the center of the TSP and appears to coincide with the peak +Pt flaw amplitude observed in the post pull eddy current data. Thus, it may have been affected by the tube pull operation and led to the large increase in +Pt flaw amplitude at this location.

3.1.4 Preliminary Metallography Results

Table 3.4 presents a length versus depth profile based on SEM measurement for the main flaw at the 01H TSP. Table 3.5 presents a length versus depth profile based on SEM measurement of the flaw at the 02H TSP. For the 01H TSP, the OD cracking was confined to one major patch area of the tube, extending essentially the entire axial length of the TSP and extending circumferentially for about 60 to 90° of arc. This patch was located azimuthally between about -45° to +45° from the designated 0° location. After chemical analysis of the heavy deposit patch areas, less significant areas of OD cracking may be found beneath these deposits. The burst opening of the 01H TSP was not located within the heavy deposit patch area. This may be a result of the additional crevice cleaning step performed as part of the 1R14 chemical cleaning program.

3.1.5 Potential Damage During Tube Pull

The pre-pull +Pt depth profile for the 01H elevation cracking indicates a length of 0.65", maximum depth of 88%TW, and an average depth of 62%TW. Depth profile evaluation from SEM examination indicates the 100%TW length due to corrosion was 0.252". Using the depth from phase angle, the predicted pre pull burst pressure for a flow stress of 76.73 ksi is 5612 psi. For the post pull +Pt depth profile, the predicted burst pressure from phase is 4615 psi. The depth profiles from phase angle show a reduced burst pressure for the post pull case versus the pre-pull case.

Figure 3.2 suggests that for the portion of the flaw above the centerline of the TSP, the pre-pull and post pull voltage plots are coincident, while below the centerline of the TSP, the voltage profiles are significantly different. The peak amplitude above the centerline of the TSP is consistent with 100%TW degradation; however, this area appears not to have been affected. Below the centerline of the TSP, the large amplitude increase (1.5 to 4.5 volts) at -0.10" may involve tearing of 2 closely spaced, <100%TW depth sections, thus producing such a large change in response. The +Pt amplitude response is increased with increasing 100%TW length, however if only one throughwall crack were involved, the point of peak amplitude

would be expected at the center of the flaw. In this case, the large amplitude response appears to have occurred at one end of the 100%TW length. Comparison of the pre-pull and post pull depth profiles in Figure 3.3 show that the depth estimates between about the TSP centerline and 0.25" below the TSP centerline are significantly elevated for the post pull case, again suggesting that a potential change in the 100%TW length of the flaw occurred. Figures 3-2 and 3-3 overlay the corrosion depth profile obtained from SEM analysis over the +Pt voltage and depth from phase plots. These figures show that the post pull maximum +Pt flaw amplitude and maximum depths are obtained outside of the corrosion depth profile indicating 100%TW degradation.

Based on the significant drop in predicted burst pressure from pre-pull to post pull conditions using the phase/depth analysis profile, and the presumed increase in 100%TW length from pre-pull to post pull conditions, it is probable that damage such as ligament tearing to the 01H intersection could have occurred during the tube pull operations. Table 3.4 presents a summary of the above sizing data for the phase based model in comparison with the destructive examination results.

3.1.6 Effectiveness of Chemical Cleaning Process

Freespan Regions:

The freespan regions of the tube were totally free of OD deposits, with a shiny condition.

TSP Regions:

The 02H TSP region was totally free of OD deposits, with shiny metal patches observed and very light loose deposit patches.

The 01H TSP region had two heavy deposit patches than ran over essentially the ¾" thickness of the TSP. These patches were located azimuthally at approximately 70° and 300°. The width of these deposit patches extended for approximately 20° arc (about 0.15"). Three additional heavy deposit patches, circular in nature, were noted at approximately 110°, 190°, and 240°, located above the TSP centerline. The diameter of these patches was approximately 1/8" to ¼". In between these heavy deposit patches, very light, loose surface deposit was noted. Shiny tube metal could not be observed at the 01H TSP. As previously noted, the location of the dominant axial cracking extended from about 315° arc to 0° arc to 45° arc, for a total of about 60° to 90° arc. The area of the dominant cracking was free from heavy deposits. From these observations, it would appear that upon startup, effective communication of secondary side bulk fluid would be provided to the crevice region, permitting boric acid introduction to the crevice region, thereby possibly reducing future crack growth rates. The partial deposit

removal at the 01H TSP can be expected to result in a fully packed crevice with time. The heavy deposit areas did not experience spalling of the deposits during the burst test.

3.1.7 Summary

The 01H and 02H TSP crevice regions of SG C, R15 C62 had OD intergranular corrosion. The predominant degradation mode is characterized as axial ODSCC. Consistent with previous Beaver Valley Unit 1 pulled tubes, there appears to be a cellular corrosion component that includes oblique cracking at depths less than the dominant axially oriented corrosion. The burst pressures of the 01H and 02H TSP regions exceeded the regulatory requirement of 1.4 x SLB pressure differential. For the 02H TSP region, no leakage was reported during elevated temperature leak testing. This is expected for the low amplitude bobbin indication (1.29 volts) found at this intersection. For the 01H TSP, leakage was reported for all test pressures ranging from normal operating to SLB conditions. The observance of leakage for this indication (5.3 volts) is not unanticipated since all 7/8" OD US pulled tubes with bobbin amplitudes exceeding 4.03 volts have produced leakage at SLB conditions. The leak rate for this intersection does represent a potential impact to the leak rate correlation. These implications are discussed later. The leak testing for the 01H TSP suggests that ductile tearing of a circumferential non degraded ligament occurred between 2200 and 2480 psi, resulting in a leak rate change from 0.013 gpm to 0.11 gpm.

3.2 Beaver Valley Unit 1 Pulled Tube Evaluation for Voltage-Based Repair Criteria Application

The pulled tube examination results were evaluated for application to the EPRI database for ARC applications. The data for incorporation into the EPRI database were then defined and reviewed against the EPRI outlier criteria to provide acceptability for the database.

3.2.1 Eddy Current Data Review

The post pull laboratory inspection results show a 71% increase in bobbin amplitude and a 52% increase in +Pt amplitude for the 01H intersection. The 02H intersection shows the bobbin amplitude was increased by nearly a factor of 3. The tube cutting operation may have introduced slight surface damage at the 02H intersection, rendering the post pull +Pt data inconclusive for this intersection. These increases tend to indicate that some ligaments likely tore during the tube pulling operation. However, increases of these magnitudes in the bobbin voltage are not unusual.

3.2.2 Beaver Valley Unit 1 Data for ARC Applications

The pulled tube leak test, burst test and destructive examination results are summarized in Table 3.5. The leak rates in this table have been adjusted to the reference conditions using the EPRI leak rate adjustment procedure commonly applied for data in the ARC database.

The Beaver Valley Unit 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 lea rate measurements and indications without leak test measurements. Criteria 1a to 1e are not applicable to the Beaver Valley Unit 1 indications. EPRI Criterion 2a applies to atypical ligament morphology for indications having high burst pressures relative to the burst/voltage correlation. Criterion 2a is not applicable to the Beaver Valley Unit 1 indications. Criterion 2b applies to large voltage indications that are more than 20 volts higher than the next adjacent data point, and is not applicable. Criterion 2c (not yet approved) applies to large voltage indications with atypical morphologies and subsequent leak rate test results that do not trend consistent with the pulled tube database. Criterion 2c is not applicable, however, the impact of the 2c criterion to the current approved database is substantial. Without application of the 2c criterion, the probability of leak for the 5.3 volt indication reported at 01H is approximately 20%, whereas if the 2c criterion is applied to the current database, the probability of leak for the 5.3 volt indication at 01H is approximately 50%. All 7/8" OD pulled tubes with bobbin amplitudes ≥ 4.03 volts have resulted in leakage at SLB conditions. Clearly without application of the 2c criterion, the calculated probability of leakage does not follow a trend that is consistent with the pulled tube database. Criterion 3 applies to potential errors in the leakage measurements and is not applicable to the Beaver Valley Unit 1 indications since there are no known errors in the measurements and the leak rates are not low relative to leak rate correlations.

3.3 Comparison of Beaver Valley Unit 1 Data with the EPRI Database

This section reports on the evaluations performed utilizing the leak rate and burst pressure test data described in the previous section. The data obtained from the tests are compared to the reference EPRI database for nominal 7/8" by 0.050" SG tubes as identified in Reference 9-4. The results of the destructive examinations of the tube sections are delineated in the previous two sections. Those results revealed no information that would lead to a conclusion that the data should not be included in the database.

This section presents results from the evaluations carried out to examine the effects of including the leak rate and burst pressure test results from the Beaver Valley Unit 1 pulled tube specimens on the reference database probability of leak, leak rate, and burst pressure

correlations to the bobbin amplitude.

3.3.1 Burst Pressure vs Bobbin Amplitude

The results from the burst tests, performed on tube specimens that exhibited a non-zero bobbin amplitude at a TSP elevation location, were considered for evaluation. A plot of the burst pressures of the Beaver Valley Unit 1, 2001 specimens is depicted on Figures 3.4 and 3.5 relative to the burst pressure correlation using the reference database. Figure 3.6 indicates that the probability of burst is essentially unaffected by the new data.

A visual examination of the data relative to the EPRI database indicates that the measured burst pressure of the 02H intersection, adjusted to the reference database material property value, lies well above the mean correlation line. The measured burst pressure of the 01H intersection, adjusted to the reference database material property value, lies significantly below the mean correlation line, and falls slightly below the lower tolerance bound (4250 psi vs 4453 psi).

The net effect of the changes on the SLB structural limit, using 95%/95% lower tolerance limit material properties, is to decrease it by 0.31 V, i.e., from 9.09 to 8.78 V.

3.3.2 Probability of Leak Correlation

The data of Table 3.5 were examined relative to the reference correlation for the probability of leak (POL) as a function of the common logarithm of the bobbin amplitude. Figure 3-7 illustrates the Beaver Valley Unit 1 data relative to the reference correlation. The 02H TSP exhibited expected POL behavior, i.e., the indication had low bobbin amplitude (1.29 V) and a low calculated probability of leakage, and did not leak. The 01H TSP had larger bobbin amplitude (5.3 V), and with inclusion of the EdF data in the POL database, also had a moderately low (22%) probability of leakage, and did leak at SLB conditions. Without the EdF data in the POL database, the probability of leakage is 52%, and is much more consistent with the performance of the US pulled tube database. Based on the impact the EdF data on the POL database, it can be argued that the 01H TSP represents an outlier point (outliers generally have an extremely low probability of occurrence, this is not an outlier, just a 1 in 5 chance of happening, and since several tubes get pulled over the years, these events should happen), however, if the EdF data is removed from the POL database, it can be argued that the leakage performance of the US 7/8" pulled tubes is much more consistent with POL. The US 7/8" OD pulled tubes that have leaked at SLB conditions range in bobbin amplitude from 4.03 to 13.55 volts. If the EdF data is included in the POL, the POL values for these indications ranges from 0.2 to 0.62, whereas if the EdF data is not included, the POL ranges from 0.29

to 0.96. Table 3.10 presents a comparison of the calculated POL with and without EdF data in the POL database for the 7/8" OD US pulled tubes that leaked at SLB conditions. The effective (observed) POL for all 7/8" OD US pulled tubes ≥4.03 volts is 1.0. The lowest reported 7/8" OD US pulled tube with leakage at SLB is 2.81 volts. There are 4, 7/8" OD US pulled tubes >2.81 volts but <4.03 volts that did not leak. There are 80, 7/8" OD US pulled tubes with reportable bobbin amplitudes < 2.81 volts that did not leak at SLB conditions.

In order to assess the quantitative effect of the new data on the correlation curve, the database was expanded to include the Beaver Valley Unit 1, 2001 pulled tube data points 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 3-10.

1) A 3.75% decrease (smaller absolute of a negative value) in the *logistic* slope intercept parameter (from -4.31823 to -4.15642).
2) A 2.46% decrease in the logistic slope parameter (from 4.21652 to 4.11275).
3) The absolute values of the variance and covariance of the parameters changed by 9.1 to 11.7%.
4) The deviance of the regression increased by 3.8%. An increase is expected when additional data is added. The Pearson standard error increased by 0.2%, i.e., from 74.5% to 74.7%. The ideal value for the Pearson standard error is unity, so this change is not significant and does not indicate a reduction in performance.

The addition of the Beaver Valley Unit 1, 2001 data had a negligible impact upon the POL. For example, for a 5 volt bobbin indication, the POL without Beaver Valley Unit 1 data is 0.203, whereas with the Beaver Valley Unit 1 data, the POL of a 5 volt indication is 0.219.

3.3.3 SLB Leak Rate vs. Bobbin Amplitude Correlation

As indicated previously, only the 01H TSP of R15 C62 leaked at SLB conditions. The following changes to the regression equation parameters resulted from the addition of the new data.

1) The intercept of the correlation curve increased (smaller absolute of a negative value) by 59% from about -0.527 to about -0.214.
2) The slope of the correlation curve decreases by 24% from about 0.987 to about 0.755.
3) The standard deviation of the common logarithm of the leak rate residual errors increases by 3.3%.

4) The *p* value for the slope coefficient increased from 3.5% to 7.9%.

The last effect described is the most significant in that the use of the regression equation is not permitted for simulations when the *p* value is greater than 5% per the guidance of GL 95-05. From a Bayesian statistics perspective, the *p* value is the probability that the true slope is equal to or less than zero (the "less than" situation being contrary to realistic expectation). Accordingly, it is then noted that the inclusion of the new data also increases the average leak rate (for indications that leak) by 4.9%, the average of the common logarithm of the leak rate by 5.5% and the standard deviation of the logarithm of the leak rate by 0.7%. The database for the 7/8" diameter tubes is susceptible to fluctuations in the *p* value more so than the database for the 3/4" diameter tubes (one of the arguments for the acceptance of the correlation is the strong value for the 3/4" diameter tubes). Hence, it is to be expected that there will be swings from below to above and back as data is added to the database. For example, the addition of a 5 volt indication with a leak rate of the order of 0.5 lph would result in the *p* value being less than 5% once again. However, this observation does not change the numerical results and future simulations will be affected.

The net effect of including the additional data is to increase the expected, i.e., arithmetic average, leak rate for bobbin amplitudes over the range of the data. For a 5 volt bobbin indication, the 95% leak rate without Beaver Valley Unit 1 data is 50.9 l/hr, with Beaver Valley Unit 1 data is 77.6 l/hr.

As with POL, the impact of the EdF data must be considered. If EdF data is excluded via the 2c exclusion criterion, the p value without and with Beaver Valley Unit 1 data changes from 0.9 to 2.7%.

3.4 Beaver Valley Unit 1 EOC-15 Leak Rate Estimation Including R15 C62 Leak Test Results

Since additional leak data is available from the present tube pulled examination for Beaver Valley-1, a sensitivity analysis was performed to estimate the impact upon predicted leak rate at EOC-15 conditions with the leak test results of the 2001 pulled tube included in the Reference 9-5 database. Until such time that the Industry database is formally updated, approved and issued for use in accordance with the NRC approved NEI protocol, the leak rate results with the newest pulled tube data from Beaver Valley added to said database are provided for information only.

The inclusion of the new leak rate data from tube R15 C62 in the ARC leak rate database for 7/8" tubes results in a data spread large enough that the *p* –value for the correlation slope parameter now exceeds the 5% limit established by the NRC. If the *p*-value exceeds 5%, the

GL 95-05 methodology requires that a bounding, constant leak rate (independent of voltage) plus uncertainty be applied to all simulated leaking indications.

Since the reference operational assessment analyses for Cycle 15 (using Reference 9-5 database) showed a substantial margin in the projected EOC-15 tube burst probability, only the leak rate data was updated and supplemental calculations were performed for the limiting SG. Reference 9-5 has recommended that the EdF data in the 7/8" tube database be excluded from the ARC database because they differ substantially from the domestic pulled tube in the potential for leakage at higher voltages (above 4 to 5 volts). An additional exclusion criterion for this purpose is presented in Reference 9-5. With EdF data excluded, inclusion of the latest Beaver Valley-1 leak rate data would not have a major impact of the leak rate correlation. However, if the EdF data is retained, the one-sided p-value for slope parameter in the updated leak rate vs bobbin voltage correlation exceeds 5%, which does not satisfy the GL 95-05 acceptance limit. Supplemental EOC-15 leak rate projections using the updated leak rate data were performed (for the limiting SG) both with the correlation and using a technique appropriate when a valid correlation not exist.

Cases 1a and 1b in Table 3-12 show calculated SLB leak rates when the new data is included in the leak rate correlation but not in the POL correlation. A comparison of the calculated leak rates for Case 1a vs. 2a and Case 1b vs. 2c show that the impact of the new leak data on POL is not as significant as the impact on leak rate. The bulk of the impact on leak rate arises from the requirement to assume the leak rate to be independent of voltage when the *p*-value for the correlation slope parameter exceeds the 5% limit. This is evident from comparison of the leak rates calculated with and without applying a leak vs. voltage correlation (compare Case 1a vs. 1b and Case 2a vs. 2c). A comparison of the calculated leak rates for Cases 2a and 2b show that the use of voltage-dependent POPCD reduces leak rate by about 32%.

The limiting EOC-15 leak rate thus predicted is 33.6 gpm (room temperature), for the condition where a correlation is assumed not to exist (Case 2a). However, it is noted that the Addendum 4 update (Reference 9-5) has presented justification for excluding the EdF data in the database for 7/8" tubes because they are not consistent with US pulled tube or model boiler data. An exclusion criterion is provided in the Addendum 4 update to address such indications. If the EdF data is excluded, the *p* –value for the leak rate correlation slope parameter meets the 5% limit after including the present data from tube R15 C62, and the resulting leak rate correlation yields a EOC-15 leak rate of 3.72 gpm for SG-A (Case 3 of Table 3-12). The NRC has not yet provided a ruling on the Addendum 4 exclusion criterion.

The industry has suggested that for the no-correlation case, the bounding leak rate grossly overestimates postulated leakage. If a similar methodology is applied to postulated leakage at normal operating conditions, postulated leakage would far exceed 1 gpm at normal operating conditions. The NRC has argued that packed crevice corrosion products could

preclude leakage at normal operating conditions for indications with significant throughwall corrosion lengths. For the Beaver Valley condition, the chemical cleaning crevice cleaning step is believed to have removed the vast majority of the crevice packing product (see Section 3.1.6). Thus for Beaver Valley Unit 1, if the leak rate prediction assumptions for the no correlation case are considered, and if the constant POD of 0.6 was an accurate assessment of true POD, primary to secondary leakage would be expected at levels far above the 150 gpd technical specification limit. No primary to secondary leakage is currently reported at Beaver Valley Unit 1.

Table 3-1: BVPS Unit 1, SG C, R15 C62, 01H TSP Leak Rate Test Data			
ΔP (psi)	Pri. Temp. (°F)	Sec. Temp. (°F)	Leak Rate (gpm)
1457	610	616	0.0004
1429	609	614	0.0004
1766	580	592	0.0017
1749	581	593	0.0015
2067	561	535	0.0066
2197	575	504	0.0128
2488	598	401	0.1097
2463	601	400	0.1153
2560	Normalized (1)	Normalized (1)	0.181

(1): Normalized according to methodology provided by ERPI NP-7480-L.

Table 3-2: BVPS Unit 1, SG C, R15 C62 Burst Test Results			
Location	Burst Pressure (psi)	Burst Opening Length	Burst Opening Width
TTS	10984	1.781"	0.349"
01H	4741	0.585"	0.085"
02H	8640	1.053"	0.272"
Freespan	10813	1.775"	0.355"

Table 3-3: Comparison of Destructive Exam Corrosion Profile and NDE Based Sizing Data for R15 C62 01H			
	Pre-Pull	Post Pull	SEM Corrosion Profile
Parameter	Phase-Depth	Phase-Depth	Truth
Max Depth	88%	94.5%	100%
Avg Depth	62%	68.5%	70.9%
Length	0.65"	0.71"	0.68"
Length >80%TW	0.21"	0.36"	0.36"
100%TW Length	0.00"	0.00"	0.252"
Burst Pressure	5612 psi	4615 psi	4741 psi

Table 3-5: Beaver Valley Unit 1 2001 Pulled Tube Data for ARC Applications																
Tube	TSP	Bobbin Data		+Pt Volts	Destructive Examination Results				Leak Rate (l/hr)		Burst Pressure Data - ksi					
		Volts	Depth		Max Depth	Avg Depth	Crack Length (inch)	No. Lig. (2)	NormOp 1300 psid	SLB 2560 psid (5)	Meas. Burst Pressure	Yield Str. (ksi)	Ult. Str. (ksi)	Adj. Burst Pressure (3)	Use in Corr. (4)
R15 C62	01H	5.30	81%	2.99	100%	70.92%	0.68" 0.25"TW	9	0.051	42.6	4.741	48.463	104.997	4.250	B, POL, L
R15 C62	02H	1.29	59%	0.19	60%	40.64%	0.53"	2	0	0	8.640	48.463	104.997	7.745	B, POL
	FS (1)										10.813	48.463	104.997	9.693	

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
3. Burst pressure adjusted to 68.78 ksi average flow stress at 650°F for 7/8" diameter tubing.
4. 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.
5. SLB leak rate at 2560 psid.

Table 3-6: R15 C62 01H Destructive Examination Burst Crack Depth Profile Based on SEM Analysis			
Tube	Elevation Relative to TSP Centerline	Elevation and Depth Relative to Top of Flaw	Comments
R15 C62 01H	0.355	0.00 0%	
	0.345	0.01 9%	
	0.335	0.02 12%	
	0.325	0.03 0%	
	0.315	0.04 46%	
	0.305	0.05 41%	Ligament: 0.002" width
	0.295	0.06 42%	
	0.265	0.09 40%	Ligament: 0.005" width
	0.235	0.12 63%	Ligament: 0.001" width
	0.195	0.16 88%	Ligament: 0.006" width
	0.175	0.18 91%	
	0.165	0.19 100%	
			Ligament (at 0.33" elevation): 0.002" width
			Ligament (at 0.36" elevation): 0.003" width
	-0.085	0.44 100%	Ligament (at 0.43" elevation): 0.007" width
	-0.095	0.45 92%	
	-0.135		Ligament (at 0.47" elevation): 0.003" width
		0.49 83%	
	-0.155	0.51 64%	
	-0.185	0.54 75%	Ligament: 0.006" width
	-0.215	0.55 66%	
	-0.225	0.58 50%	
	-0.245	0.59 36%	
	-0.255	0.61 40%	Ligament: 0.001" width
	-0.285	0.64 26%	
	-0.305	0.66 10%	Ligament: 0.002" width
	-0.325	0.68 0%	
		Max Depth 100%TW Avg Depth 70.92%TW	

Table 3-7: R15 C62 02H Destructive Examination Burst Crack Depth Profile Based on SEM Analysis				
Tube	Elevation Relative to TSP Centerline	Elevation and Depth Relative to Top of Flaw		Comments
R15 C62 02H	0.255	0	0	
	0.245	0.01	8	
	0.215	0.04	19	
	0.205	0.05	28	
	0.195	0.06	36	Ligament: 0.002" width
	0.155	0.1	48	
	0.145	0.11	60	
	0.135	0.12	56	
	0.125	0.13	51	
	0.095	0.16	52	
	0.055	0.2	48	
	0.045	0.21	45	
	0.005	0.25	48	
	-0.005	0.26	44	
	-0.015	0.27	40	
	-0.025	0.28	36	
	-0.035	0.29	47	
	-0.065	0.32	44	
	-0.075	0.33	48	
	-0.115	0.37	44	
	-0.145	0.4	43	Ligament: 0.003" width
	-0.175	0.43	44	
	-0.225	0.48	40	
	-0.235	0.49	39	
	-0.255	0.51	28	
	-0.265	0.52	7	
	-0.275	0.53	0	
		Max Depth	60%TW	
		Avg Depth	40.64%TW	

Table 3-8: Effect of Beaver Valley Unit 1, 2001 Data on the 7/8" Tube Burst Pressure vs Bobbin Amplitude Correlation

$$P_b = a_0 + a_1 \log(Volts)$$

Parameter	Addendum 4 Database	Addendum 4 Database with BVPS Unit 1, 2001 Data	New / Old Ratio
a_0	7.55943	7.55184	0.999
a_1	-2.37763	-2.39285	1.006
r^2	82.36%	81.97%	0.995
$\sigma Error$	0.81919	0.82802	1.011
Mean log(V)	0.28645	0.28921	
SS log(V)	50.4190	50.6409	
N (data pairs)	93	95	
Str. Limit (2560 psi)	9.09 V	8.78 V	0.966
Str. Limit (2405 psi)	11.40 V	11.00 V	0.965
p Value for a_1	2.4×10^{-36}	1.14×10^{-36}	2.10
Reference σf	68.78 ksi		

Notes: (1) Values reported correspond applying a safety factor of 1.4 on the differential pressure associated with a postulated SLB event.
(2) Numerical values are reported only to demonstrate compliance with the requirement that the value be less than 0.05
(3) 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 Beaver Valley Unit 1, 2001 Data on the 7/8" Tube Probability of Leak Correlation

$$P(Leak) = \frac{1}{1 + e^{-[b_1 + b_2 \log(Volts)]}}$$

Parameter	Addendum 4 Database	Addendum 4 Database with BVPS Unit 1, 2001 Data	New / Old Ratio
Logistic Intercept, b_1	-4.31823	-4.15642	0.963
Logistic Slope, b_2	4.21652	4.11275	0.975
V_{11} (1)	0.66934	0.59110	0.883
V_{12}	-0.58947	-0.52488	0.890
V_{22}	0.58997	0.53648	0.909
Number of Data	139	141	
Deviance	78.83	81.83	1.038
MSE	0.575	0.589	1.023
Pearson SD	74.5%	74.7%	1.003

Notes: (1) Parameters V_{ij} are elements of the covariance matrix of the coefficients, b_i, of the regression analysis.

Table 3-10: POL Comparison of 7/8" OD US Pulled Tubes with Leakage at SLB						
	7/8" US Pulled Tubes with Leakage at SLB Conditions and Bobbin Amplitude					
POL Case	R4 C73 2.81 V	R28 C35 4.03 V	R15 C62 5.30 V	R34 C53 6.8 V	R21 C22 7.56 V	R2 C85 13.55 V
Add 4 with BV, with EdF	9%	16%	24%	32%	37%	62%
Add 4 with BV, without EdF	11%	29%	51%	71%	77%	96%
2560 psi Leak Rate (l/hr)	0.08	1.84	42.6	2.08	0.07	140
100%TW Corrosion Length	0.18"	0.00" (96% max depth)	0.252"	0.282"	0.15"	0.42"

Table 3-11: Effect of Beaver Valley Unit 1 Data on the Leak Rate vs. Bobbin Amplitude Correlation (2560 psi)

$$Q = 10^{b_3 + b_4 \log(Volts)}$$

Parameter	EPRI Addendum 4 Database	Addendum 4 Database with BVPS Unit 1, 2001 Data	Addendum 4 Database with BVPS Unit 1, 2001 Data w/o EdF Data	New / Old Ratio
Intercept, b_3	-0.526882	-0.213666	-0.450217	0.405529
Slope, b_4	0.987179	0.754577	1.017213	0.764377
Index of Deter., r^2	11.7%	7.0%	13.6%	0.598291
Residuals, σError (b_5)	0.808109	0.834540	0.784088	1.03271
Data Pairs, N	29	30	28	
Mean of Log (V)	1.15437	1.140031	1.124122	0.987578
SS of Log (V)	2.39739	2.576203	2.437548	1.074586
p Value for b_4	3.5%	7.9%	2.7%	2.257
Mean Log(Leak)	0.61268	0.64657	0.69326	1.0553
St. Dev. Log(Leak)	0.84449	0.85031	0.82791	1.0069
Mean Leak Rate (lph)	17.2845	18.1283	19.1525	1.0488

Table 3-12
Beaver Valley-1 EOC-15 Projections
Supplemental Leak Rate Results for the Limiting SG (SG-A)

Assumed Cycle 15 duration = 545 EFPD

Case	POL Correlation	Leak Rate Database	Leak Rate Correlation Used?	95/95 EOC-15 Leak Rate	Comments
Reference	Addendum-4 (EDF data included)	Addendum-4 (EDF data included)	Yes	5.50 gpm	Does NOT include 2001 Beaver Valley-1 data, POD=0.6
Case 1a	Addendum-4 (EDF data included)	Updated database with EDF and 2001 Beaver Valley-1 Data	No	30.4 gpm	POD=0.6
Case 1b			Yes	12.0 gpm	POD=0.6 Leak rate correlation applied - *p* > 5%
Case 2a	Updated database including EDF data and 2001 Beaver Valley-1 Data	Updated database including EDF data and 2001 Beaver Valley-1 Data	No	33.6 gpm	POD=0.6
Case 2b				25.7 gpm	POPCD
Case 2c			Yes	13.7 gpm	POD=0.6 Leak rate correlation applied *p* > 5%
Case 3	Updated database with 2001 Beaver Valley-1 Data EDF data excluded	Updated database with 2001 Beaver Valley-1 Data EDF data excluded	Yes	3.44 gpm	EDF data excluded

Figure 3.1
Field +Pt Terrain Plot for R15 C62, 01H TSP, SG C

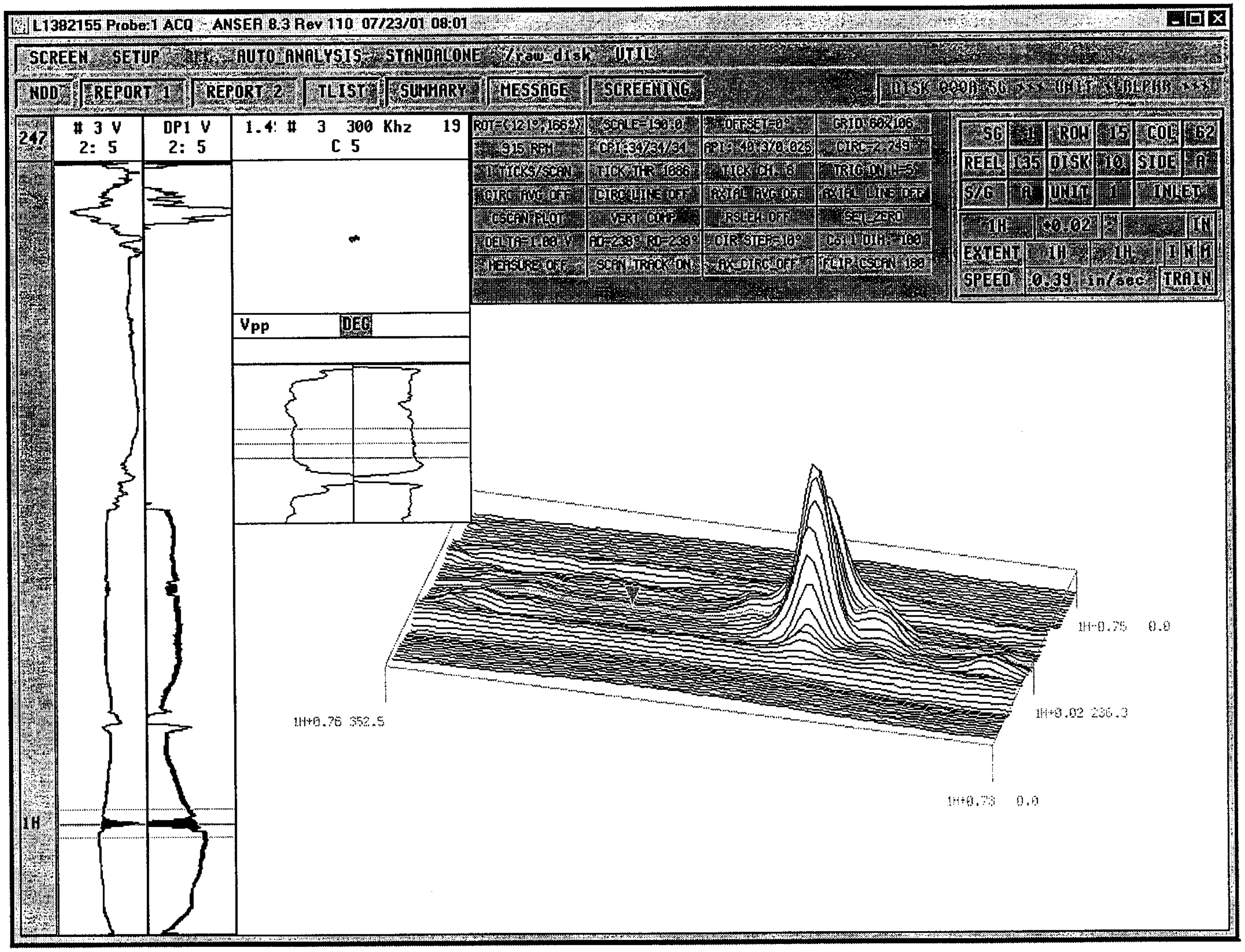


Figure 3.1
Field +Pt Terrain Plot for R15 C62, 01H TSP, SG C

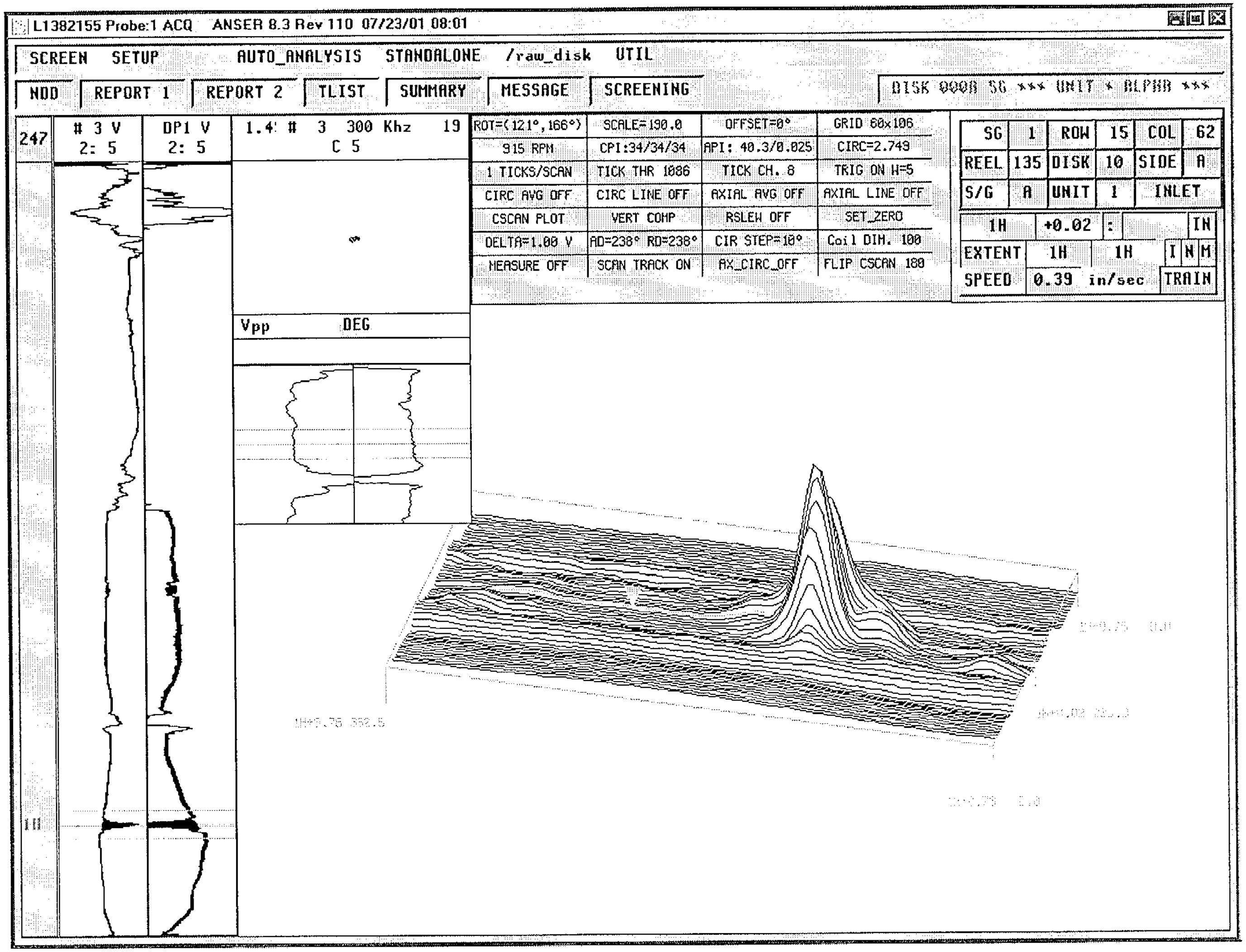


Figure 3.2
Pre-Pull and Post Pull +Pt Amplitude Plot for Flaw 2 at 01H of R15 C62

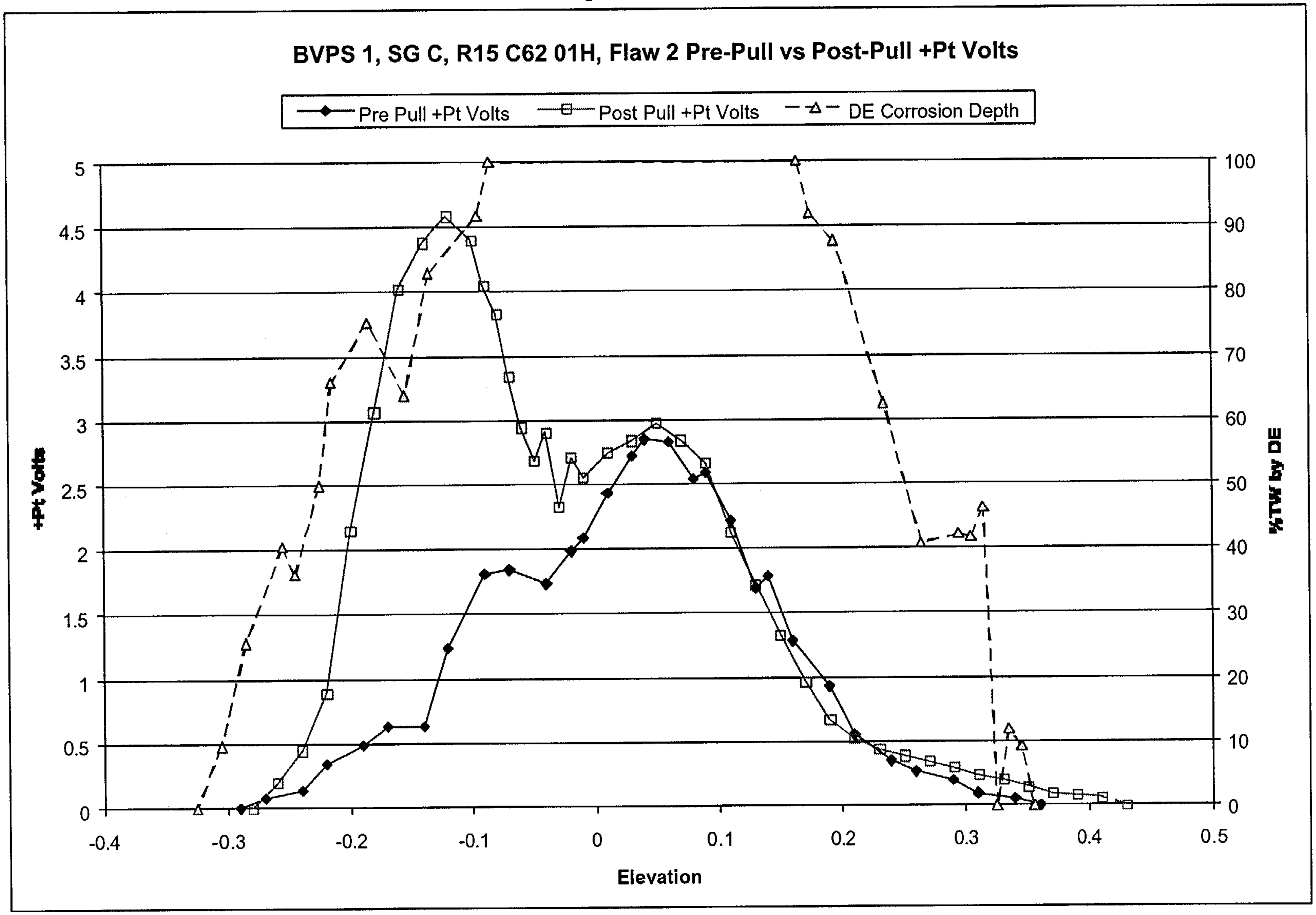


Figure 3.3
Pre-Pull and Post Pull Depth Plot for Flaw 2, R15 C62 at 01H

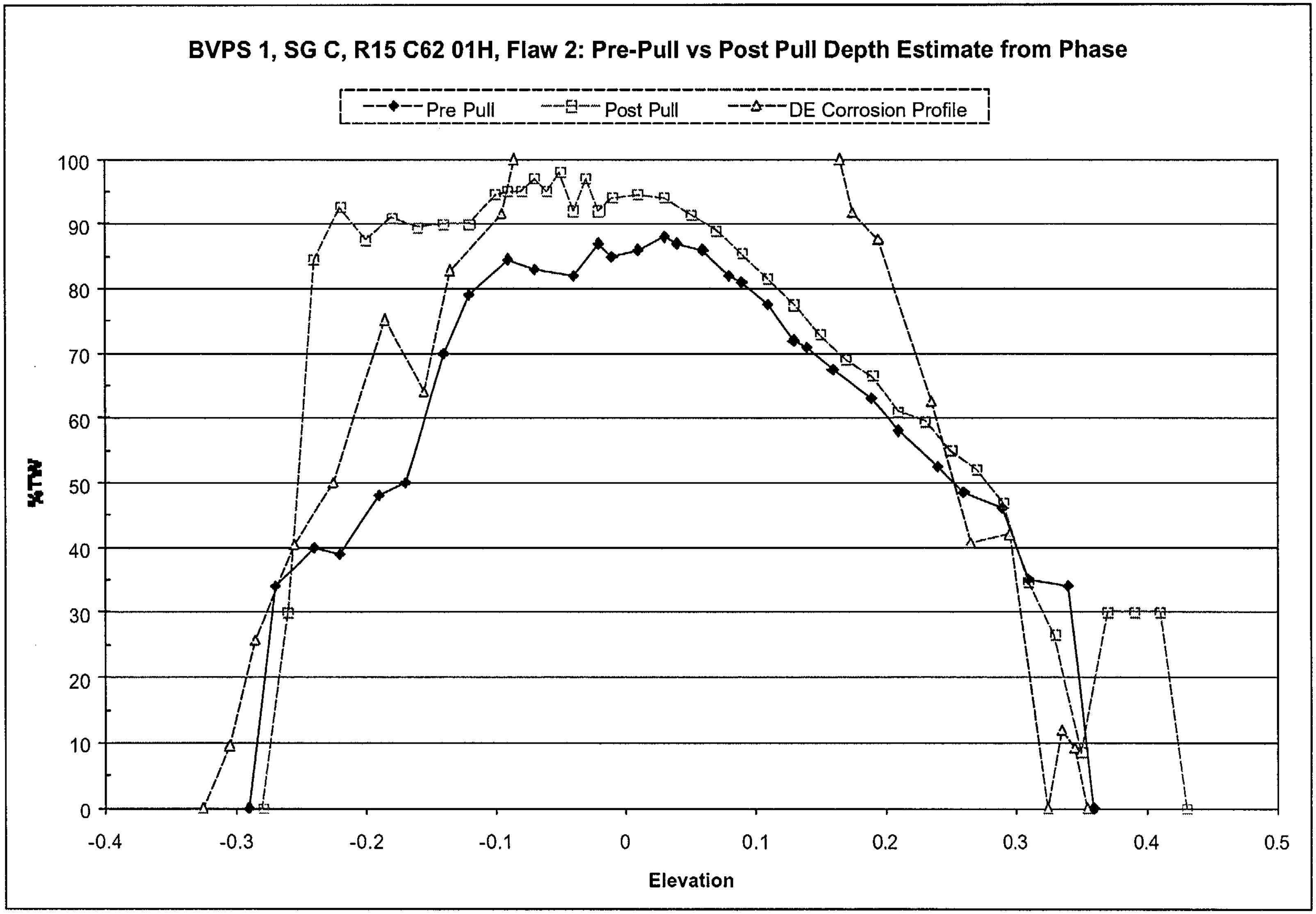


Figure 3.4
Post Burst Photograph of R15 C62, 01H TSP

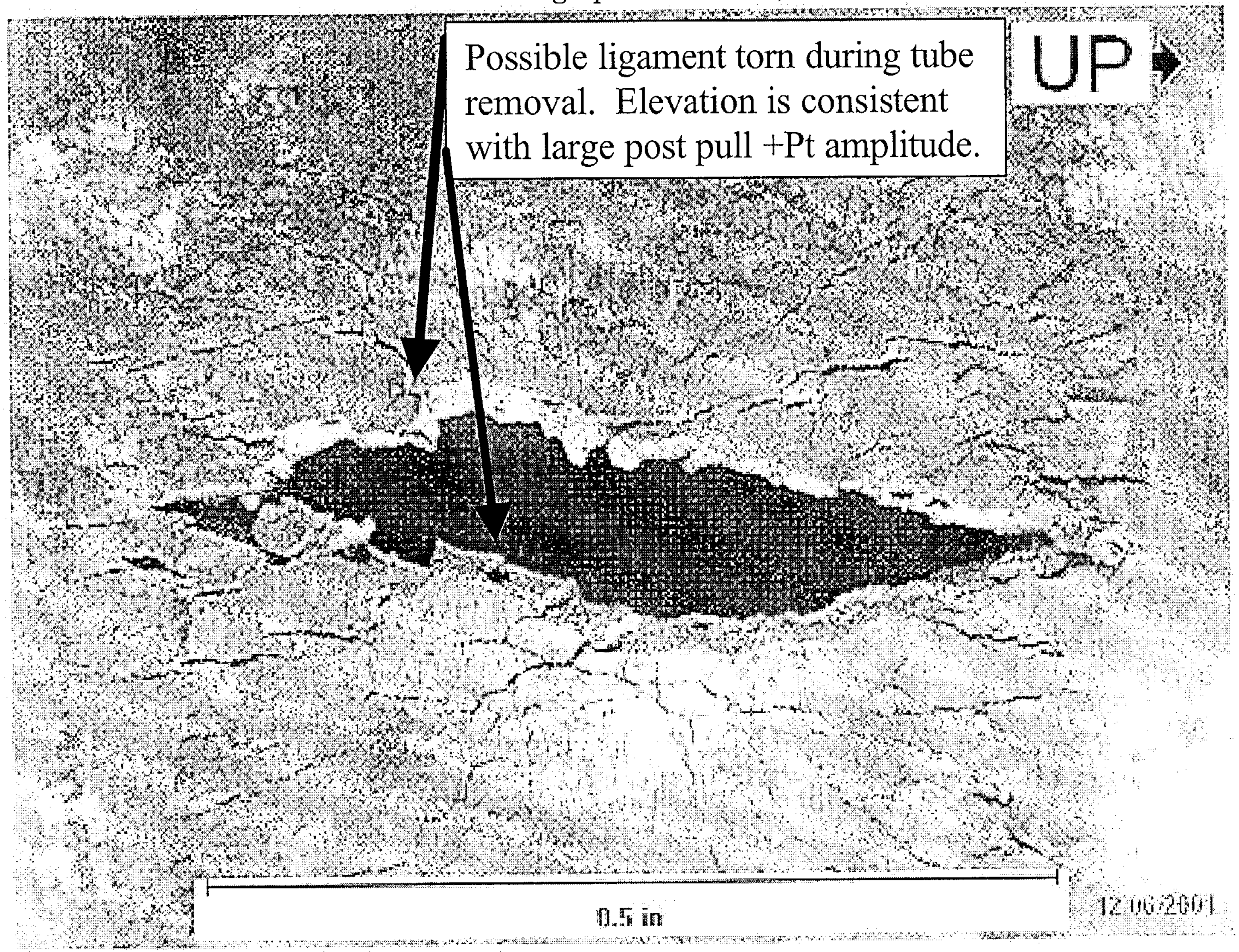


Figure 3.5

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

Additional Data, Reference σ_f = 68.8 ksi @ 650°F

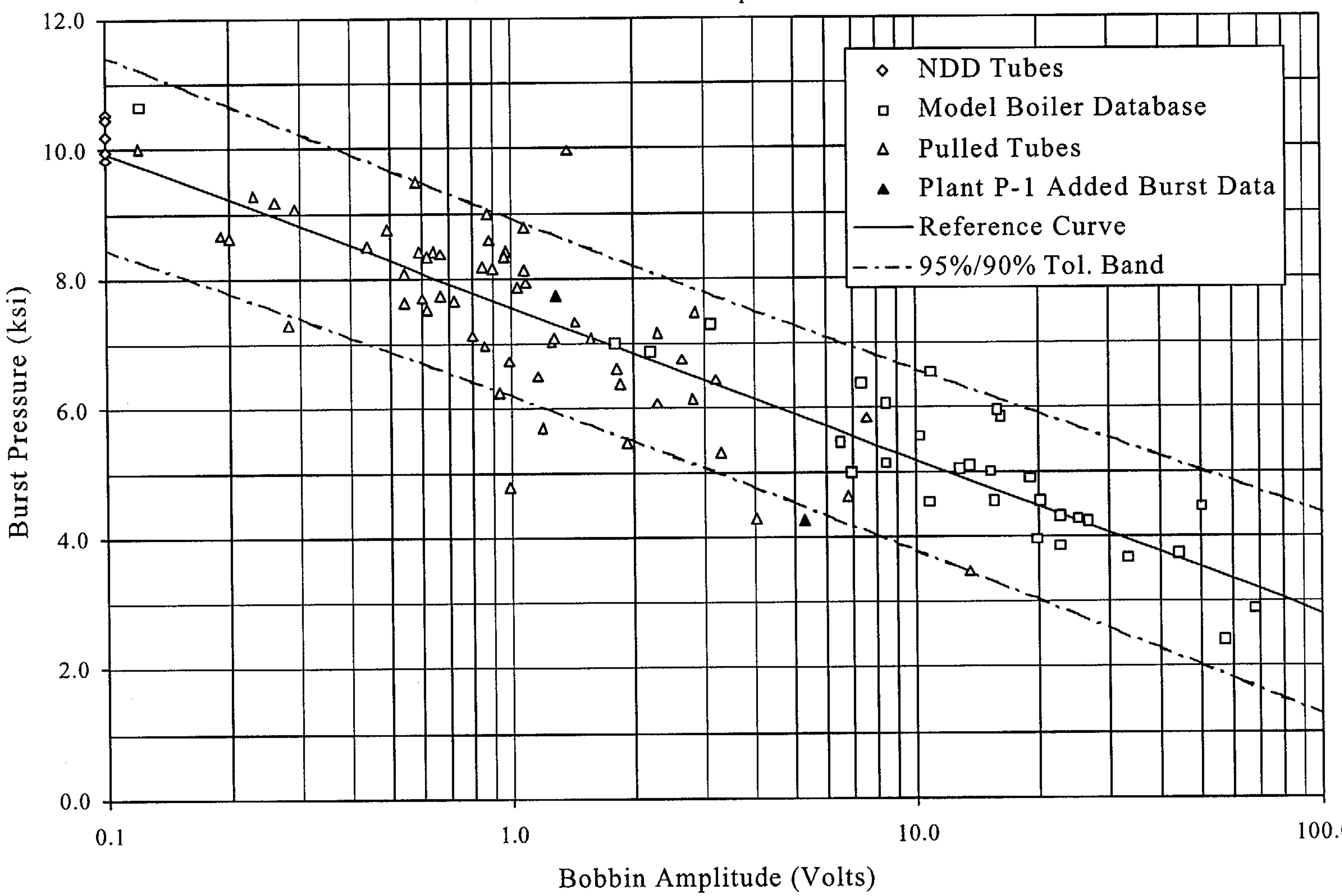


Figure 3.6

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

Reference Database, Reference σ_f = 68.8 ksi @ 650°F

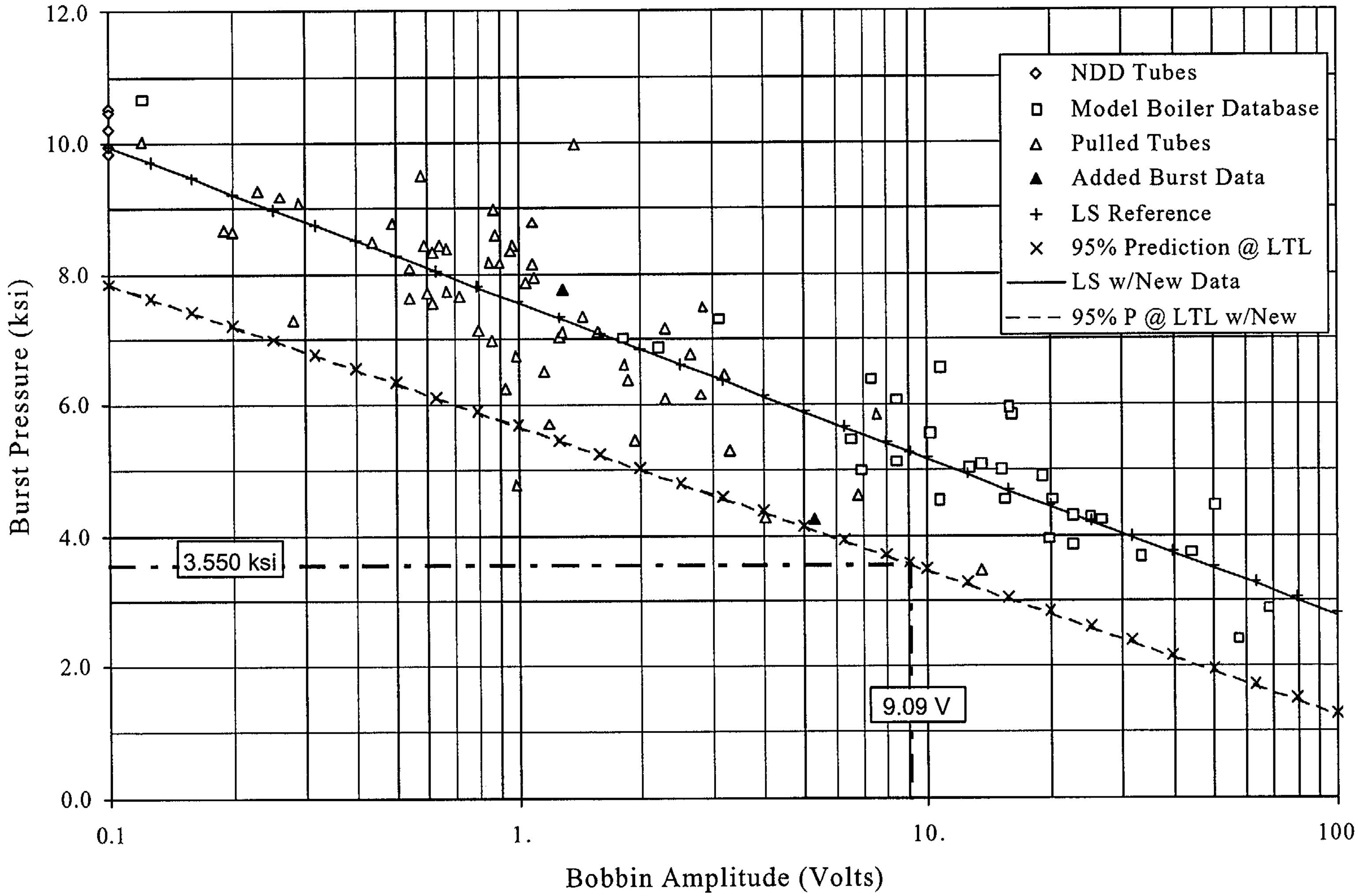
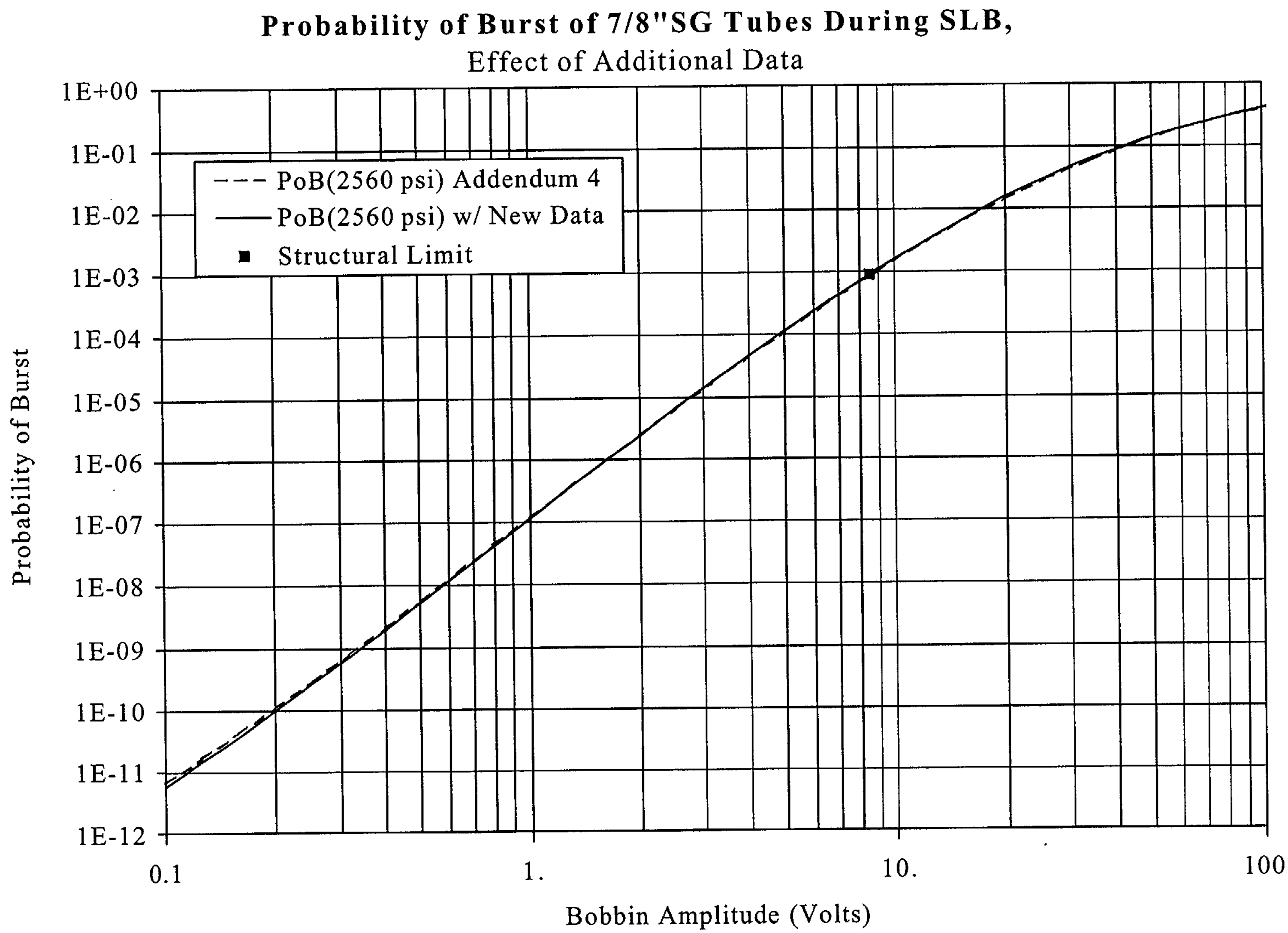
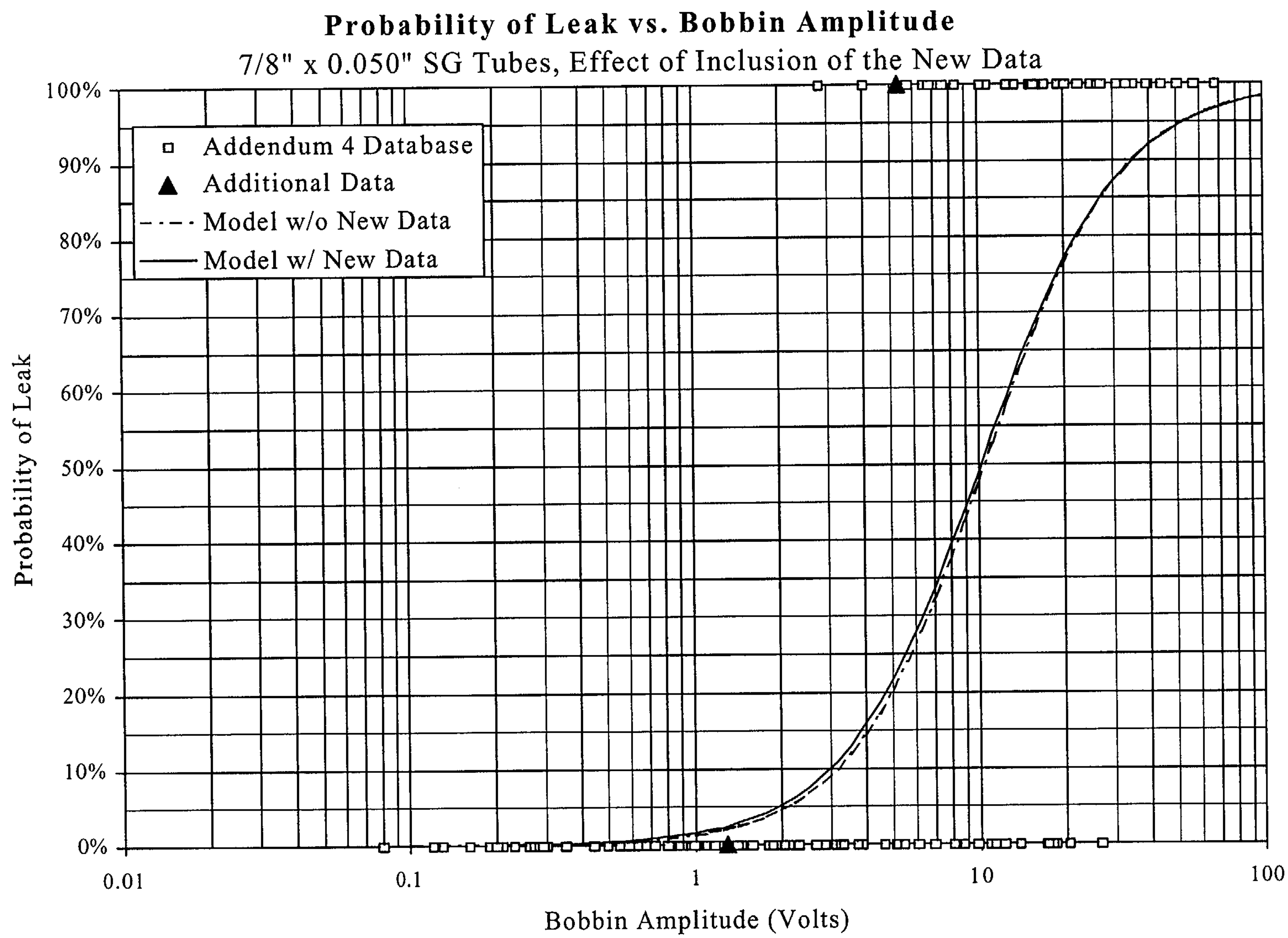


Figure 3.7



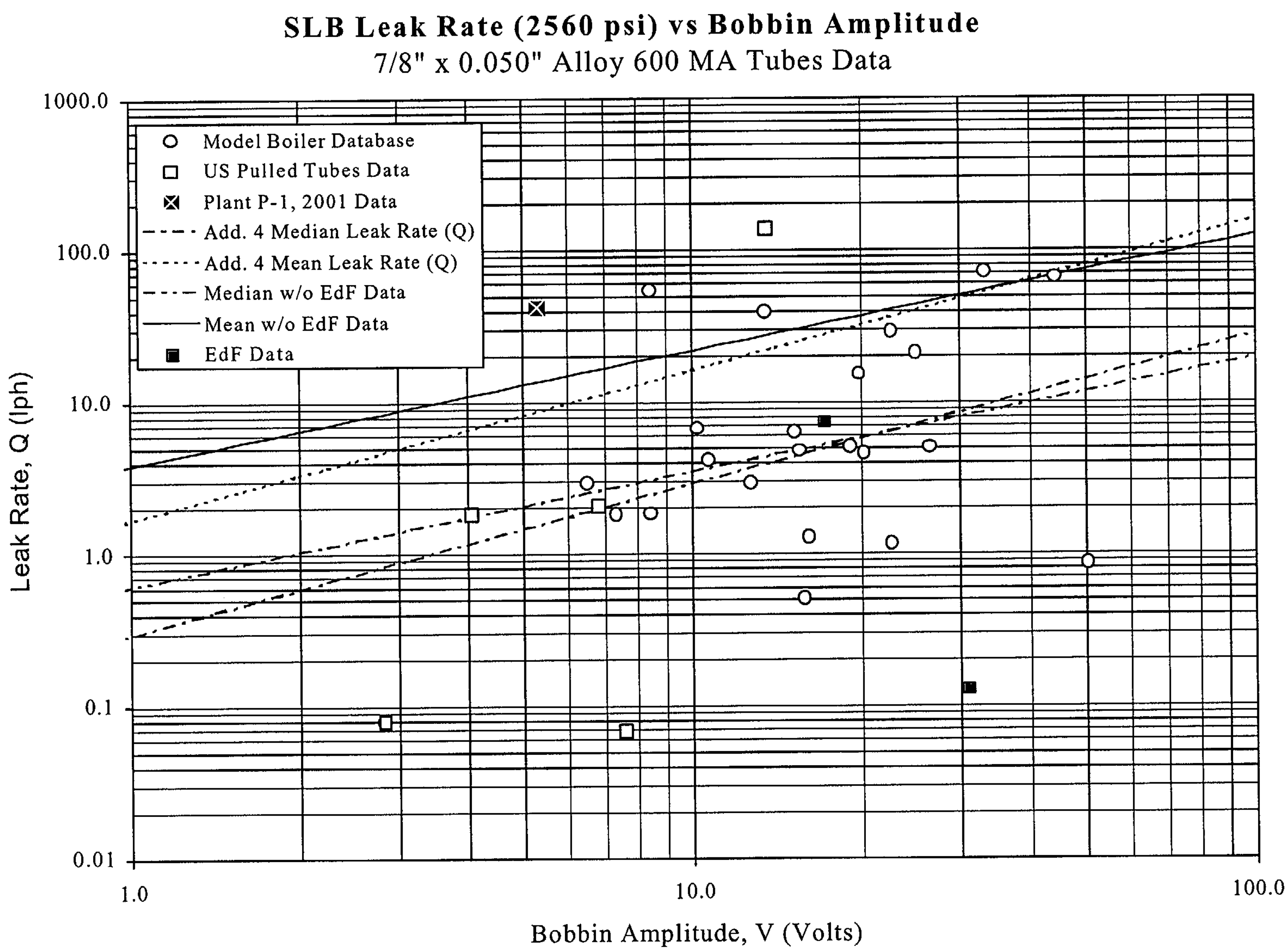
Probability of Burst of 7/8"SG Tubes During SLB,
Effect of Additional Data
PoB(2560 psi) Addendum 4
PoB(2560 psi) w/ New Data
Structural Limit
Probability of Burst
1E+00
1E-01
1E-02
1E-03
1E-04
1E-05
1E-06
1E-07
1E-08
1E-09
1E-10
1E-11
1E-12
0.1
1.
10.
100.
Bobbin Amplitude (Volts)

Figure 3.8



Probability of Leak vs. Bobbin Amplitude
7/8" x 0.050" SG Tubes, Effect of Inclusion of the New Data
Addendum 4 Database
Additional Data
Model w/o New Data
Model w/ New Data
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Probability of Leak
0.01
0.1
1
10
100
Bobbin Amplitude (Volts)

Figure 3.9



SLB Leak Rate (2560 psi) vs Bobbin Amplitude
7/8" x 0.050" Alloy 600 MA Tubes Data
Model Boiler Database
US Pulled Tubes Data
Plant P-1, 2001 Data
Add. 4 Median Leak Rate (Q)
Add. 4 Mean Leak Rate (Q)
Median w/o EdF Data
Mean w/o EdF Data
EdF Data
1000.0
100.0
10.0
1.0
0.1
0.01
Leak Rate, Q (lph)
1.0
10.0
100.0
Bobbin Amplitude, V (Volts)

4.0 EOC-14 Inspection Results and Voltage Growth Rates

4.1 EOC-14 Inspection Results

According to the guidance provided by the NRC Generic Letter 95-05, the EOC-14 inspection of the Beaver Valley Unit-1 SGs consisted of a complete, 100% eddy current (EC) bobbin probe full length examination of the tube bundles in all three SGs. RPC examination was also performed for all but 3 indications with amplitude 2 volts and above and 20 percent of the hot leg indications between 1 and 2 volts. The 3 indications above 2 volts that could not be RPC inspected were present in tubes that had sleeves at elevations below the elevation of the >2 volt indications, which restricted access to those indications. Those 3 indications were removed from service. All 17 indications above 2 volts that were RPC inspected were confirmed, and they were also removed from service. Only a total of 8 ODSCC indications were found on the cold leg side at the TSPs from all 3 SGs combined. There were no circumferential indications at TSPs, and no indications extending outside TSPs. Dents 2 volts or larger on the hot leg side of the first three TSPs and all other TSP dents over 5 volts were also inspected with RPC; no degradation, either circumferential or ID initiated, was detected. Additionally, the 100 largest distorted signal indications < 2 volts were RPC inspected in each SG to confirm morphology. Axial ODSCC only was reported in these additionally tested indications.

A summary of the EC indications for all three SGs is shown on Table 4-1, which tabulates the number of field bobbin indications, the number of those indications that were RPC inspected, the number of RPC confirmed indications, and the number of indications removed from service due to tube repairs. The indications that remain active for Cycle 15 operation is the difference between the observed and the ones removed from service. No tubes were deplugged in the current inspection with the intent of returning them to service after inspection in accordance with the alternate repair criteria (ARC).

Overall, the combined data for all three SGs of Beaver Valley Unit-1 show the following:

- Out of a total of 3533 TSP indications identified during the inspection, a total of 469 were RPC inspected.
- Of the 469 RPC inspected, 436 were RPC confirmed.
- Twenty indications exceeded the 2 volt repair limit.
- A total of 3368 indications were returned to service for Cycle 15 operation.

A review of Table 4-1 indicates that more indications (a quantity of 1455, with 269 indications

above 1.0 volt) were returned to service in SG-A than the other SGs; thereby it potentially will be the limiting SG at EOC-15. It is noted that one relatively large indication (5.3 volts) was found in SG-C in the EOC-14 inspection, and although it was removed from service, the residual indication resulting from application of a constant POD=0.6 may result in the EOC-15 burst probability projection for SG-C exceeding that for SG-A.

Figure 4-1 shows the actual bobbin voltage distribution determined from the EOC-14 EC inspection; Figure 4-2 shows the population distribution of those EOC-14 indications removed from service due to tube repairs; Figure 4-3 shows the distribution for indications returned to service for Cycle 15 operation. Of the 132 indications removed from service, only 20 indications exceeding 2 volts were repaired due to ODSCC at TSPs. The rest of the indications are in tubes plugged for degradation mechanisms other than ODSCC at TSPs.

The distribution of EOC-14 indications as a function of support plate location is summarized in Table 4-2 and plotted in Figure 4-4. The data show a strong predisposition of ODSCC to occur in the first few hot leg TSPs (3310 out of 3533 indications occurred at the hot leg intersections in the first three TSPs), although the mechanism extended to higher TSPs. Only a total of 8 indications were detected on the cold leg side in all 3 SGs combined. This distribution indicates the predominant temperature dependence of ODSCC at Beaver Valley Unit-1, similar to that observed at other plants.

4.2 Voltage Growth Rates

For projection of leak rates and tube burst probabilities at the end of Cycle 15 operation, voltage growth rates were developed from EOC-14 inspection data and a reevaluation of the EOC-13 inspection EC signals for the same indications. Table 4-3 shows the cumulative probability distribution for growth rate in each Beaver Valley Unit-1 steam generator during Cycle 14 (March 2000 - September 2001) on an EFPY basis, along with the corresponding Cycle 13 growth rate distributions. Cycle 14 growth data for all 3 SGs are also plotted in Figure 4-5. The curve labeled "cumulative" in Figure 4-5 represents averaged composite growth data from all three SGs.

Average growth rates for each SG during Cycle 14 are summarized in Table 4-4, and all three SGs show comparable average growth rates. The average growth rates over the entire voltage range vary between 8.2 % and 9.0% (of the BOC voltage) per EFPY, between the SGs, with an overall average of 8.5% per EFPY. SG-A had a slightly lower growth than the other two SGs. The difference in voltage growth for indications below and above 0.75 volts is not significant. Table 4-5 provides a comparison of average growth data for the last 8 operating cycles. The Cycle 14 growth rates are less than the Cycle 13 growth rates, which may be a residual effect of the chemical cleaning crevice cleaning process applied at the 1R14 outage.

The bobbin voltage growth distributions for the last two cycles in the form of cumulative probability distribution functions (CPDF) are shown in Table 4-3, and the same data is presented in a graphical form on Figure 4-6. The growth data are presented on an EFPY basis to account for the difference in the length of the two operating periods. Since the Cycle 13 growth distribution in Figure 4-6 lies to the right of the Cycle 14 distribution, the former distribution is considered more limiting. However, since the Cycle 14 distribution includes one relative large value in the tail (3.44 volts), it may yield a higher burst probability than the Cycle 13 growth distribution. Therefore, Cycle 15 operational assessment analysis was carried out using both Cycle 13 and 14 growth distributions and the larger SLB leak rate and tube burst probability values from the two sets of analysis are reported.

Table 4-6 lists the top 30 indications on the basis of Cycle 14 growth rates in descending order, and the data confirms that Cycle 14 had only modest growth. With the exception of one indication, all indications had under 1.5 volts growth during Cycle 14. Of these 30 highest growth indications, 16 were found in previously plugged tubes that were deplugged and returned to service at BOC-14. The occurrence of more than 50% of the top growth indications for Cycle 14 in a relatively small population of deplugged tubes returned to service at BOC-14 shows that indications in deplugged tubes experience higher growth rates than rest of the indication population. This growth behavior is consistent with that for tubes deplugged in previous outages at Beaver Valley Unit-1 as well as at several other plants. It is also noted that BOC-14 voltages were not available for 5 of the 6 new indications (all in deplugged tubes) and they were conservatively set to 0.1 volt to maximize growth rate. The Cycle 14 growth data shown in Tables 4-2 to 4-5 Figures 4-5 and 4-6 represent the combined data for tubes active in Cycle 13 and deplugged returned to service at BOC-14.

Some plants have experienced growth rates that demonstrated a potential dependency on the BOC voltages of previously identified indications. Large growths were observed primarily in indications with a BOC voltage over 1.5 volts. To determine if Beaver Valley Unit-1 exhibited a similar trend, the growth rate data for Cycle 14 was plotted against BOC voltage, and the resulting plot is shown in Figure 4-7. Although the largest growth was observed in the largest left in service at BOC-14, the rest of Cycle 14 growth data do not show any trend to increase with the BOC voltage. Therefore, growth can be assumed independent of voltage in the Monte Carlo analysis for operational assessment.

4.3 Probe Wear Criteria

An alternate probe wear criteria approved by the NRC (Reference 9-6) was applied during the EOC-14 inspection. When a probe does not pass the 15% wear limit, this alternate criteria requires that only tubes with indications above 75% of the repair limit inspected since the last successful probe wear check be reinspected with a good probe. As the repair limit for Beaver

Valley Unit-1 is 2 volts, all tubes containing indications for which the worn probe voltage is above 1.5 volts are to be inspected with a new probe. A total of 28 indications with a bobbin voltage above 1.5 volts were found in the calibration groups that failed probe wear checks, and the tubes containing those indications were reinspected with a new probe. No new indications were indicated during reinspection with a new probe, and no indications had its voltage increase above the repair limit when reinspected with a good probe. For indications with a worn probe voltage above 1.5 volts, the average difference between the worn and new probe voltages is only about 0.21 volt. Figure 4-8 shows plots of the worn probe voltages plotted against the new probe voltages for all three SGs. The data for SG-A and SG-B are shown in the same plot. The data in Figure 4-8 show a consistent relationship between the two voltages, with worn probe voltages being generally higher.

Composite data from all three SGs are plotted in Figure 4-9. Also shown in Figure 4-9 as a solid line is a linear regression for the data, dashed lines representing tolerance limits that bound 90% of the population at 95% confidence, and chained lines representing ±25% band for the new probe voltages. The mean regression line has a slope slightly above 45° indicating that, on the average, worn probe voltages are slightly higher than the new probe voltages. The dotted horizontal line at 1.5 worn probe volts demarcates indications requiring retest from those that do not. The shaded area at the bottom shows the region where a tube requiring repair may be left in service because of probe wear. In the Beaver Valley-1 EOC-14 inspection, there are no occurrences for which a worn probe was less than 1.5 volts and the new probe voltage exceeded the plugging limit, i.e., no pluggable tubes were missed due to probe wear considerations. Among the indications requiring retesting (worn probe volts > 1.5 volts), only 3 indications fall outside the 90%/95% tolerance limit bands. However, the worn probe voltages for 2 of those indications are higher than the corresponding new probe voltages, i.e., the worn probe voltages are conservative, and the third is just outside the tolerance band. Therefore the data for these indications are acceptable.

Overall, it is concluded that the criteria to retest tubes with worn probe voltages above 75% of the repair limit is adequate. The alternate probe wear criteria used in the EOC-14 inspection is consistent with the NRC guidance provided in Reference 9-6.

As required by Reference 9-6, the number of new indications detected in the present inspection in tubes that were inspected with a worn probe in the last inspection was also determined. Out of a total of 335 new indications found in the current inspection, only 24 are in tubes inspected with a worn probe in the last inspection, which is not considered a disproportionate number of indications since they were found in a tube population making up 8 calibration groups. Also, actual indication population distributions from the current inspection were compared against the projected distributions based on the prior cycle data present--ed in Reference 9-2, and the projections were found to be conservative (see Section 6.0 for details). Thus, the requirements specified in Reference 9-6 for applying the alternate

probe wear criteria are met.

4.4 NDE Uncertainties

The NDE uncertainties applied for the Cycle 14 voltage distributions in the Monte Carlo analyses for leak rate and burst probabilities are the same as those previously reported in the Beaver Valley Unit-1 voltage-based repair criteria report of Reference 9-2 and NRC Generic Letter 95-05 (Reference 9-1). 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. If the random sample of probe wear selected during the Monte Carlo simulations exceed 15%, sampling of the probe wear distribution is continued until a value less than 15% is picked. 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 for SLB leak rates and tube burst probabilities based on the EOC-14 actual voltage distributions as well as for the EOC-15 projections. In the EOC-15 projection analysis, NDE uncertainty adjustment is applied to the BOC voltage before growth is added to obtain EOC voltage.

4.5 Probability of Prior Cycle Detection (POPCD)

The inspection results at EOC-14 permit an evaluation of the probability of detection at the prior EOC-13 inspection. For voltage-based repair criteria 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 voltage-based repair criteria 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) for the EOC-13 inspection can then be defined as follows.

$$\underset{(\text{EOC }13)}{\text{POPCD}} = \frac{\text{EOC-14 RPC confirmed indications reported in EOC-13 inspection} + \text{Indications confirmed and repaired in EOC-13 inspection}}{\{\text{Numerator}\} + \text{New indications RPC confirmed in EOC-14 inspection}}$$

POPCD is evaluated at the 2000 EOC-13 voltage values (from 2001 reevaluation for growth rate) since it is an EOC-13 POPCD assessment. The indications detected at EOC-13 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-14. It is also appropriate to include the plugged tubes for voltage-based repair criteria 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-14 indications not reported in the EOC-13 inspection. The new indications include EOC-13 indications present at detectable levels but not reported, indications present at EOC-13 below detectable levels and indications that initiated during Cycle 14. Thus, this definition, by including newly initiated indications, differs from the traditional POD definition. Since the newly initiated indications are appropriate for voltage-based repair criteria 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-14 indications were RPC inspected. Since only a fraction of bobbin indications are generally RPC inspected, POPCD could be distorted by using only the RPC inspected indications. Thus, 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 2001 EOC-14 indications not RPC inspected since inclusion for the EOC-13 inspection could increase POPCD by including indications on a tube plugged for non-ODSCC causes which could have RPC NDD indication. In addition, the objective of using RPC confirmation for POPCD is to distinguish detection of indications at EOC_{n-1} that could contribute to burst at EOC_n so that the emphasis is on EOC_n RPC confirmation. This POPCD can be obtained by replacing the EOC-14 RPC confirmed by RPC confirmed plus not RPC inspected in the above definition of POPCD. For this report, both POPCD definitions are evaluated for Beaver Valley Unit-1.

The POPCD evaluation for the 2000 EOC-13 inspection data is shown on Figure 4-9 and summarized in Table 4-7. A generic POPCD distribution developed by analyzing data from 29 inspections in 13 plants, presented in Table 7-4 of Reference 9-5, is also shown in Figure 4-9. Only the POPCD values based on a relatively small number of indications (less than 30) in Table 4-7 (voltage bins up to 0.8 volt for RPC confirmed indications category) have a value below the NRC mandated POD value of 0.6. The rest of the POPCD values in Table 4-7 are substantially higher than 0.6. The POPCD values exceed 0.90 beyond 1.0 volt.

In summary, the Beaver Valley Unit-1 EOC-14 POPCD strongly supports a voltage dependent POD substantially higher than the NRC mandated POD value of 0.6 above about 0.8 volt and approaching unity at about 2.0 volts, and it is in good agreement with the generic POPCD distribution presented in Reference 9-5

4.6 Assessment of RPC Confirmation Rates

This section tracks the 2000 EOC-13 indications left in service at BOC-14 relative to RPC inspection results in 2001 at EOC-14. Composite results for all SGs are given in Table 4-8. For the 2000 bobbin indications left in service, the indications are tracked relative to 2000 RPC confirmed, 2000 RPC NDD, 2000 bobbin indications not RPC inspected and 2000 bobbin indications with no indication found in 2001. Also included are new 2001 indications. The table shows, for each category of indications, the number of indications RPC inspected and RPC confirmed in 2001 as well as the percentage of RPC confirmed indications.

Out of a total of 30 RPC NDD indications from all three SGs left in service in 2000, 11 were RPC tested in 2001 and 4 of those were confirmed. Thus, the overall RPC confirmation rate for 2000 RPC NDD indications is about 36%. This overall confirmation rate is significantly below that found for RPC NDD indications tested in last inspection (87.1% in 2000), but slightly above that for the 1997 inspection (27.3%). For successive ARC inspections at other plants, the confirmation rate for RPC NDD indications left in service was typically < 40%.

The NRC SER for Beaver Valley-1 (Reference 9-7) allows for consideration of only a fraction of RPC NDD indications from current inspection in establishing BOC voltage distribution for the next cycle. The fractional value applicable is the largest RPC confirmation rate for prior cycle RPC NDD indications found during the last two outages, but it may not be less than 0.7. Since the RPC confirmation rate for the 2000 inspections was 87%, all EOC-14 RPC NDD indications were included in the Cycle 15 operational assessment.

Table 4-1
Beaver Valley Unit 1 September 2001 Outage
Summary of Inspection and Repair For Tubes in Service During Cycle 14

Voltage Bin	Steam Generator A						Steam Generator B					
	In-Service During Cycle 14				RTS for Cycle 15		In-Service During Cycle 14				RTS for Cycle 15	
	Field Bobbin Indications	RPC Inspected	RPC Confirmed	Indications Repaired	All Indications	Confirmed & Not Inspected Indications Only	Field Bobbin Indications	RPC Inspected	RPC Confirmed	Indications Repaired	All Indications	Confirmed & Not Inspected Indications Only
0.1	1	0	0	0	1	1	0	0	0	0	0	0
0.2	7	1	1	0	7	7	21	0	0	0	21	21
0.3	73	3	3	6	67	67	52	0	0	2	50	50
0.4	135	7	5	1	134	132	117	1	1	3	114	114
0.5	203	2	2	7	196	196	139	2	2	4	135	135
0.6	203	8	8	6	197	197	168	1	1	3	165	165
0.7	187	5	5	4	183	183	147	2	2	1	146	146
0.8	171	5	5	8	163	163	99	7	3	1	98	94
0.9	148	3	3	8	140	140	101	15	13	3	98	96
1	108	12	11	7	101	100	69	3	3	0	69	69
1.1	66	8	8	4	62	62	47	8	7	0	47	46
1.2	70	11	10	1	69	68	38	8	8	0	38	38
1.3	40	22	22	3	37	37	24	24	24	1	23	23
1.4	34	29	28	2	32	31	26	23	23	1	25	25
1.5	18	16	16	0	18	18	20	16	16	0	20	20
1.6	26	21	21	2	24	24	10	8	8	0	10	10
1.7	7	6	6	0	7	7	8	7	7	1	7	7
1.8	11	10	9	0	11	10	7	7	7	0	7	7
1.9	10	9	9	2	8	8	7	7	7	1	6	6
2	4	4	4	0	4	4	4	3	3	0	4	4
2.1	3	3	3	3	0	0	5	4	4	5	0	0
2.2	1	1	1	1	0	0	1	1	1	1	0	0
2.4	1	0	0	1	0	0	0	0	0	0	0	0
2.5	2	1	1	2	0	0	0	0	0	0	0	0
2.8	1	1	1	1	0	0	0	0	0	0	0	0
5.3	0	0	0	0	0	0	0	0	0	0	0	0
Total	1530	188	182	69	1461	1455	1110	147	140	27	1083	1076
> 1V	294	142	139	22	272	269	197	116	115	10	187	186
>2v	8	6	6	8	0	0	6	5	5	6	0	0

Voltage Bin	Steam Generator C						Composite of All SGs					
	In-Service During Cycle 14				RTS for Cycle 15		In-Service During Cycle 14				RTS for Cycle 15	
	Field Bobbin Indications	RPC Inspected	RPC Confirmed	Indications Repaired	All Indications	Confirmed & Not Inspected Indications Only	Field Bobbin Indications	RPC Inspected	RPC Confirmed	Indications Repaired	All Indications	Confirmed & Not Inspected Indications Only
0.1	1	0	0	0	1	1	2	0	0	0	2	2
0.2	17	1	1	0	17	17	45	2	2	0	45	45
0.3	44	0	0	1	43	43	169	3	3	9	160	160
0.4	93	1	0	2	91	90	345	9	6	6	339	336
0.5	101	1	1	7	94	94	443	5	5	18	425	425
0.6	113	1	1	2	111	111	484	10	10	11	473	473
0.7	87	0	0	3	84	84	421	7	7	8	413	413
0.8	105	3	1	4	101	99	375	15	9	13	362	356
0.9	85	0	0	2	83	83	334	18	16	13	321	319
1	49	5	1	1	48	44	226	20	15	8	218	213
1.1	36	9	7	4	32	30	149	25	22	8	141	138
1.2	26	5	3	0	26	24	134	24	21	1	133	130
1.3	39	11	9	2	37	35	103	57	55	6	97	95
1.4	22	22	18	0	22	18	82	74	69	3	79	74
1.5	18	18	17	0	18	17	56	50	49	0	56	55
1.6	17	17	16	1	16	15	53	46	45	3	50	49
1.7	13	13	13	1	12	12	28	26	26	2	26	26
1.8	8	8	8	0	8	8	26	25	24	0	26	25
1.9	7	7	6	0	7	6	24	23	22	3	21	20
2	6	6	6	0	6	6	14	13	13	0	14	14
2.1	4	4	4	4	0	0	12	11	11	12	0	0
2.2	1	1	1	1	0	0	3	3	3	3	0	0
2.4	0	0	0	0	0	0	1	0	0	1	0	0
2.5	0	0	0	0	0	0	2	1	1	2	0	0
2.8	0	0	0	0	0	0	1	1	1	1	0	0
5.3	1	1	1	1	0	0	1	1	1	1	0	0
Total	893	134	114	36	857	837	3533	469	436	132	3401	3368
> 1V	198	122	109	14	184	171	689	380	363	46	643	626
>2v	6	6	6	6	0	0	20	17	17	20	0	0

Table 4-2
Beaver Valley Unit 1 September 2001
TSP ODSCC Indication Distributions for Tubes in Service During Cycle 14

Tube Support Plate	Steam Generator A					Steam Generator B				
	Number of Indications	Maximum Voltage	Average Voltage	Largest Growth	Average Growth	Number of Indications	Maximum Voltage	Average Voltage	Largest Growth	Average Growth
01H	813	2.13	0.78	1.31	0.08	578	2.12	0.79	1.24	0.07
02H	511	2.71	0.73	1.41	0.07	324	2.07	0.71	1.12	0.09
03H	127	2.45	0.73	1.42	0.08	116	1.79	0.58	0.49	0.06
04H	40	1.92	0.66	0.84	0.08	61	1.35	0.56	0.37	0.04
05H	23	1.10	0.49	0.46	0.06	21	0.98	0.46	0.17	0.02
06H	9	0.95	0.47	0.17	0.04	5	0.52	0.41	0.16	0.08
07H	3	0.43	0.38	0.07	-0.31	4	0.40	0.35	0.05	0.03
07C	3	0.53	0.49	0.17	0.12	1	0.27	0.27	0.08	0.08
04C	0	-	-	-	-	0	-	-	-	-
02C	0	-	-	-	-	0	-	-	-	-
01C	1	0.65	0.65	0.19	0.19	0	-	-	-	-
Total	1530					1110				

Tube Support Plate	Steam Generator C					Composite of All SGs				
	Number of Indications	Maximum Voltage	Average Voltage	Largest Growth	Average Growth	Number of Indications	Maximum Voltage	Average Voltage	Largest Growth	Average Growth
01H	448	5.30	0.88	3.44	0.10	1839	5.30	0.81	3.44	0.08
02H	292	1.91	0.70	0.86	0.07	1127	2.71	0.71	1.41	0.08
03H	101	1.54	0.64	0.45	0.07	344	2.45	0.65	1.42	0.07
04H	21	1.49	0.62	0.24	0.06	122	1.92	0.60	0.84	0.06
05H	20	0.55	0.34	0.30	0.02	64	1.10	0.43	0.46	0.04
06H	8	0.51	0.33	0.19	0.03	22	0.95	0.41	0.19	0.04
07H	0	-	-	-	-	7	0.43	0.36	0.07	-0.12
07C	0	-	-	-	-	4	0.53	0.44	0.17	0.11
04C	2	0.35	0.34	0.04	0.03	2	0.35	0.34	0.04	0.03
02C	1	0.42	0.42	-0.02	-0.02	1	0.42	0.42	-0.02	-0.02
01C	0	-	-	-	-	1	0.65	0.65	0.19	0.19
Total	893					3533				

Table 4-3
Beaver Valley Unit 1 September 01
Signal Growth Statistics For Cycle 14 on an EFPY Basis

Delta Volts	Steam Generator A			Steam Generator B			Steam Generator C			Cumulative		
	Cycle 13	Cycle 14		Cycle 13	Cycle 14		Cycle 13	Cycle 14		Cycle 13	Cycle 14	
	CPDF	No. of Inds	CPDF	CPDF	No. of Inds	CPDF	CPDF	No. of Inds	CPDF	CPDF	No. of Inds	CPDF
-0.5	0.0	1	0.001	0.0	0	0.0	0.0	0	0.0	0.0	1	0.0
-0.4	0.0	4	0.003	0.0	0	0.0	0.0	0	0.0	0.0	4	0.001
-0.3	0.0	8	0.008	0.0	4	0.004	0.0	0	0.0	0.0	12	0.005
-0.2	0.0	20	0.022	0.0	14	0.016	0.0	9	0.01	0.0	43	0.017
-0.1	0.0031	87	0.078	0.004	60	0.07	0.001	30	0.044	0.003	177	0.067
0	0.0936	371	0.321	0.078	254	0.299	0.102	246	0.319	0.0909	871	0.314
0.1	0.6098	647	0.744	0.551	501	0.75	0.613	364	0.727	0.5926	1512	0.742
0.2	0.9009	251	0.908	0.877	170	0.904	0.87	158	0.904	0.8853	579	0.905
0.3	0.9795	83	0.962	0.97	78	0.974	0.977	54	0.964	0.9759	215	0.966
0.4	0.9961	33	0.984	0.996	18	0.99	0.994	23	0.99	0.9954	74	0.987
0.5	0.9992	10	0.99	0.997	5	0.995	0.998	5	0.996	0.998	20	0.993
0.6	1.0	1	0.991	1.0	2	0.996	0.999	1	0.997	0.9997	4	0.994
0.7		3	0.993		0	0.996	1.0	2	0.999	1.0	5	0.995
0.8		4	0.995		2	0.998		0	0.999		6	0.997
0.9		2	0.997		1	0.999		0	0.999		3	0.998
1		2	0.998		1	1.0		0	0.999		3	0.999
1.1		3	1.0		0			0	0.999		3	0.9997
2.6		0			0			1	1.0		1	1.0
Total		1530			1110			893			3533	

Table 4-4
Beaver Valley Unit 1 - September 2001 Outage
Average Voltage Growth During Cycle 14

Voltage Range	Number of Indications	Average Voltage BOC	Average Voltage Growth		Percent Growth	
			Entire Cycle	Per EFPY #	Entire Cycle	Per EFPY #
	Composite of All Steam Generator Data					
Entire Voltage Range	3533	0.67	0.076	0.057	11.4%	8.5%
V_{BOC} < .75 Volts	2371	0.48	0.080	0.060	16.6%	12.4%
≥ .75 Volts	1162	1.05	0.068	0.050	6.4%	4.8%
	Steam Generator A					
Entire Voltage Range	1530	0.67	0.074	0.055	11.0%	8.2%
V_{BOC} < .75 Volts	1032	0.49	0.086	0.064	17.5%	13.1%
≥ .75 Volts	498	1.05	0.049	0.036	4.6%	3.4%
	Steam Generator B					
Entire Voltage Range	1110	0.65	0.073	0.054	11.2%	8.4%
V_{BOC} < .75 Volts	763	0.47	0.075	0.056	15.9%	11.8%
≥ .75 Volts	347	1.03	0.068	0.050	6.6%	4.9%
	Steam Generator C					
Entire Voltage Range	893	0.69	0.083	0.062	12.1%	9.0%
V_{BOC} < .75 Volts	576	0.47	0.075	0.056	15.9%	11.9%
≥ .75 Volts	317	1.07	0.097	0.073	9.1%	6.8%

. Based on Cycle 14 duration of 490 EFPD (1.342 EFPY)

Table 4-5
Beaver Valley Unit 1 September 2001
Average Voltage Growth for Cycle 14
Composite of All Steam Generator Data

Bobbin Voltage Range	Number of Indications	Average Voltage BOC	Average Voltage Growth		Average Percentage Growth	
			Entire Cycle	Per EFPY	Entire Cycle	Per EFPY
	Cycle 14 (2000 - 2001) - 490 EFPD					
Entire Voltage Range	3533	0.67	0.076	0.057	11.4%	8.5%
$V_{BOC} < .75$ Volts	2371	0.48	0.080	0.060	16.6%	12.4%
$\geq .75$ Volts	1162	1.05	0.068	0.050	6.4%	4.8%
	Cycle 13 (1997 - 2000) - 500 EFPD					
Entire Voltage Range	3024	0.56	0.138	0.101	24.8%	18.1%
$V_{BOC} < .75$ Volts	2371	0.43	0.127	0.093	29.6%	21.7%
$\geq .75$ Volts	653	1.03	0.180	0.131	17.5%	12.8%
	Cycle 12 (1996 - 1997) - 415.4 EFPD					
Entire Voltage Range	2910	0.60	-0.025	-0.022	-4.3%	-3.8%
$V_{BOC} < .75$ Volts	2181	0.46	-0.020	-0.017	-4.4%	-3.8%
$\geq .75$ Volts	729	1.01	-0.042	-0.037	-4.1%	-3.6%
	Cycle 11 (1995 - 1996) - 352.94 EFPD					
Entire Voltage Range	1936	0.60	-0.005	-0.005	-0.8%	-0.9%
$V_{BOC} < .75$ Volts	1434	0.46	0.006	0.007	1.3%	1.4%
$\geq .75$ Volts	502	0.94	-0.037	-0.038	-4.0%	-4.1%
	Cycle 10 (1993 - 1995) - 435.79 EFPD					
Entire Voltage Range	1089	0.66	0.020	0.017	3.0%	2.5%
$V_{BOC} < .75$ Volts	751	0.50	0.040	0.034	8.0%	6.7%
$\geq .75$ Volts	338	1.01	-0.010	-0.008	-1.0%	-0.8%
	Cycle 9 (1991 - 1993) - 492.75 EFPD					
Entire Voltage Range	1125	0.57	0.090	0.067	15.8%	11.7%
$V_{BOC} < .75$ Volts	918	0.47	0.090	0.067	19.1%	14.2%
$\geq .75$ Volts	207	1.02	0.090	0.067	8.8%	6.5%
	Cycle 8 (1989 - 1991) - 390.82 EFPD					
Entire Voltage Range	952	0.95	0.180	0.168	18.9%	17.7%
$V_{BOC} < .75$ Volts	366	0.58	0.160	0.150	27.6%	25.8%
$\geq .75$ Volts	586	1.18	0.190	0.178	16.1%	15.0%
	Cycle 7 (1987 - 1989) - 438.3 EFPD					
Entire Voltage Range	918	0.66	0.290	0.242	43.9%	36.6%
$V_{BOC} < .75$ Volts	622	0.49	0.270	0.225	55.1%	45.9%
$\geq .75$ Volts	296	1.01	0.340	0.283	33.7%	28.1%

Table 4-6
Beaver Valley Unit 1 September 2001
Summary of Largest Voltage Growth Rates for BOC-14 to EOC-14

Steam Generator				Bobbin Voltage			EOC-13	EOC-14 RPC		New
SG	Row	Col	Elevation	EOC	BOC	Growth	Deplugged Tube ?	Inspected?	Confirmed ?	Indication ?
C	15	62	01H	5.3	1.86	3.44	N	Y	Y	N
A	2	48	03H	1.54	0.10#	1.42	Y	N	-	Y
A	3	21	02H	2.34	0.93	1.41	Y	N	-	N
A	3	56	02H	2.49	1.13	1.36	Y	N	-	N
A	2	57	01H	1.9	0.59	1.31	Y	N	-	N
A	28	70	02H	2.71	1.42	1.29	N	Y	Y	N
B	7	81	01H	1.66	0.42	1.24	N	Y	Y	N
B	17	14	02H	1.36	0.24	1.12	N	N	-	N
A	19	58	01H	1.58	0.48	1.1	Y	N	-	N
A	2	57	02H	1.21	0.10#	1.09	Y	N	-	Y
A	20	52	01H	2.03	0.96	1.07	N	Y	Y	N
B	13	35	02H	2.01	0.99	1.02	Y	N	-	N
A	14	34	03H	1.41	0.4	1.01	Y	N	-	N
A	10	40	01H	1.75	0.77	0.98	Y	N	-	N
B	10	33	01H	1.06	0.10#	0.96	Y	N	-	Y
A	2	48	01H	1.08	0.10#	0.96	Y	N	-	Y
A	5	19	01H	1.56	0.66	0.9	Y	N	-	N
C	39	33	02H	1.41	0.55	0.86	N	Y	Y	N
A	3	56	04H	1.34	0.5	0.84	Y	N	-	N
A	3	20	03H	0.95	0.10#	0.83	Y	N	-	Y
C	4	15	01H	1.39	0.57	0.82	N	Y	N	Y
C	37	41	01H	1.85	1.05	0.8	N	Y	Y	N
B	19	61	02H	2.07	1.28	0.79	N	Y	Y	N
B	14	68	01H	2.04	1.32	0.72	N	Y	Y	N
A	13	3	01H	1.18	0.49	0.69	N	N	-	N
B	14	68	02H	1.82	1.15	0.67	N	Y	Y	N
C	38	55	01H	1.48	0.84	0.64	N	Y	Y	N
A	27	21	01H	1.03	0.41	0.62	N	N	-	N
A	15	42	03H	1.18	0.56	0.62	Y	N	-	N
A	29	41	01H	1.19	0.58	0.61	Y	N	-	N

Assumed BOC-14 voltage since EOC-13 voltage was not available.

Table 4-7
Beaver Valley Unit 1 2001 EOC-14 Evaluation for Probability of Prior Cycle Detection
Composite of All Steam Generator Data

Voltage Bin	New Indications		2001 Bobbin, Field Call in 2000 Inspection		2000 Inspection Bobbin	POPCD			
	2001 Inspection RPC Confirmed	2001 Inspection RPC Confirmed plus not Inspected	2001 Inspection RPC Confirmed	2001 Inspection RPC Confirmed plus not Inspected	2000 Inspection Confirmed and Plugged	RPC Confirmed		RPC Confirmed Plus Not Inspected	
						Frac.	Count	Frac.	Count
> 0 - 0.2	3	39	0	64	0	0.0	0 / 3	0.621	64 / 103
0.2 - 0.4	11	114	1	662	0	0.083	1 / 12	0.853	662 / 776
0.4 - 0.6	12	91	10	933	0	0.455	10 / 22	0.911	933 / 1024
0.6 -0 .8	12	50	17	691	0	0.586	17 / 29	0.933	691 / 741
0.8 - 1.0	7	22	50	393	0	0.877	50 / 57	0.947	393 / 415
1.0 - 1.2	3	6	81	181	1	0.965	82 / 85	0.968	182 / 188
1.2 - 1.4	1	3	108	125	2	0.991	110 / 111	0.977	127 / 130
1.4 - 1.6	0	1	76	77	1	1.000	77 / 77	0.987	78 / 79
1.6 - 1.8	0	0	31	31	0	1.000	31 / 31	1.000	31 / 31
1.8 - 2.0	0	0	16	17	0	1.000	16 / 16	1.000	17 / 17
2.0 - 2.2	0	0	0	0	9	1.000	9 / 9	1.000	9 / 9
TOTAL	49	326	390	3174	13				
> 1V	4	10	312	431	13				

Table 4-8
Beaver Valley Unit 1
Analysis of RPC Data from 2000 and 2001 Inspections
Combined Data from All Steam Generators

Group of Indications	Total 2000 Inspection Bobbin Indication	Total 2001 Inspection Bobbin Indication	Total 2001 Inspection RPC Inspected	Total 2001 Inspection RPC Confirmed	Percent 2001 Inspection RPC Confirmed
Less than or Equal to 1.0 Volt in 2001 Inspection					
2000 Inspection Bobbin Left in Service	2550	2529	42	34	81.0
- 2000 Inspection RPC Confirmed	204	204	11	11	100.0
- 2000 Inspection RPC NDD	18	18	2	2	100.0
- 2000 Inspection RPC Not Inspected	2307	2307	29	21	72.4
- No 2001 Inspection Bobbin *	21	-	-	-	-
New 2001 Inspection Indication	-	315	50	42	84.0
Sum of All 2001 Inspection Indication	2550	2844	92	76	82.6
Greater than 1.0 Volt in 2001 Inspection					
2000 Inspection Bobbin Left in Service	669	669	372	356	95.7
- 2000 Inspection RPC Confirmed	383	383	287	282	98.3
- 2000 Inspection RPC NDD	12	12	9	2	22.2
- 2000 Inspection RPC Not Inspected	274	274	76	72	94.7
- No 2001 Inspection Bobbin *	0	-	-	-	-
New 2001 Inspection Indication	-	20	8	7	87.5
Sum of All 2001 Inspection Indication	669	689	380	363	95.5
All Voltages in 2001 Inspection					
2000 Inspection Bobbin Left in Service	3219	3198	414	390	94.2
- 2000 Inspection RPC Confirmed	587	587	298	293	98.3
- 2000 Inspection RPC NDD	30	30	11	4	36.4
- 2000 Inspection RPC Not Inspected	2581	2581	105	93	88.6
- No 2001 Inspection Bobbin *	21	-	-	-	-
New 2001 Inspection Indication	-	335	58	49	84.5
Sum of All 2001 Inspection Indication	3219	3533	472	439	93.0

* Indications split is based on 2000 Inspection bobbin voltage

Figure 4-1
Beaver Valley Unit 1 September 2001 Outage
Bobbin Voltage Distributions at EOC-14 for Tubes in Service During Cycle 14

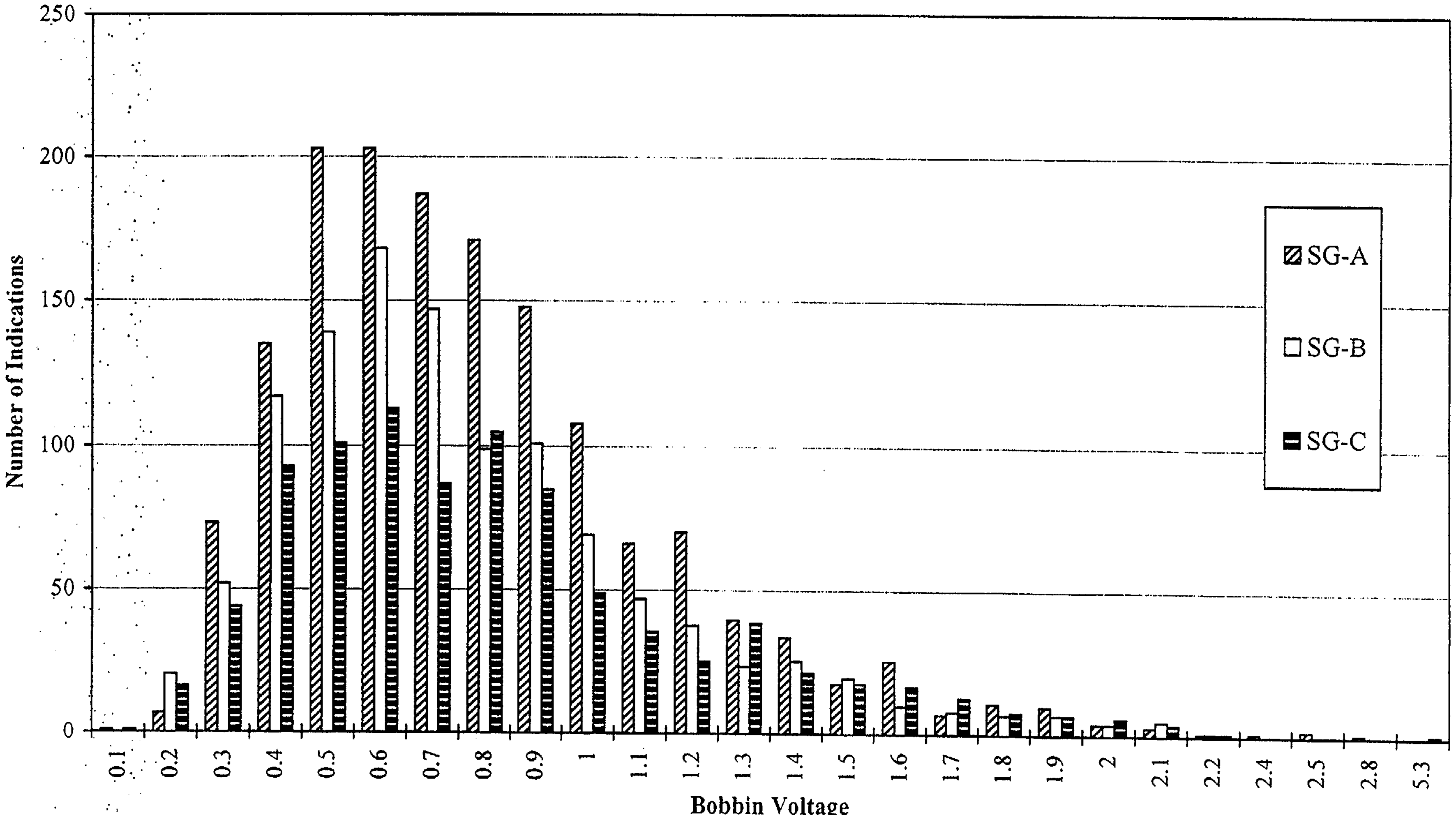
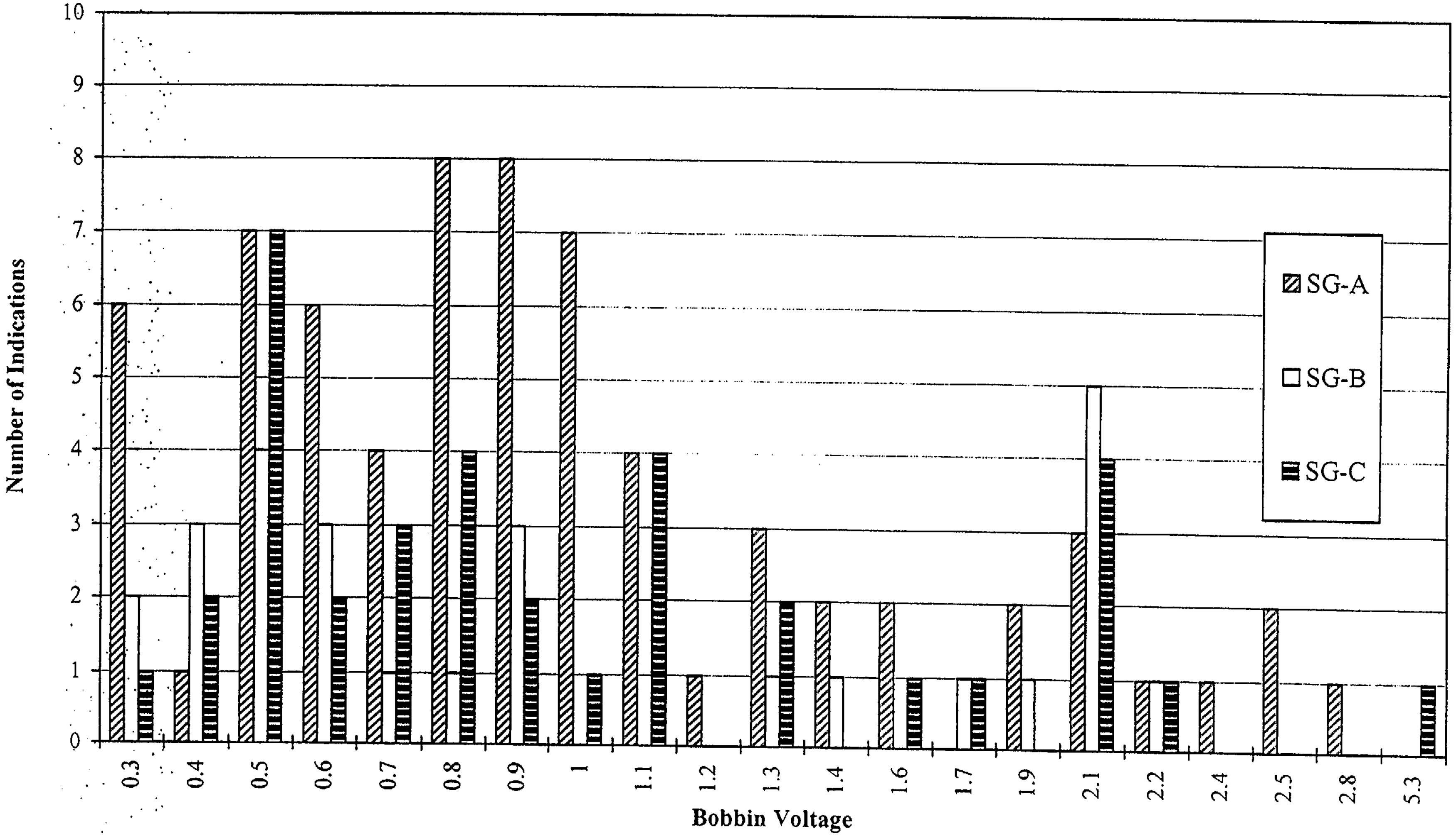
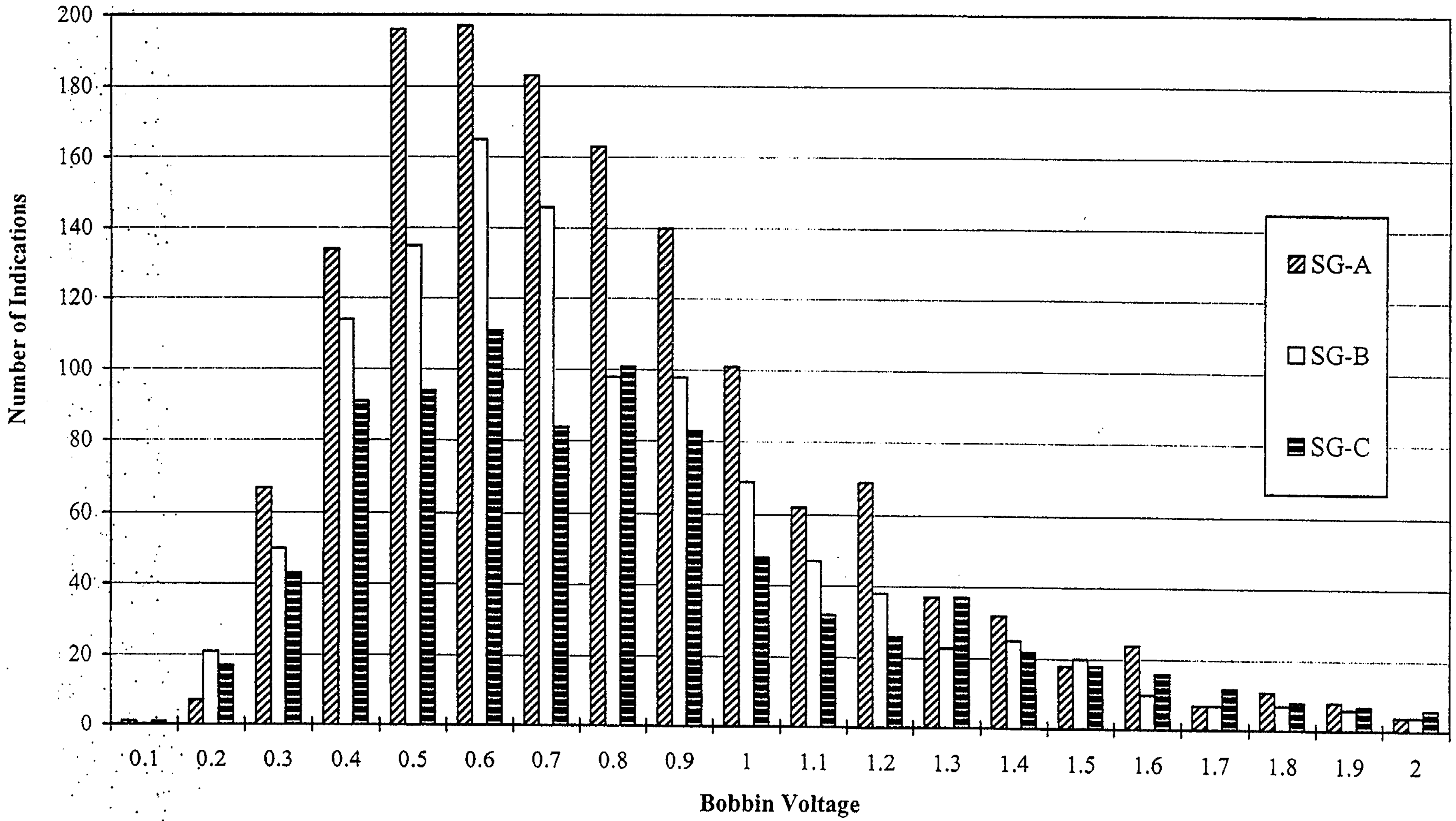


Figure 4-2
Beaver Valley Unit 1 September 2001 Outage
Bobbin Voltage Distribution for Tubes Plugged After Cycle 14 Service



Bobrpc:xlsFig2

Figure 4-3
Beaver Valley Unit 1 September 2001 Outage
Bobbin Voltage Distributions for Tubes Returned to Service for Cycle 15



Bobnrpc.xlsFig3

Figure 4-4
Beaver Valley Unit 1 - September 2001
ODSCC Axial Distributions for Tubes in Service During Cycle 14

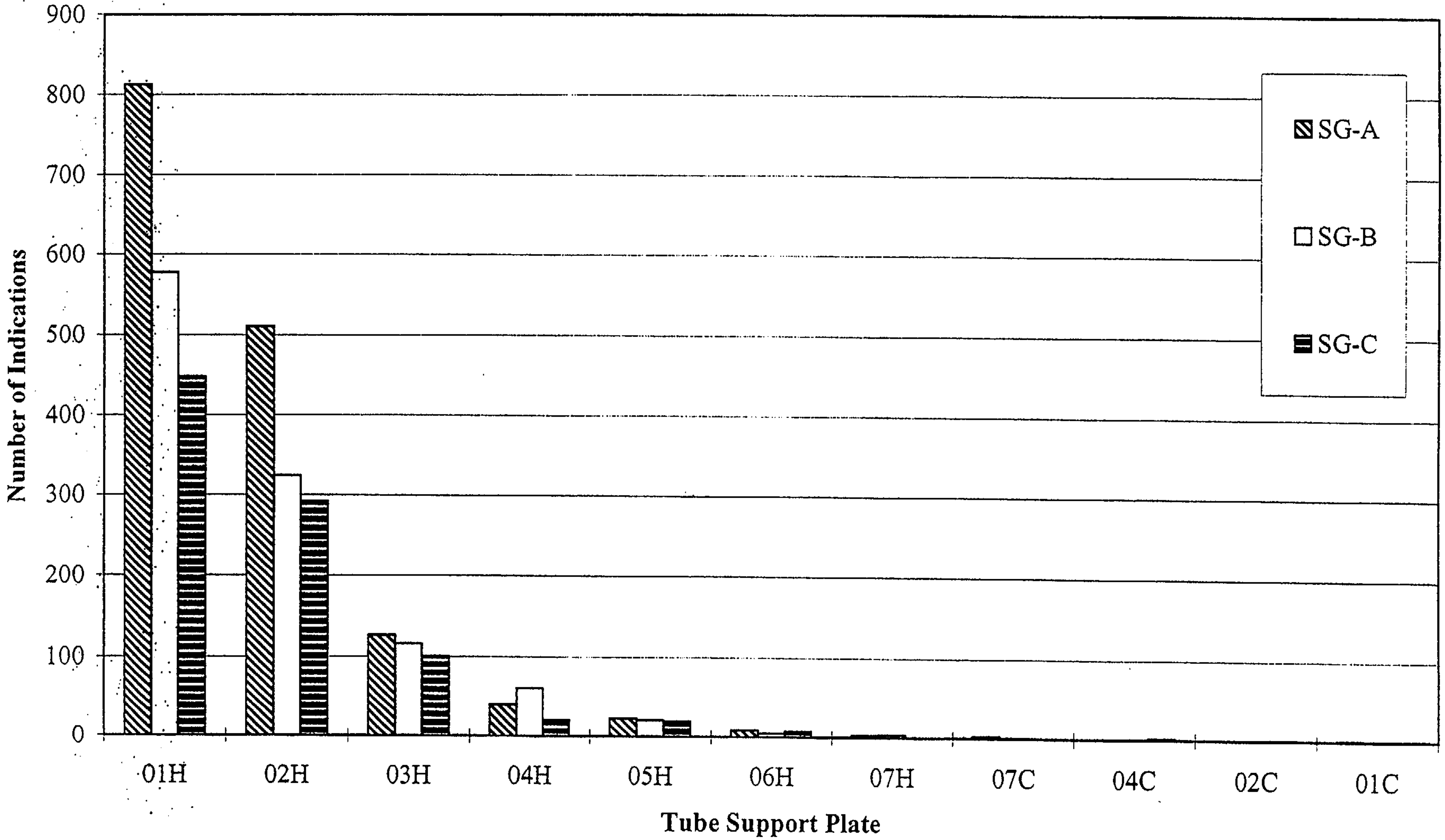
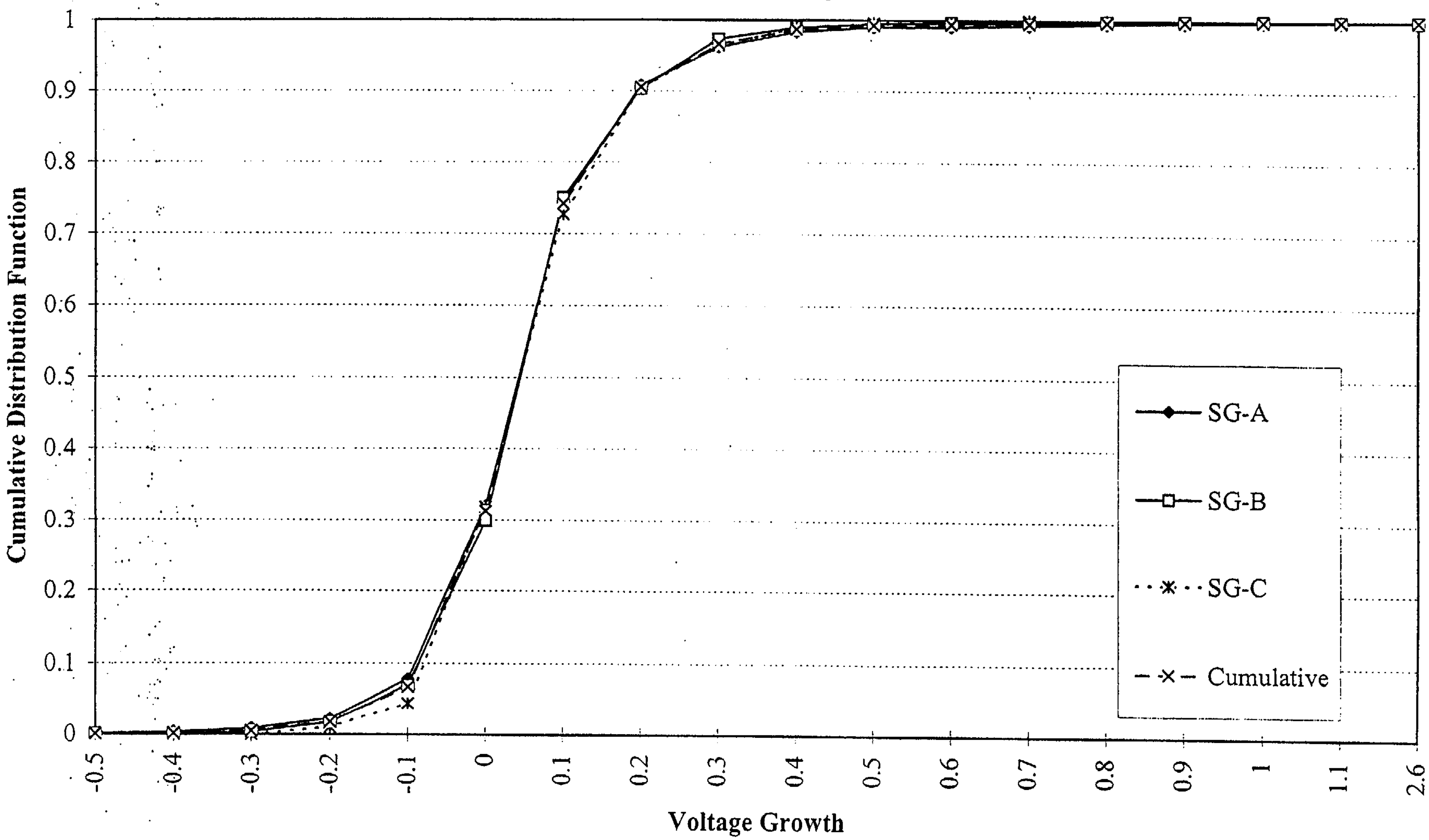
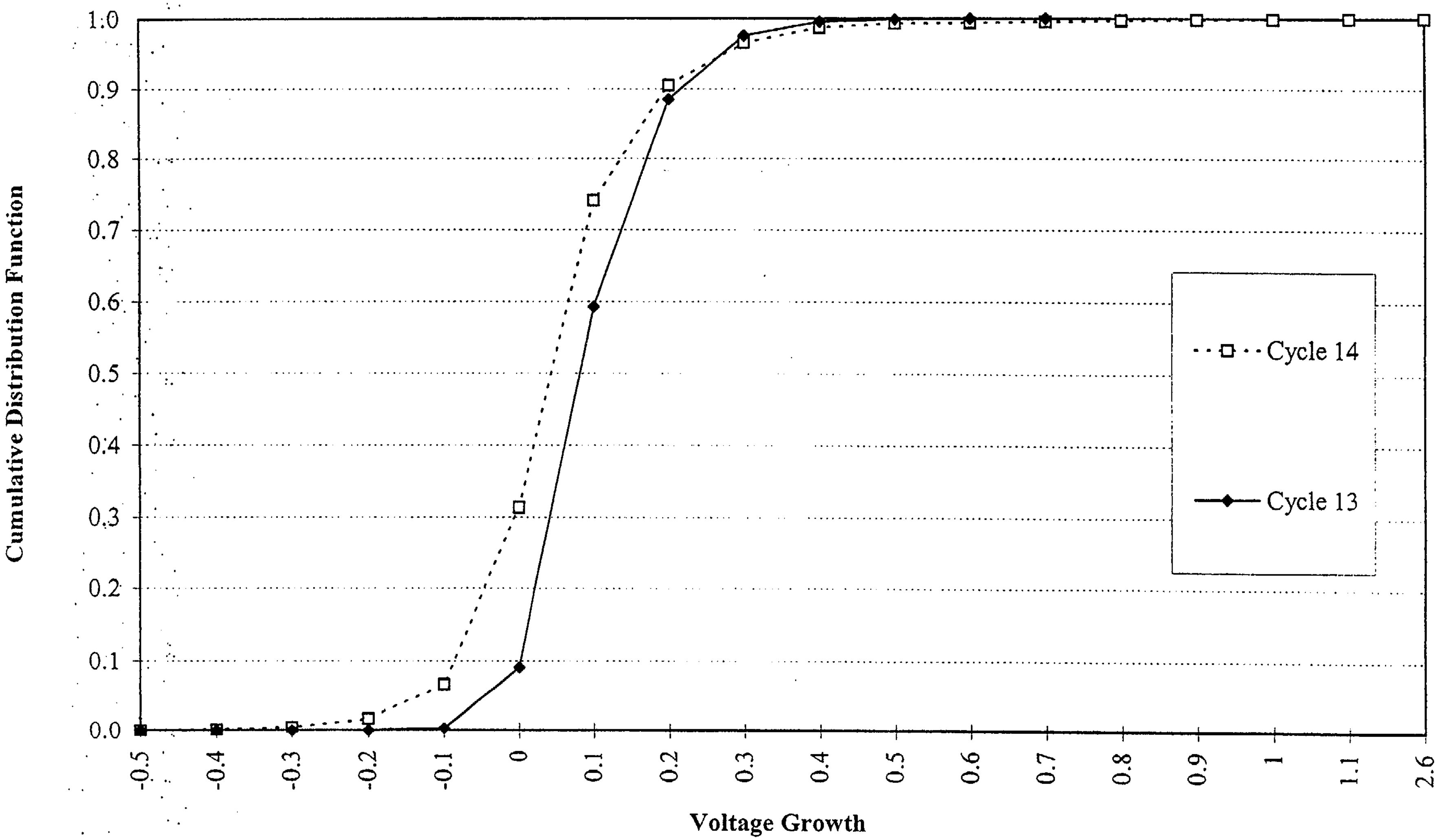


Figure 4-5
Beaver Valley Unit 1Cycle 14 (April 2000 to Sept. 2001)
Cumulative Probability Distributions for Voltage Growth on an EFPY Basis



Growth.xls Fig2

Figure 4-6
Beaver Valley Unit 1 - September 2001
Bobbin Signal Growth History - Cumulative Probability Distributions on an EFPY Basis
Composite of All Steam Generators



Growth.xls Fig3 12/22/01 4:15 PM

Figure 4-7
Beaver Valley Unit -1 September 2001 Outage
Voltage Growth During Cycle 14 vs BOC-14 Voltage -- All SG Data

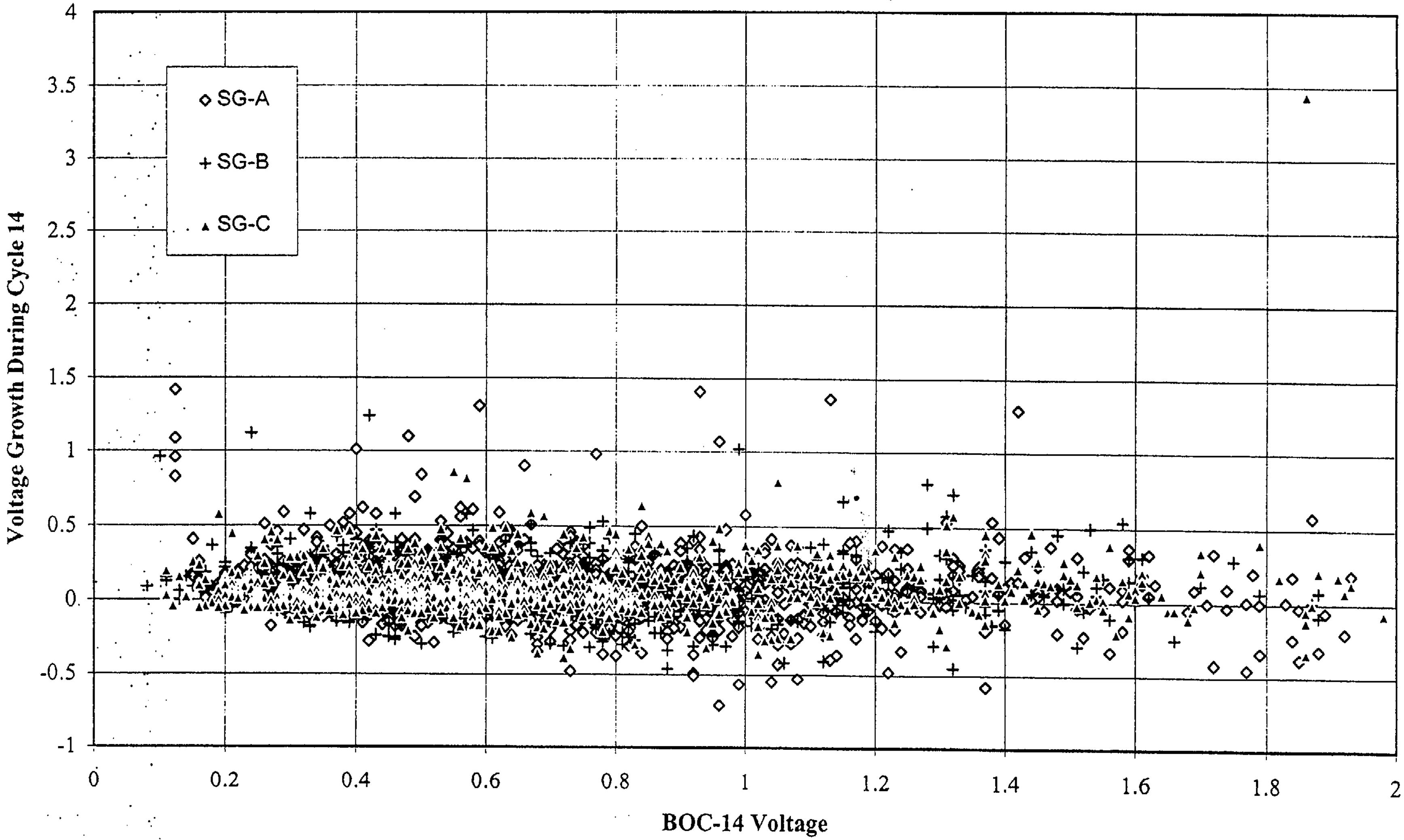
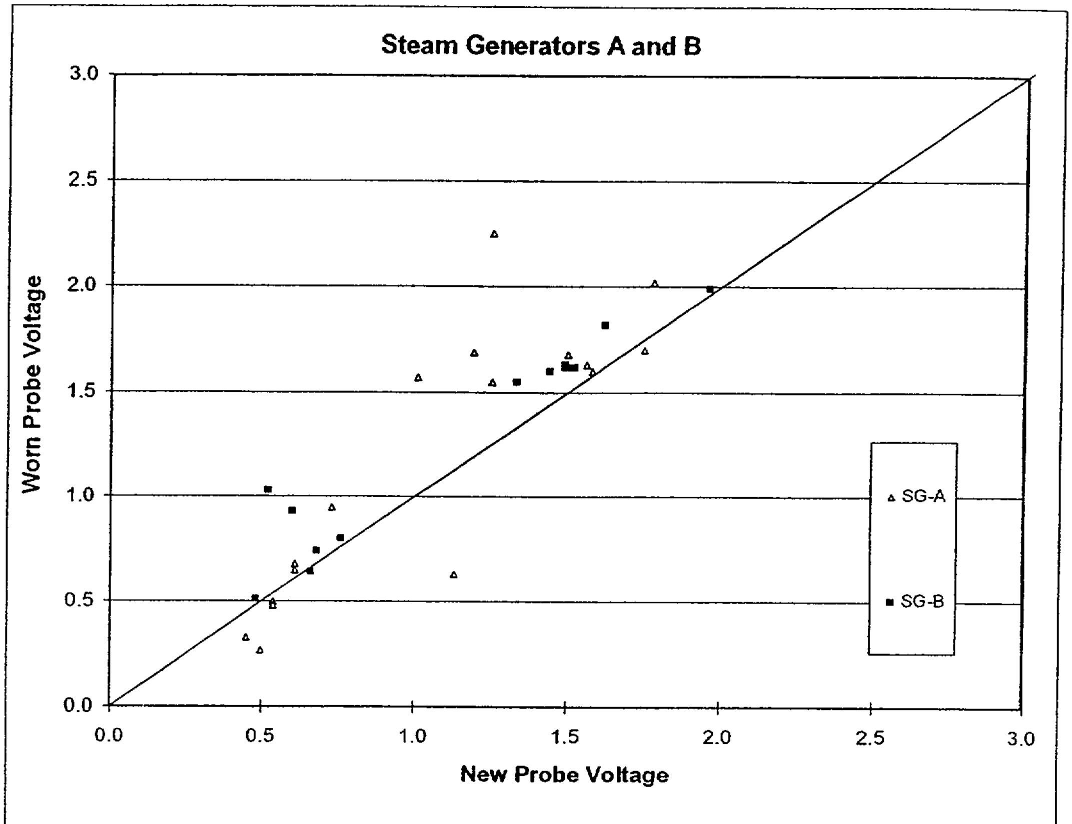


Figure 4-8
Beaver Valley Unit-1 EOC-14 Inspection
Comparison of Worn Probe Voltage Against New Probe Voltage



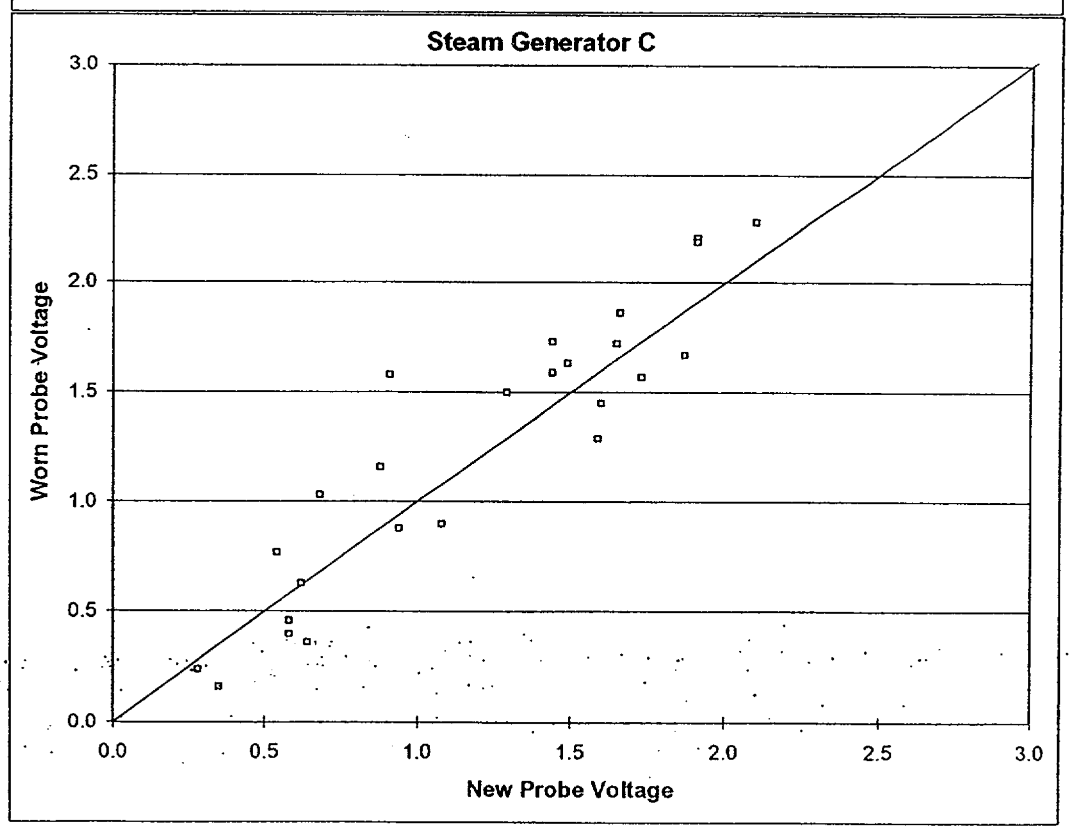


Figure 4-9
Beaver Valley Unit-1 April 2000
Worn Probe Volts vs New Probe Volts

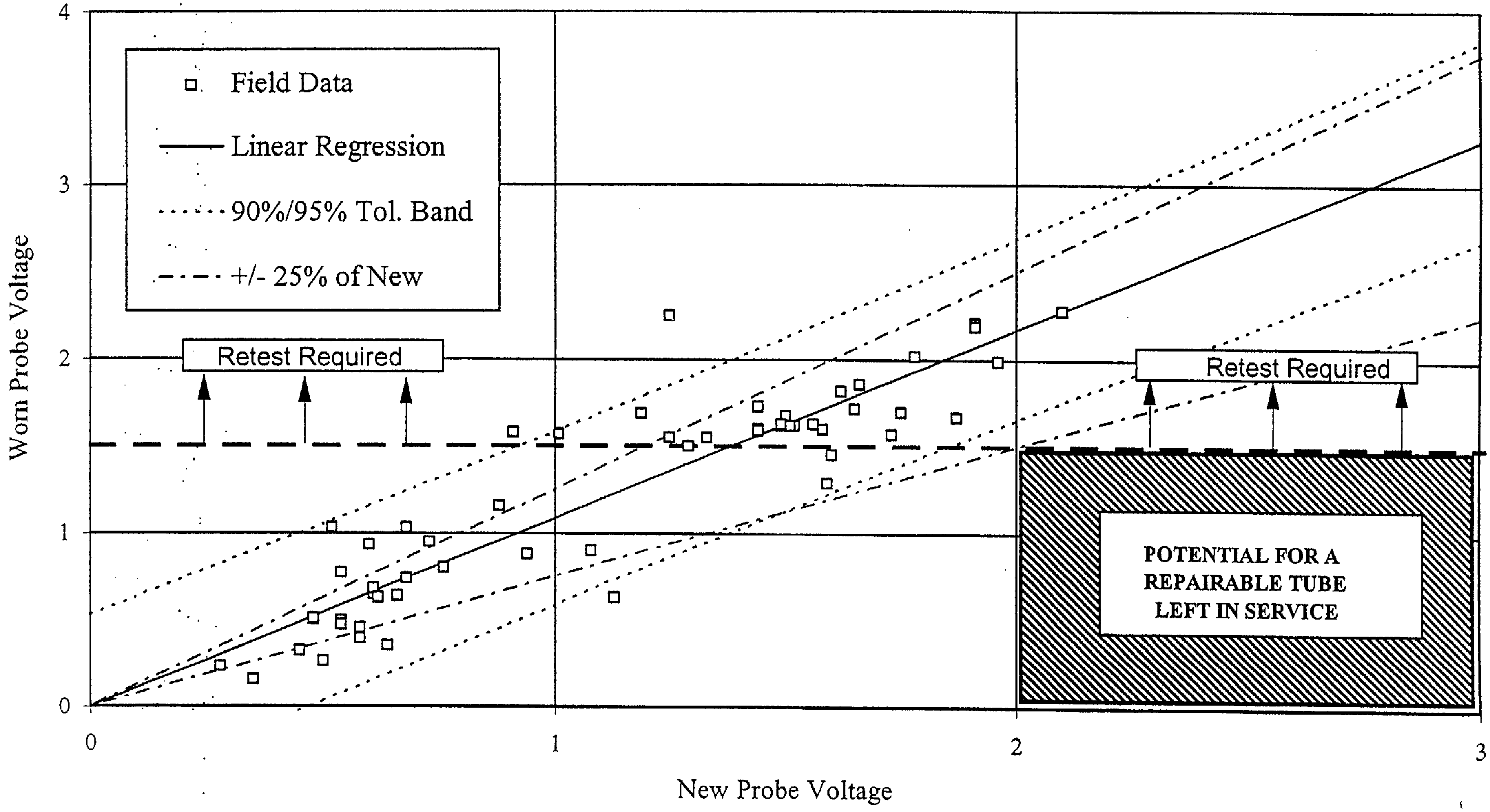


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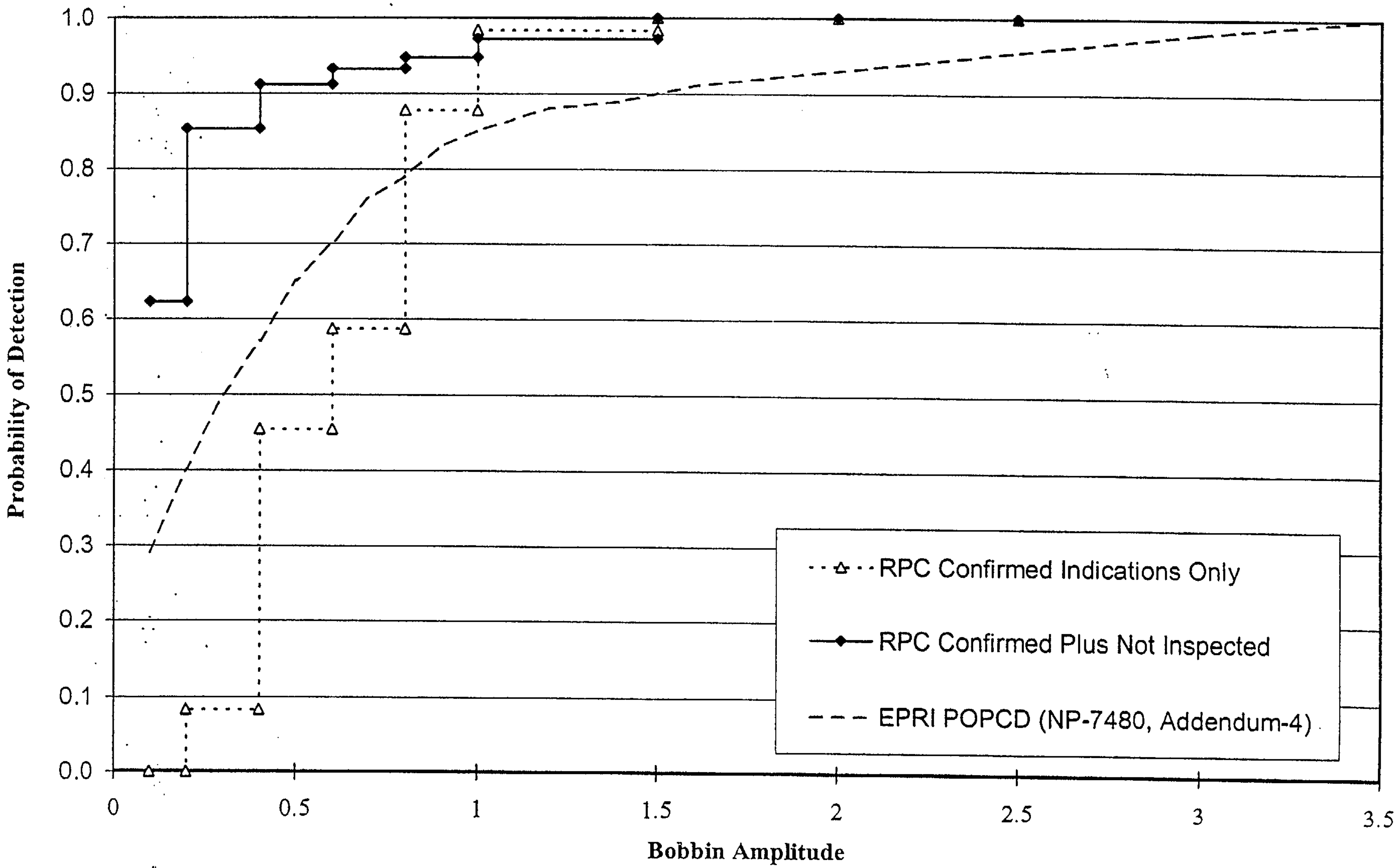
Figure 4-10
Beaver Valley Unit 1
2001 EOC-14 Evaluation for POPCD at EOC-13



Popcd.xls|Fig1|12/10/01|11:11 AM

5.0 Database Applied for Leak and Burst Correlations

Leak and burst correlations based the latest update to the ARC database documented in Reference 9-5 (Addendum-4 update) were utilized to perform a reference set of calculations for Cycle 15 operational assessment.

The leak rate data for 7/8" tubes in the Addendum-4 database (Reference 9-5) provides an acceptable voltage dependent leak rate correlation as the one-sided p-value for the slope parameter is below the 5% threshold specified in the Generic Letter 95-05. The following are the correlations for burst pressure, probability of leakage and leak rate used in the reference analysis for this report (Reference 9-5).

$$\text{Burst Pressure } (ksi) = 7.55943 - 2.37763 \times \log(volts)$$

$$\text{Probability of Leak} = \frac{1}{1+e^{-\left(-4.31823+4.21652\times\log(volts)\right)}}$$

$$\text{Leak Rate } (l/hr) = 10^{\left(-0.526882+0.987179\times\log(volts)\right)}$$

The above leak rate equation is the same as the one in Addendum 3 of the EPRI Database Report (Reference 9-4) as there was no new leak rate data when Reference 9-5 was prepared. It corresponds to 2560 psi pressure differential across the tube wall.

The upper voltage repair limit applied at the EOC-14 inspection was developed using the database presented in Reference 9-4, which is the latest database available for 7/8" diameter tubes prior to the 1R14 outage. The structural limit was determined to be 8.34 volts. The upper voltage repair limit established for EOC-14 was 5.18 volts. The EOC-14 upper voltage repair limit based on the more recent database presented in Reference 9-5 (Addendum-4) is 5.65 volts.

6.0 SLB Analysis Methods

A Monte Carlo analysis technique is used to calculate the SLB leak rates and tube burst probabilities for both actual EOC-14 and projected EOC-15 voltage distributions. The Monte Carlo analysis accounts for parameter uncertainty. The analysis methodology is described in the Westinghouse generic methods report of Reference 9-3, and the same methodology was applied to leak and burst analyses performed during the EOC-13 outage.

In general, the methodology involves application of correlations for burst pressure, probability of leakage and leak rate to a measured or calculated EOC distribution to estimate the likelihood of tube burst and primary-to-secondary leakage during a postulated SLB event. Uncertainties associated with burst pressure, leak rate probability and leak rate correlations' parameters are explicitly included by sampling distributions for the parameter uncertainties through the Monte Carlo sampling process. NDE uncertainties are also included. The voltage distributions used in the leak and burst projections for the next operating cycle are obtained by applying growth data to the BOC distribution. The BOC voltage distributions include an adjustment for detection uncertainty and occurrence of new indications, in addition to the adjustments for NDE uncertainties. Comparisons of projected EOC voltage distributions with actual distributions after a cycle of operation have shown that the Monte Carlo analysis technique yields conservative estimates for EOC voltage distribution as well as leak and burst results based on those distributions.

Equation 3.5 in Reference 9-3 was used to determine the true BOC voltage. The method of treating fractional indications is discussed in Section 3.6 of Reference 9-3. Fractional indications in the EOC voltage bins are retained, and the tail of the distribution is integrated to define discrete values corresponding to the last 1/3rd and 2/3rd of an indication.

7.0 Bobbin Voltage Distributions

This section describes the salient input data used to calculate EOC bobbin voltage distributions and presents results of calculations to project EOC-15 voltage distributions. Also, EOC-14 voltage projections performed during the last outage based on EOC-13 inspection bobbin voltage data are compared with the actual bobbin distributions from the current inspection.

7.1 Calculation of Voltage Distributions

The analysis for EOC voltage distribution starts with a cycle initial voltage distribution which is projected to the end of cycle conditions based on the growth rate and the anticipated cycle operating period. The number of indications assumed in the analysis to project EOC voltage distributions, SLB leak rates and tube burst probabilities is obtained by adjusting the number of reported indications to account for detection uncertainty and birth of new indications over the projection period. This is accomplished by using a POD factor, which is defined as the ratio of the actual number of indications detected to total number of indications present. A conservative value is assigned to POD based on historic data, and the value used herein is discussed in Section 7.2. The calculation of projected bobbin voltage frequency distribution is based on a net total number of indications returned to service, defined as follows.

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

where,

$N_{Tot\ RTS}$	=	Number of bobbin indications being returned to service for the next cycle,
N_i	=	Number of bobbin indications (in tubes in service) identified after the previous cycle,
POD	=	Probability of detection,
$N_{repaired}$	=	Number of N_i which are repaired (plugged) after the last cycle,
$N_{deplugged}$	=	Number of indications in tubes deplugged after the last cycle and returned to service in accordance with voltage-based repair criteria.

There are no deplugged tubes returned to service at BOC-13; therefore, Ndeplugged = 0. As noted in Section 4-6, an NRC SER for Beaver Valley-1 (Reference 9-6) allows for consideration of only a fraction of RPC NDD indications from current inspection in establishing BOC voltage distribution for the next cycle. The fractional value applicable is the largest RPC confirmation rate for prior cycle RPC NDD indications found during the last two outages, but it may not be less than 0.7. The RPC confirmation rates in 2000 for 1997 RPC

NDD indications was about 87%; therefore, it would be justified to consider 87% of EOC-14 RPC NDD indication in the Monte Carlo analysis for tube integrity. However, all EOC-14 RPC NDD indications were included in establishing the BOC-15 indication distributions shown in Table 7-2. During the Monte Carlo simulations, voltages for bins with 3 or more indications are selected by randomly sampling the voltage bins. For bins with fewer than 3 indications, each indication is considered to be in a separate bin, and the actual indication voltage is utilized in the calculations.

The methodology used in the projection of EOC bobbin voltage frequency predictions is described in Reference 9-3, and it is same as that used in performing EOC-14 predictions during the last (EOC-13) outage (Reference 9-2). Salient input data used for projecting EOC-14 bobbin voltage frequency are further discussed below.

7.2 Probability of Detection (POD)

The Generic Letter 95-05 (Reference 9-1) requires the application of a constant POD value of 0.6 to define the BOC distribution for EOC voltage projections, unless an alternate POD is approved by the NRC. A POD value of 1.0 represents the ideal situation where all indications are detected. A voltage-dependent POD provides a more accurate prediction of voltage distributions consistent with voltage based repair criteria experience. In this report both NRC mandated constant POD of 0.6 as well as a voltage-dependent POD developed for EPRI (POPCD) are used. The EPRI POPCD is developed by analyses of 29 inspections in 13 plants and is presented in Table 7-4 of Reference 9-5. The POPCD values applied represent lower 95% confidence bound, and they are reproduced here in Table 6-1 as well as graphically illustrated in Figure 7-1.

7.3 Limiting Growth Rate Distribution

As discussed in Section 4.2, the NRC guidelines in Generic Letter 95-05 stipulate that the more conservative growth rate distributions from the past two inspections should be utilized for projecting EOC distributions for the next cycle. Since the Cycle 13 growth distribution in Figure 4-6 lies to the right of the Cycle 14 distribution, the former distribution is considered more limiting. However, since the Cycle 14 distribution includes one relative large value in the tail (3.4 volts), it may yield a higher burst probability that the Cycle 13 growth distribution. Therefore, Cycle 15 operational assessment analysis was carried out using both Cycle 13 and 14 growth distributions and the larger SLB leak rate and tube burst probability values from the two sets of analysis are reported. Since the growth distributions for all 3 SGs are close each other for both Cycles 13 and 14, all SG composite growth distribution was used for all 3 SGs.

Growth distributions used in the Monte Carlo calculations are specified in the form of a histogram, so no interpolation is performed between growth bins. This assures that the largest growth value in the distribution is utilized in the Monte Carlo simulations.

7.4 Cycle Operating Period

The operating periods used in the growth rate/EFPY calculations and voltage projections are as follows.

Cycle 14	-	490 EFPD	or	1.34 EFPY (actual)
Cycle 15	-	545 EFPD	or	1.49 EFPY (projected)

7.5 Projected EOC-15 Voltage Distribution

Calculations for EOC-15 bobbin voltage projections were performed for all three SGs based on the EOC-14 distributions shown in Table 7-2. The BOC distributions were adjusted to account for probability of detection as described above, and the adjusted number of indications at BOC-15 are also shown in Table 7-2. Calculations were performed using a constant POD of 0.6 as well as the EPRI POPCD distribution (presented in Table 7-1). SG A has the largest number of indications at BOC-15.

Cycle 13 growth distribution was found to be more limiting than the Cycle 14 distribution for SLB leak rate prediction. The projected EOC-15 voltage distributions for all three SGs based on the Cycle 13 growth distribution are summarized on Table 7-3. These results are also shown graphically on Figures 7-2 to 7-4. In general, the results based on a constant POD of 0.6 are slightly more conservative (slightly larger number of indications in most voltage bins) than those using the voltage-dependent EPRI POPCD.

7.6 Comparison of Actual and Projected EOC-14 Voltage Distributions

Table 7-4 and Figure 7-5 provide a comparison of the EOC-14 actual measured bobbin voltage distributions with the corresponding projections performed using the last (EOC-13) inspection bobbin voltage data and presented in Reference 9-2. The EOC-14 projections based on a constant POD of 0.6 as well as the voltage-dependent POPCD are shown. As predicted in Reference 9-2, SG-A has the largest number of indications. With the exception of a single indication in SG-C, the projected number of indications in every voltage bin above 0.5 volt based on both POD=0.6 as well as EPRI POPCD exceed the actual number of indications detected at EOC-14.

A comparison of the actual and projected voltage distributions in Figure 7-5 show that the indication population above 0.5 volt is substantially overestimated in the projections based on a constant POD of 0.6. This POD value is conservative for voltages above about 0.5 volt but non-conservative below 0.5 volt as seen in Figure 7-1. However, the projections based on POPCD show better agreement with the actual voltages, while still remaining conservative, over the entire voltage range than found for POD = 0.6

Table 7-1
EPRI POPCD Distribution
Based on Data from 29 Inspections in 13 Plants

Voltage Bin	EPRI POPCD#
0.1	0.29
0.2	0.40
0.3	0.50
0.4	0.57
0.5	0.65
0.6	0.70
0.7	0.76
0.8	0.79
0.9	0.83
1	0.85
1.2	0.88
1.4	0.89
1.6	0.91
1.8	0.92
2	0.93
3	0.98
3.5	1.0

Data from Table 7-4 in Reference 9-5.

Table 7-2
Beaver Valley Unit 1 September 2001
EOC-14 Bobbin and Assumed BOC-15 Bobbin Distributions Used in SLB Leak Rate and Tube Burst Analyses

Voltage Bin	Steam Generator A				Steam Generator B				Steam Generator C			
	EOC - 14		BOC - 15		EOC - 14		BOC - 15		EOC - 14		BOC - 15	
	Field Bobbin Indications	Indications Repaired	POD 0.6	POPCD	Field Bobbin Indications	Indications Repaired	POD 0.6	POPCD	Field Bobbin Indications	Indications Repaired	POD 0.6	POPCD
0.1	1	0	1.67	4.17	0	0	0	0	1	0	1.67	4.17
0.2	7	0	11.67	20.59	21	0	35.00	61.76	17	0	28.33	50.00
0.3	73	6	115.67	159.91	52	2	84.67	116.18	44	1	72.33	99.00
0.4	135	1	224.00	253.72	117	3	192.00	217.75	93	2	153.00	173.47
0.5	203	7	331.33	320.42	139	4	227.67	220.19	101	7	161.33	155.90
0.6	203	6	332.33	296.99	168	3	277.00	247.75	113	2	186.33	166.66
0.7	187	4	307.67	252.16	147	1	244.00	200.37	87	3	142.00	116.18
0.8	171	8	277.00	214.08	99	1	164.00	127.57	105	4	171.00	132.36
0.9	148	8	238.67	174.72	101	3	165.33	121.69	85	2	139.67	102.94
1	108	7	173.00	123.12	69	0	115.00	83.13	49	1	80.67	58.04
1.1	66	4	106.00	73.19	47	0	78.33	54.97	36	4	56.00	38.11
1.2	70	1	115.67	78.55	38	0	63.33	43.18	26	0	43.33	29.55
1.3	40	3	63.67	41.69	24	1	39.00	25.82	39	2	63.00	41.58
1.4	34	2	54.67	35.36	26	1	42.33	27.57	22	0	36.67	24.18
1.5	18	0	30.00	19.67	20	0	33.33	21.86	18	0	30.00	19.67
1.6	26	2	41.33	26.26	10	0	16.67	10.87	17	1	27.33	17.48
1.7	7	0	11.67	7.57	8	1	12.33	7.65	13	1	20.67	13.05
1.8	11	0	18.33	11.83	7	0	11.67	7.53	8	0	13.33	8.60
1.9	10	2	14.67	8.70	7	1	10.67	6.49	7	0	11.67	7.49
2	4	0	6.67	4.26	4	0	6.67	4.26	6	0	10.00	6.38
2.1	3	3	2.00	0.18	5	5	3.33	0.30	4	4	2.67	0.24
2.2	1	1	0.67	0.05	1	1	0.67	0.05	1	1	0.67	0.05
2.3	0	0	0	0	0	0	0	0	0	0	0	0
2.4	1	1	0.67	0.05	0	0	0	0	0	0	0	0
2.5	2	2	1.33	0.08	0	0	0	0	0	0	0	0
2.8	1	1	0.67	0.03	0	0	0	0	0	0	0	0
3.2	0	0	0	0	0	0	0	0	0	0	0	0
5.3	0	0	0	0	0	0	0	0	1	1	0.67	0.00
Total	1530	69	2481.0	2127.3	1110	27	1823.0	1606.9	893	36	1452.3	1265.1
> 1V	294	22	468.0	307.5	197	10	318.3	210.5	198	14	316.0	206.4
> 2V	8	8	5.3	0.4	6	6	4.0	0.4	6	6	4.0	0.3

Table 7-3
Beaver Valley Unit 1 September 2001
Projected Voltage Distribution at EOC - 15
Based on Cycle 13 Growth

Voltage Bin	Steam Generator A		Steam Generator B		Steam Generator C	
	Projected Number of Indications at EOC - 15					
	POD 0.6	POPCD	POD 0.6	POPCD	POD 0.6	POPCD
0.1	0.19	0.38	0.15	0.23	0.27	0.49
0.2	2.36	3.48	3.47	4.98	3.27	4.96
0.3	14.43	18.25	17.61	23.55	14.89	20.20
0.4	54.45	63.23	48.06	57.57	39.78	48.16
0.5	122.29	130.69	103.40	113.10	81.67	90.00
0.6	205.43	202.90	159.08	158.43	119.14	119.75
0.7	263.74	242.33	205.13	189.55	146.63	136.49
0.8	289.74	249.90	221.33	191.86	155.21	134.75
0.9	285.91	233.28	210.54	173.31	154.44	126.28
1.0	261.11	202.96	184.64	145.12	142.22	110.72
1.1	223.00	166.66	153.30	115.91	120.78	90.61
1.2	181.05	131.08	122.24	89.53	96.59	70.30
1.3	142.40	100.60	94.73	67.74	75.90	53.80
1.4	109.81	76.17	72.66	50.92	60.69	42.09
1.5	83.65	57.12	55.80	38.48	49.58	33.85
1.6	63.23	42.62	42.92	29.16	40.91	27.57
1.7	47.62	31.78	32.91	22.11	33.62	22.44
1.8	35.78	23.64	25.07	16.65	27.27	18.03
1.9	26.74	17.48	18.99	12.41	21.71	14.21
2.0	19.79	12.76	14.24	9.15	16.90	10.93
2.1	14.35	9.10	10.55	6.61	12.76	8.13
2.2	10.17	6.30	7.66	4.65	9.33	5.83
2.3	6.99	4.20	5.39	3.16	6.56	4.01
2.4	4.69	2.69	3.66	2.06	4.43	2.63
2.5	3.09	1.66	2.39	1.29	2.87	1.65
2.6	2.01	0.99	1.50	0.77	1.79	1.00
2.7	1.31	0.31	0.91	0.00	1.07	0.27
2.8	0.87	0.00	0.17	0.70	0.62	0.70
2.9	0.58	0.70	0.70	0.30	0.35	0.00
3.0	0.23	0.30	0.00		0.08	0.30
3.1	0.00		0.30		0.00	
3.2	0.70				0.00	
3.3	0.00				0.00	
3.4	0.30				0.70	
5.9					0.30	
TOTAL	2478.0	2033.6	1819.5	1529.3	1442.3	1200.2
> 1 V	978.4	686.2	666.1	471.6	584.8	408.4
> 1.5 V	238.5	154.5	167.4	109.0	181.3	117.7
> 2 V	45.3	26.3	33.2	19.5	40.9	24.5

Table 7-4
Beaver Valley Unit 1 September 2001
Comparison of Predicted and Actual EOC-14 Voltage Distributions

Voltage Bin	Steam Generator A			Steam Generator B			Steam Generator C		
	Number of Indications								
	EOC-14 Prediction		EOC-14 Actual	EOC-14 Prediction		EOC-14 Actual	EOC-14 Prediction		EOC-14 Actual
	POD = 0.6	POPCD		POD = 0.6	POPCD		POD = 0.6	POPCD	
0.1	0.09	0.14	1	0.11	0.18	0	0.13	0.22	1
0.2	2.65	3.94	7	2.70	4.10	21	3.15	4.96	17
0.3	18.21	24.83	73	16.73	23.64	52	17.84	26.01	44
0.4	66.15	82.02	135	51.64	65.19	117	50.74	65.56	93
0.5	141.70	160.54	203	115.90	133.37	139	100.65	117.69	101
0.6	216.12	224.35	203	170.89	180.30	168	137.04	145.62	113
0.7	265.32	253.82	187	204.99	200.01	147	156.07	151.63	87
0.8	278.34	248.17	171	204.79	185.95	99	155.94	139.52	105
0.9	258.20	217.83	148	186.05	159.11	101	143.92	120.39	85
1.0	220.01	177.41	108	157.96	128.31	69	123.19	97.79	49
1.1	179.43	139.23	66	126.43	98.58	47	100.14	76.29	36
1.2	142.16	106.98	70	97.42	73.57	38	79.53	58.67	26
1.3	109.46	80.30	40	74.16	54.51	24	62.78	45.16	39
1.4	82.02	58.88	34	57.17	41.01	26	49.79	35.09	22
1.5	60.49	42.54	18	44.56	31.33	20	39.87	27.64	18
1.6	44.35	30.59	26	34.56	23.89	10	32.08	21.93	17
1.7	32.78	22.22	7	26.30	17.93	8	25.64	17.34	13
1.8	24.63	16.43	11	19.44	13.11	7	20.19	13.53	8
1.9	18.74	12.31	10	13.92	9.28	7	15.54	10.33	7
2.0	14.25	9.20	4	9.67	6.35	4	11.71	7.72	6
2.1	10.67	6.73	3	6.55	4.22	5	8.59	5.61	4
2.2	7.74	4.73	1	4.37	2.71	1	6.11	3.96	1
2.3	5.41	3.17	0	2.87	1.69	0	4.19	2.69	0
2.4	3.63	2.03	1	1.84	1.02	0	2.75	1.74	0
2.5	2.33	1.24	2	1.18	0.34	0	1.73	1.08	0
2.6	1.44	0.58	0	0.74	0.00	0	1.04	0.45	0
2.7	0.87	0.00	0	0.07	0.70	0	0.31	0.00	0
2.8	0.13	0.70	1	0.70	0.30	0	0.00	0.70	0
2.9	0.70	0.30	0	0.00		0	0.70	0.30	0
3.0	0.00		0	0.30		0	0.30		0
3.1	0.30		0			0			0
5.3			0			0			1
TOTAL	2208.3	1931.2	1530	1634.0	1460.7	1110	1351.7	1199.6	893
> 1 V	168.0	110.2	66	122.5	81.5	42	130.9	87.4	57
> 2 V	33.2	19.5	8	18.6	11.0	6	25.7	16.5	6

Figure 7-1
EPRI Probability of Detection Distribution
Lower 95% Confidence Bound

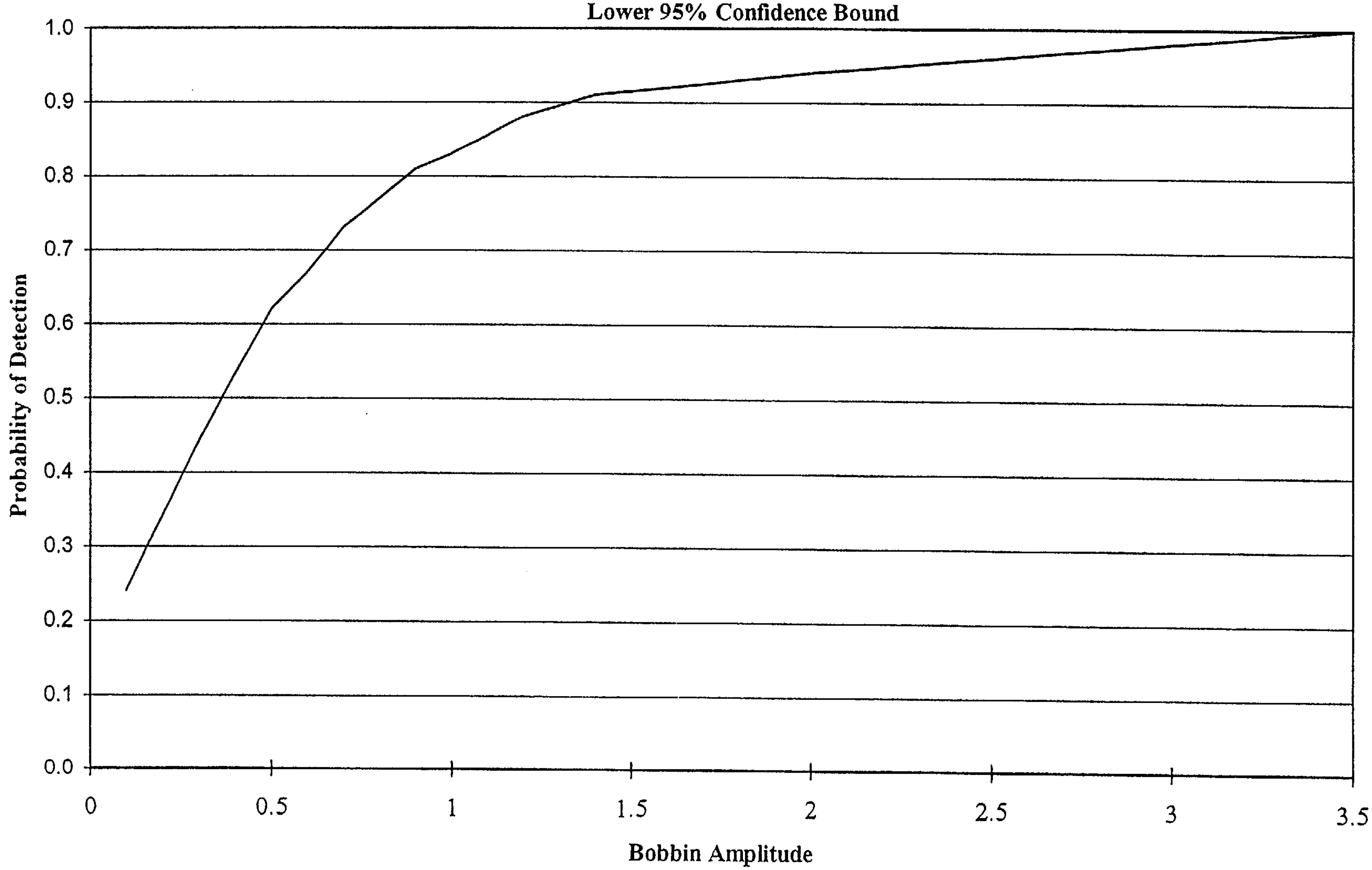


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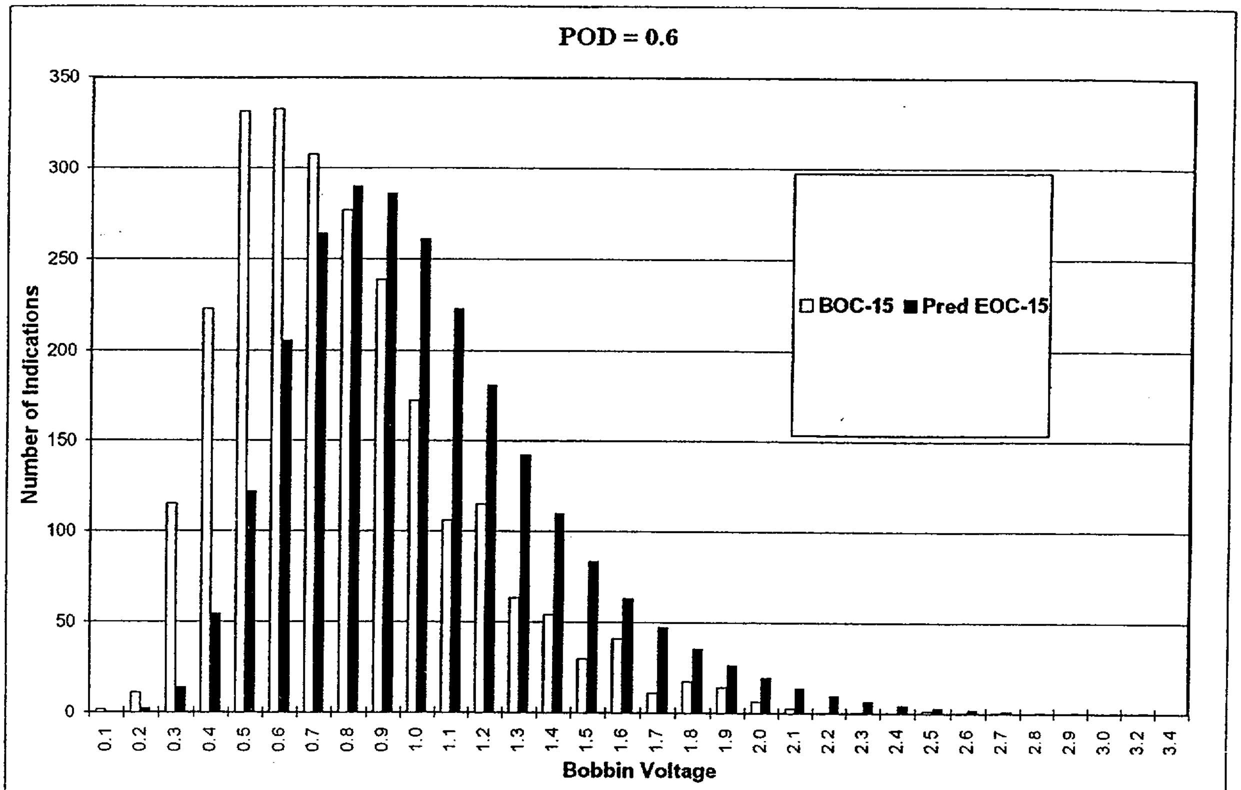
Figure 7-2
Beaver Valley Unit 1 SG-A
Predicted Bobbin Voltage Distribution for Cycle 15



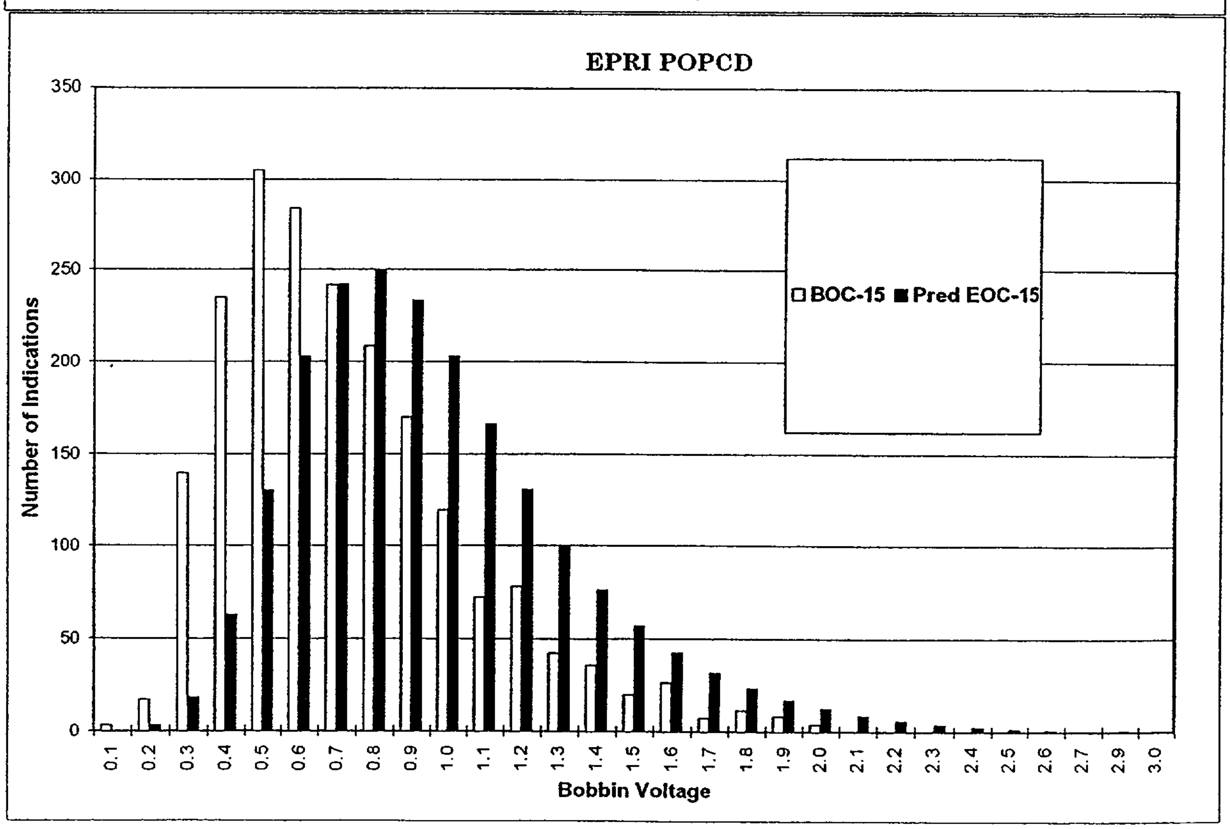
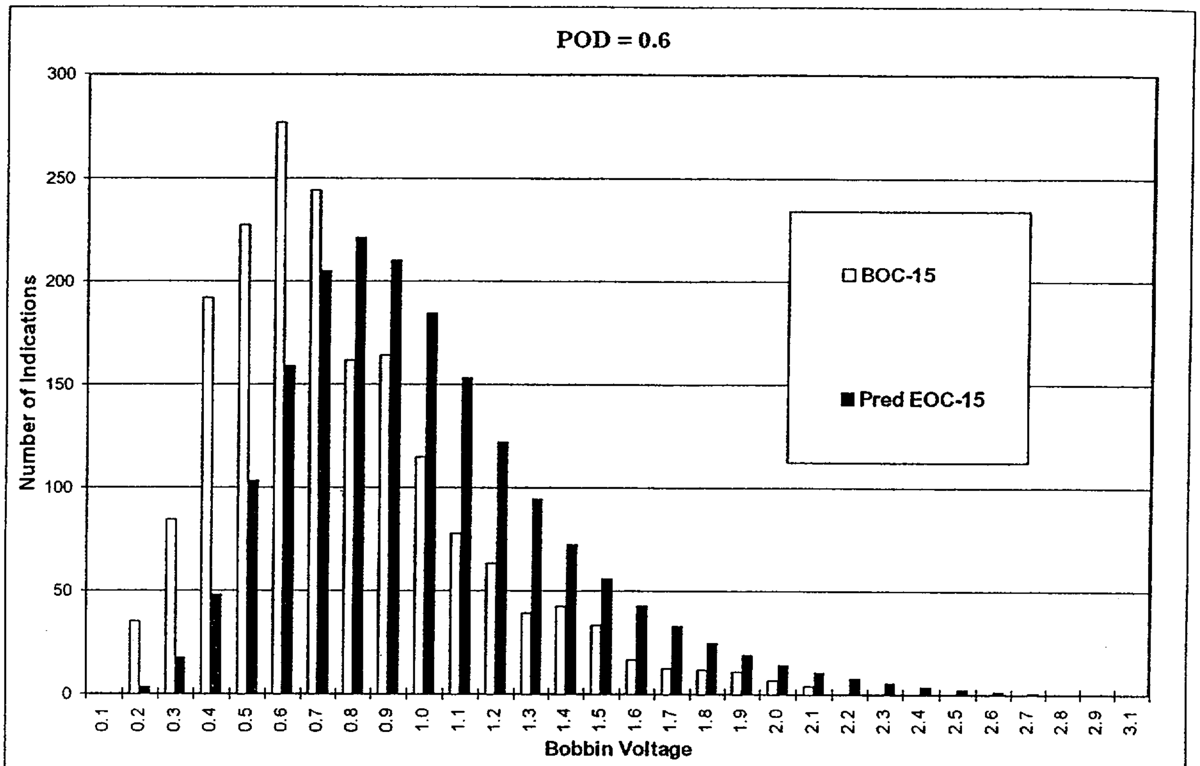


Figure 7-3
Beaver Valley Unit 1 SG-B
Predicted Bobbin Voltage Distribution for Cycle 15



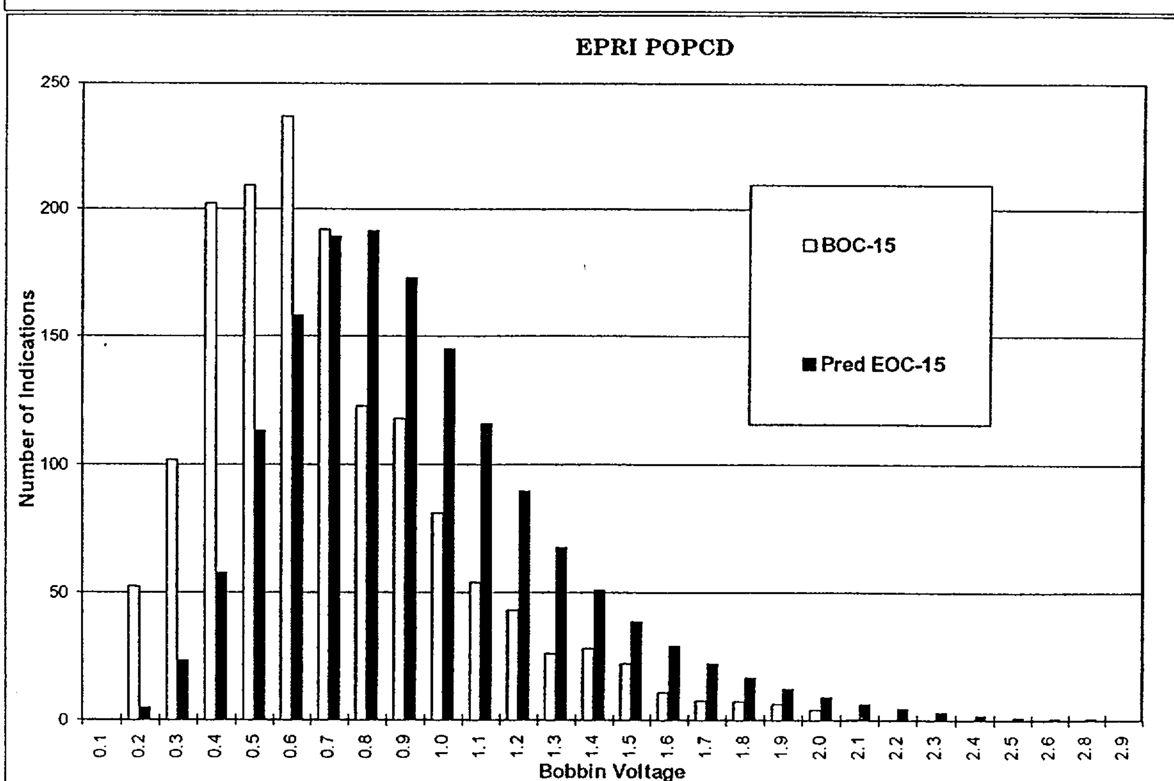
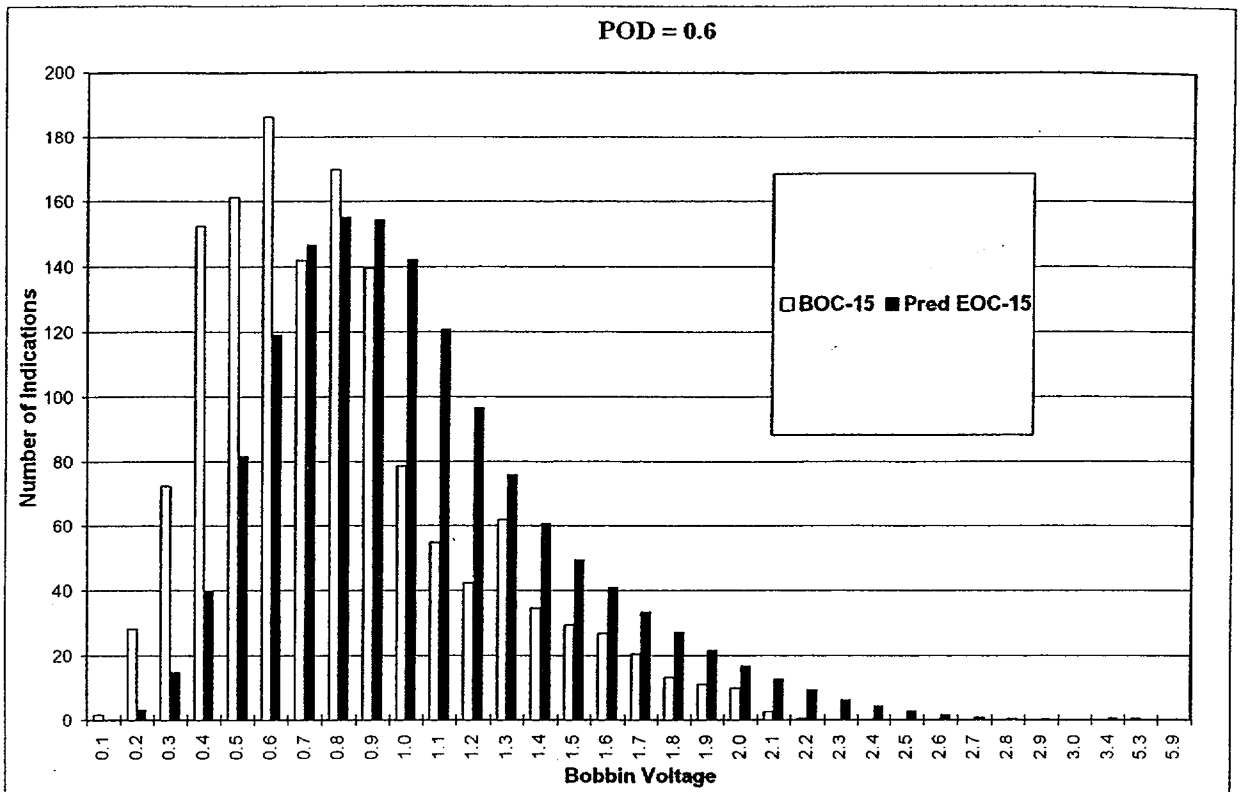


Figure 7-4
Beaver Valley Unit 1 SG-C
Predicted Bobbin Voltage Distribution for Cycle 15



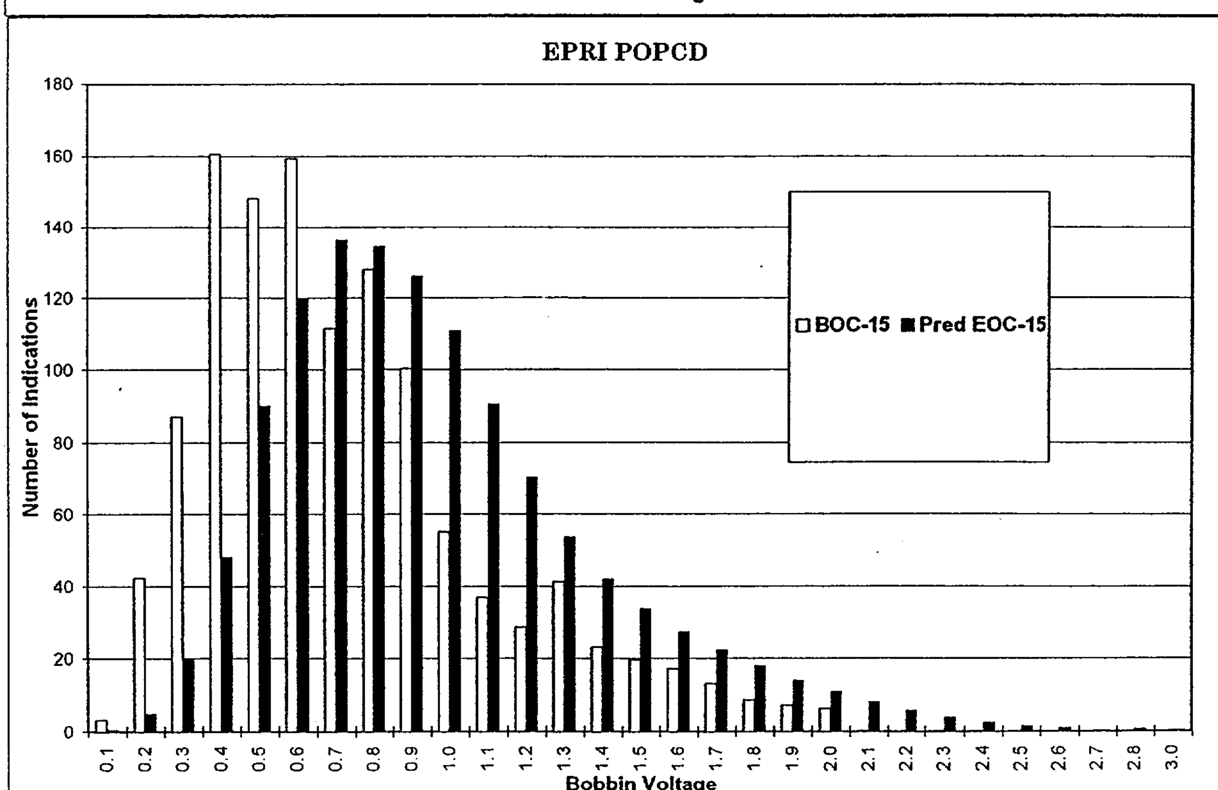
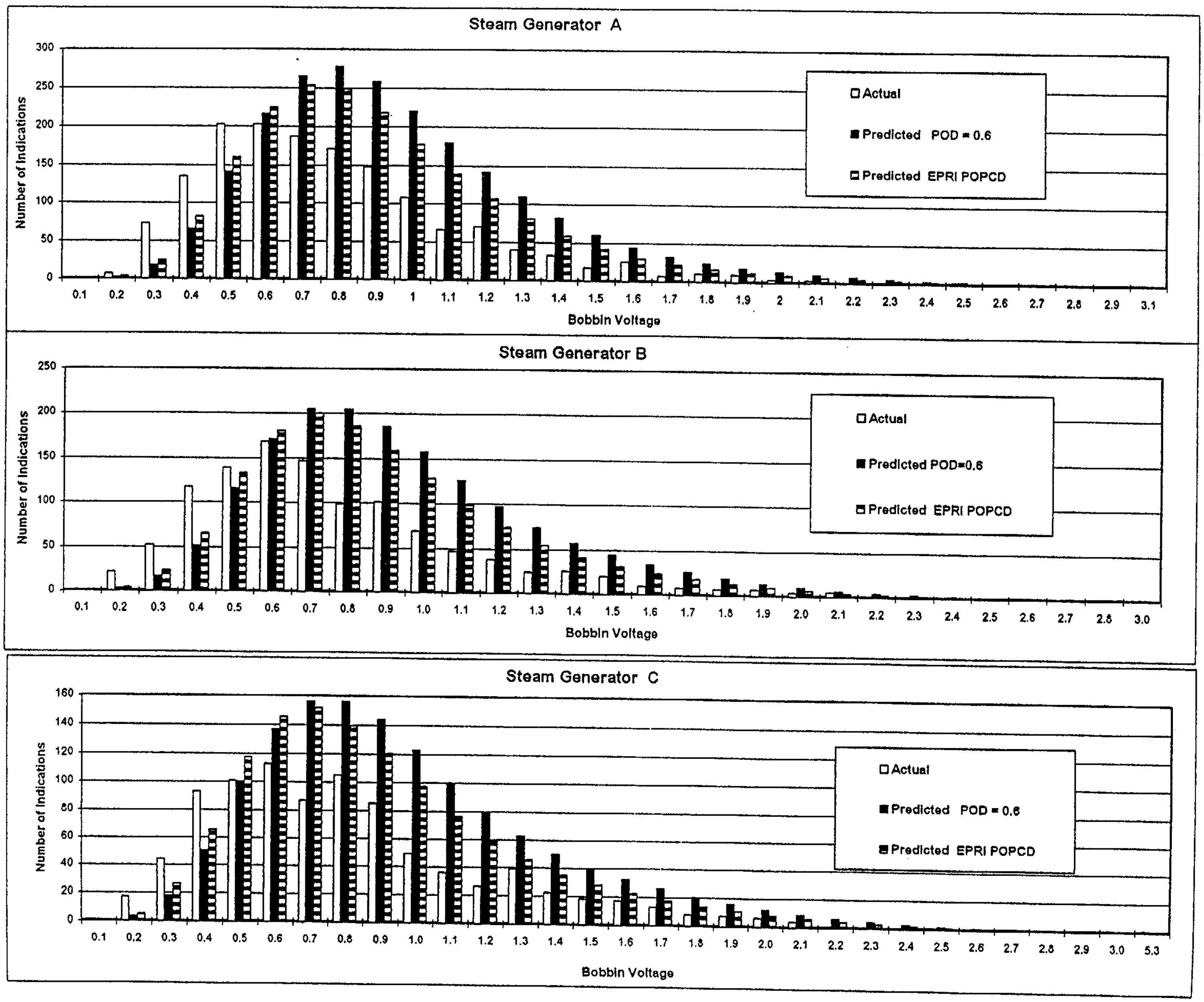


Figure 7-5
Beaver Valley Unit 1 September 2001
Bobbin Voltage Distributions for Cycle 14



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8.0 SLB Leak Rate and Tube Burst Probability Analyses

This section presents the results of the analyses carried out to predict leak rates and tube burst probabilities at the postulated SLB conditions using the actual voltage distributions from the EOC-14 inspection as well as for the projected EOC-15 voltage distributions. The methodology used in these analyses is described in Section 6.0. SG-A with the largest total number of indications as well as indications over 1 volt is expected to yield the limiting SLB leak rate and burst probability for Cycle 15.

8.1 Leak Rate and Tube Burst Probability for EOC-14

Analyses to calculate EOC-14 SLB leak rates and tube burst probabilities were performed using the actual bobbin voltage distributions presented in Table 7-2. Results of Monte Carlo calculations are summarized on Table 8-1. A comparison of the EOC-14 actuals in Table 8-1 with the corresponding predictions performed during the EOC-13 inspection, also shown in Table 8-1, indicates the following.

a) Total number of indications found in the EOC-14 inspection for all three SGs are well below their projections based on POD=0.6 as well as EPRI POPCD. With the exception of SG-C, the peak measured voltages are 0.3 to 0.8 volt below their projected values.

b) Leak rate and tube burst probability projections at EOC-14 are conservative compared to the corresponding values calculated using the EOC-14 actual measured bobbin measurements for all SGs.

c) As predicted, SG-A was confirmed as the limiting steam generator at EOC-14 based on the SLB leak rate and tube burst probability analysis using the actual EC bobbin measurements for EOC-14.

d) Limiting values for SLB leak rate (2.2 gpm at room temperature) and tube burst probability (2.1×10^{-4}) obtained using the actual measured voltages are well below the allowable SLB leakage limit effective at EOC-14 (5.5 gpm) and the NRC reporting guideline of 10^{-2} for the tube burst probability. Note that the current permissible leak rate value for Beaver Valley is 14.5 gpm.

In summary, actual measured EOC-14 bobbin voltage distributions for all SGs are well below the corresponding projections obtained using the NRC mandated probability of detection of 0.6.

8.2 Leak Rate and Tube Burst Probability for EOC-15

The SLB leak rate projection at the EOC-15 condition was carried out using the latest update to the ARC database documented in Reference 9-5. The EOC-15 steam generator burst probability was calculated using the tube burst database documented in Reference 9-5.

SG-A is again predicted to be the limiting SG. Reference calculations for the EOC-15 SLB leak rate using the ARC database documented in Reference 9-5 show that for a cycle duration of 545 EFPD the limiting EOC-15 leak rate, calculated for SG-A using the NRC mandated constant POD of 0.6, is equal to 5.5 gpm (room temperature), which is well below the current limit of 14.5 gpm. This limiting leak rate projection utilized a leak rate versus bobbin voltage correlation since the p-value for the leak rate correlation slope parameter in Reference 9-5 meets the 5% limit specified in the Generic Letter 95-05. The limiting burst probability, calculated for SG-C, is 3.1×10^{-4}, which is more than a factor of 30 below the NRC reporting guideline of 10^{-2}. Table 8-2 provides SLB leak rates and tube burst probabilities calculated using the constant POD of 0.6 as voltage dependent EPRI POPCD distribution. The application of more realistic EPRI POPCD distribution to establish BOC-15 voltage distributions results in a reduction of reference SLB leak rate projections by about 40% and tube burst probability projections by about 30% to 80% relative to the projections based on a constant POD of 0.6.

Table 8-1
Beaver Valley Unit 1 2001 EOC-14 Outage
Summary of Calculations of Tube Leak Rate and Burst Probability

Steam Generator	POD	Number of Indications(1)	Max. Volts	Burst Probability		SLB Leak Rate [gpm(2)]
				1 Tube	1 or More Tubes	
EOC - 14 PROJECTIONS						
Leak and burst database and correlations presented in Reference 9-4 (Addendum-3 database) Applied						
A	0.6	2208	3.1	1.7×10^{-4}	1.7×10^{-4}	4.5
B		1634	3.0	1.4×10^{-4}	1.4×10^{-4}	3.1
C		1352	3.0	1.4×10^{-4}	1.4×10^{-4}	2.8
A	POPCD	1931	2.9	1.3×10^{-4}	1.3×10^{-4}	3.4
B		1461	2.8	1.1×10^{-4}	1.1×10^{-4}	2.4
C		1200	2.9	1.0×10^{-4}	1.0×10^{-4}	2.1
EOC – 14 ACTUALS						
Leak and burst database and correlations presented in Reference 9-4 (Addendum-3 database) Applied						
A	1	1530	2.7	1.2×10^{-4}	1.2×10^{-4}	2.2
B		1110	2.1	5.3×10^{-5}	5.3×10^{-5}	1.5
C		817	5.3	2.1×10^{-4}	2.1×10^{-4}	1.4

Notes:

(1) Adjusted for POD.

(2) Equivalent volumetric rate at room temperature

Table 8-2

Beaver Valley Unit-1

Tube Leak Rate and Burst Probability at EOC-15

Reference Analysis

(Based on a projected Cycle 15 length 545 EFPD)

Steam Generator	POD	No. of Indic-ations[1]	Max Volts	Burst Probability		SLB Leak Rate (gpm)[2]	Comments
				1 Tube	One or More Tubes		
Leak and Burst Database and Correlations Reported in Reference 9-5 (Addendum-4) Applied (Leak rates and burst probabilities were calculated using both Cycle 13 and Cycle 14 growth data and the larger values for the two growth cases are presented)							
A	0.6	2481	3.4[3]/4.8[4]	2.5×10^{-4} [4]	2.8×10^{-4} [4]	5.50[3]	Leak rate Correlation applied
B		1823	3.1[3]/4.6[4]	1.9×10^{-4} [3]	1.9×10^{-4} [3]	3.84[3]	
C		1452	5.9[3]/5.8[4]	3.1×10^{-4} [3]	3.1×10^{-4} [3]	3.40[3]	
A	POPCD	2036	3.0[3]/4.6[4]	1.8×10^{-4} [4]	1.8×10^{-4} [4]	3.95[3]	
B		1532	2.9[3]/4.5[4]	1.5×10^{-4} [4]	1.5×10^{-4} [4]	2.81[3]	
C		1207	3.0[3]/4.3[4]	1.7×10^{-4} [3]	1.7×10^{-4} [3]	2.42[3]	

Notes

1. Number of indications adjusted for POD.
2. Volumetric leak rate adjusted to room temperature.
3. Based on Cycle 13 all SG composite growth rate distribution.
4. Based on Cycle 14 all SG composite growth rate distribution.

9.0 References

9-1 NRC Generic Letter 95-05, "Voltage-Based Repair Criteria for the Repair of Westinghouse Steam Generator Tubes Affected by Outside Diameter Stress Corrosion Cracking," USNRC Office of Nuclear Reactor Regulation, August 3, 1995.

9-2 SG-00-06-009, "Beaver Valley Unit-1 Cycle 14 Voltage-Based Repair Criteria 90-Day Report," Westinghouse Electric Company, July 2000.

9-3 WCAP-14277, Revision 1, "SLB Leak Rate and Tube Burst Probability Analysis Methods for ODSCC at TSP Intersections", Westinghouse Nuclear Services Division, December 1996.

9-4 EPRI Report NP 7480-L, Addendum 3, "Steam Generator Tubing Outside Diameter Stress Corrosion Cracking at Tube Support Plates Database for Alternate repair Limits," Electric Power Research Institute, May 1999.

9-5 EPRI Report NP 7480-L, Addendum 4, "Steam Generator Tubing Outside Diameter Stress Corrosion Cracking at Tube Support Plates Database for Alternate repair Limits," Electric Power Research Institute, March 2001.

9-6 U.S. N.R.C. Report, "Safety Evaluation by the Office of Nuclear Reactor Regulation Related to Amendment No. 198 to Facility Operating License DPR-66 Duquesne Light Company, Ohio Edison Company and Pennsylvania Power Company, Beaver Valley Power Station, Unit No. 1 Docket No. 50-334", April 1, 1996.