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PG&E Letter DCL-03-017

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Docket No. 50-323, OL-DPR-82
Diablo Canyon Unit 2
Revised Steam Generator Voltage-based Repair Criteria Probability of Detection Method for Diablo Canyon Unit 2 Cycle 12

Dear Commissioners and Staff:

Pacific Gas & Electric (PG&E) requested the use of a voltage-based alternate repair criteria (ARC) for outside diameter stress corrosion cracking (ODSCC) indications at steam generator (SG) tube support plate (TSP) intersections in PG&E letter DCL-97-034, "License Amendment Request 97-03, Voltage-Based Alternate Steam Generator Tube Repair Limit for Outside Diameter Stress Corrosion Cracking at Tube Support Plate Intersections," dated February 26, 1997. In letter DCL-97-034, PG&E requested the use of a revised bobbin probability of detection (POD) as an alternative to using a very conservative constant POD value of 0.6. This revised POD, while still conservative with application of an appropriate lower confidence bound, is a more realistic POD which is a function of voltage at the beginning of cycle and is referred to as the Probability of Prior Cycle Detection (POPCD) method. In a letter to PG&E dated March 12, 1998, the NRC issued Amendment Nos. 124 and 122 for Diablo Canyon Power Plant (DCPP) Units 1 and 2 respectively approving the use of a voltage-based ARC for ODSCC indications at SG TSP intersections. Section 3.1.3 of the NRC safety evaluation for Amendment Nos. 124 and 122 for DCPP Units 1 and 2 respectively addressed the structural and leakage integrity assessments related to the ARC and stated that "PG&E will be permitted to use a revised POD, in lieu of a constant valued of 0.6, if and when a revised POD is approved by the NRC. Until that occurs, PG&E will have to use a constant value of 0.6." This letter requests NRC approval to use the POPCD method for DCPP Unit 2 Cycle 12 using plant specific inspection results.

The POPCD method is described in EPRI Topical Report NP 7480-L, Addendum 5, "Steam Generator Tubing Outside Diameter Stress Corrosion Cracking at Tube Support Plates Database for Alternate Repair Limits, Update 2002," dated January 2003. The industry has previously requested that the NRC review and approve the use of the POPCD method.

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In a telephone conference between the industry and the NRC on September 5, 2000, the NRC identified several issues that were required to be resolved before generic approval of the POPCD method could occur. These issues included treatment of uncertainties, effect of uncertainties in the upper voltage range, characteristics of noise for the POPCD database plants, and benchmarking of POPCD in comparison with the approved POD

Enclosure 1 contains supporting information and includes information on treatment of uncertainties, effect of uncertainties in the upper voltage range, characteristics of noise, and DCPP benchmarking of the POPCD method in comparison with the approved POD. Subject to NRC approval to use the POPCD method for DCPP Unit 2 Cycle 12, PG&E will apply a lower 90 percent loglogistic confidence bound in the DCPP plant specific POPCD analyses to support the Operational Assessment for Unit 2 cycle 12. This letter also contains a description of the use of Monte Carlo techniques that could be used to develop POPCD curves. No approval of this approach is requested in this letter. This discussion is presented here for information only. Approval of the use of these techniques would be the subject of a future request.

There are no Technical Specifications changes required to implement use of the POPCD method at DCPP.

The approval of the use of the POPCD method is required to allow startup of DCPP Unit 2 for Cycle 12. PG&E requests approval of the use of the POPCD method for DCPP Unit 2 Cycle 12 no later than March 4, 2003, to support the current schedule for draining of the RCS to mid loop to prepare for SG nozzle dam removal This letter does not request approval of DCPP Unit 2 restart. PG&E will separately communicate plans for restart of DCPP Unit 2.

Sincerely,

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kjs/4328
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INFORMATION TO SUPPORT NRC APPROVAL OF USE OF THE POPCD METHOD FOR UNIT 2 CYCLE 12

Background Information

The use of a voltage-based alternate repair criteria (ARC) for outside diameter stress corrosion cracking (ODSCC) indications at steam generator (SG) tube support plate (TSP) intersections was approved by the NRC for Diablo Canyon Power Plant (DCPP) Units 1 and 2 in Amendment Nos. 124 and 122 respectively in a letter to PG&E dated March 12, 1998. PG&E requested the use of the voltage-based ARC for ODSCC at SG TSP intersections in PG&E letter DCL-97-034, "License Amendment Request 97-03, Voltage-Based Alternate Steam Generator Tube Repair Limit for Outside Diameter Stress Corrosion Cracking at Tube Support Plate Intersections," dated February 26, 1997. In this letter, as an alternative to using a very conservative constant bobbin probability of detection (POD) value of 0.6, PG&E requested the use of a revised POD method. This revised POD is a more realistic POD which is a function of voltage at the beginning of cycle and is referred to as the Probability of Prior Cycle Detection (POPCD) method. Section 3.1.3 of the NRC safety evaluation for Amendment Nos. 124 and 122 for DCPP Units 1 and 2 respectively addressed the structural and leakage integrity assessments related to the ARC and stated that "PG&E will be permitted to use a revised POD, in lieu of a constant value of 0.6, if and when a revised POD is approved by the NRC. Until that occurs, PG&E will have to use a constant value of 0.6." Based on the requirements of Amendment Nos. 124 and 122, PG&E is currently using a POD of 0.6 in ODSCC ARC structural and leakage assessments.

During Unit 2 refueling outage 11 (2R11), large voltage ODSCC indications were identified in the SG TSP intersections. As a result of these large voltage ODSCC indications, the calculated probability of burst (POB) performance criterion for Unit 2 Cycle 12 exceeds $1x10^{-2}$, the maximum value allowed by Generic Letter (GL) 95-05, "Voltage-Based Repair Criteria for Westinghouse Steam Generator Tubes Affected by Outside Diameter Stress Corrosion Cracking," dated August 3, 1995. Assuming that the SG tube plugging level is maintained below the current DCPP licensed limit of 15 percent in each SG, the use of the POPCD method will be required in order to obtain a POB less than $1x10^{-2}$ for Unit 2 Cycle 12. Therefore, this letter requests NRC approval to use the POPCD method for DCPP Unit 2 Cycle 12 using plant specific inspection results. The DCPP POPCD distributions are developed based on fitting the inspection results used to define POPCD by loglogistic functions which are commonly applied in tube integrity analyses for POD distributions. Uncertainties in the resulting POD distributions are obtained from the analyses. In addition, the DCPP POPCD results for bobbin coil detection are shown to be in good agreement with POD results obtained from Argonne National Laboratory (ANL) round-robin test results in Reference 5, the industry POPCD results, and an EPRI POD obtained from blind testing of analysts.

The POPCD method is described in EPRI Topical Report NP 7480-L, Addenda 1 through 5, "Steam Generator Tubing Outside Diameter Stress Corrosion Cracking at Tube Support Plates Database for Alternate Repair Limits," dated November, 1996 through January, 2003. The industry has previously requested that the NRC review and approve the use of the POPCD method. EPRI Topical Report NP 7480-L, Addendum 5, was transmitted to the NRC in

Reference 12. As noted previously, the use of a voltage dependent POD is supported by an eddy current reliability study performed by ANL and reported in NUREG/CR-6791, "Eddy Current Reliability Results from the Steam-Generator Mock-up Analysis Round-Robin," dated November, 2002 (Reference 5).

In DCL-97-034, PG&E requested the use of POPCD values contained in EPRI Topical Report NP 7480-L, Addendum 1, "Steam Generator Tubing Outside Diameter Stress Corrosion Cracking at Tube Support Plates Database for Alternate Repair Limits 1996 Database Update," dated November 1996, Table 7-4, under the "Recommended POD" column. These POPCD values were voltage dependent POD values developed from a database of 11 inspections and were based on the lower 95 percent confidence level at the mid-voltage of each voltage bin. The POPCD database has increased to 37 inspections in Addendum 5 with no significant changes in the POPCD distribution. For the determination of the appropriate POPCD values for DCPP Unit 2 Cycle 12, plant specific DCPP Units 1 and Unit 2 inspection results will be used.

<u>POPCD Definition</u>

The POPCD method is described in EPRI Topical Report NP 7480-L, Addendum 1.

POPCD is calculated as the ratio of indications reported at the prior inspection to the total indications found at the subsequent inspection (all indications reported in the prior cycle plus new indications). POPCD for the end of cycle (EOC) n inspection (EOC_n) is defined as:

$$POPCD = \frac{\text{EOC}_{n+1}\text{ RPC confirmed and detected at EOC}_n + \text{EOC}_n\text{ RPC confirmed and repaired at EOC}_n}{\{\text{Numerator}\} + \text{New EOC}_{n+1}\text{ RPC confirmed indications (i.e., not detected at EOC}_n\text{)}}$$

This definition of POPCD is based on the premise that all indications that can contribute significantly to structural integrity and leak rate calculations for voltage-based repair criteria application can be confirmed by rotating pancake coil (RPC) inspections. However, since only a fraction of the bobbin indications are RPC inspected, a more realistic definition of POPCD is obtained by replacing EOC_{n+1} RPC confirmed indications with EOC_{n+1} RPC confirmed plus indications not inspected. The POPCD approach treats all new indications at an inspection as having been undetected at the prior inspection even though many of the new indications may have initiated during the operating cycle. The application of POPCD for operational assessments then accounts for newly initiated indications as well as previously undetected indications.

Confidence Bounds for Loglogistic POD

The preferred approach to simulating the probability of detection is to fit a loglogistic cumulative distribution function to the empirical data. The statistically based POD distribution such as the loglogistic provides uncertainties in the POD distribution. The POD uncertainties can be included in Monte Carlo analyses, such as described below, or used to define the POD at a specified confidence level, such as the 90 percent confidence level applied in this letter and used for DCPP Unit 2 cycle 12 Operational Assessment. This allows for an analytical simulation of the probability of detection analogous to the simulation of the probability of leak for ODSCC indications at TSPs. The simulation of the probability of leak for ODSCC indications at TSPs is discussed in several documents pertaining to the application of the ODSCC ARC. The functional form of the loglogistic equation is,

$$PoD = \frac{1}{1+e^{-[b_0+b_1\log(V)]}} \qquad (1)$$

where V is the bobbin amplitude and b_0 and b_1 are parameters obtained by performing a regression analysis of the empirical POD data. The equation can be easily rearranged into the log-odds form as,

$$\ln\left(\frac{P}{1-P}\right) = b_0 + b_1\log(V) \qquad (2)$$

where the ratio in the parentheses is the odds of detection, i.e., the ratio of the probability of detection to the probability of non-detection.

For application to POPCD, the data are sorted into bins representing various voltage levels, e.g., 0.2 to 0.3 Volts, and the POD for each bin is estimated as the ratio of detected to total indications. For analysis purposes, the POD value used for fitting is the median rank or 50th percentile of the ratio values. The estimated POD values are arranged in ascending order and the maximum likelihood coefficients of the regression equation are calculated using an iteratively reweighted least squares technique. The number of indications in each bin can also be used to weight the importance of each POD estimate. The variance-covariance matrix for the parameter estimates are also obtained from the analysis and are later used for calculating confidence bounds for the equation, e.g., the 90th percentile bound to be used for the DCPP evaluations.

The following is a description of the use of Monte Carlo techniques that could be used to develop POPCD curves. No approval of this approach is requested in this letter. This discussion is presented here for information only. Approval of the use of these techniques would be the subject of a future request.

The Monte Carlo analysis consists of simulating all of the indications in a SG several thousand times. Each simulation of all of the indications in a SG is referred to as one simulation of the SG. For each simulation of a SG, a set of random possible parameters for the probability of detection equation, the intercept, slope and error standard deviation, for the population of ODSCC indications is determined and applied to all of the detected indications to establish a population of detected and undetected indications. For a given POD, P, the number of indications that remain in service, N, in a given bin is given by,

$$N = \frac{N_D}{P} - N_P \tag{3}$$

where N_D is the number of indications detected and N_P is the number of indications plugged (there were no indications from deplugging tubes and returning them to service). Because the POD is a decimal value, the fraction in the above equation will not return an integer number of tubes. The result is truncated to an integer value and a random draw from a uniform distribution is used to determine if an additional indication should be added to the total based on a comparison of the value of the remainder from the truncation to a random draw from a uniform distribution. The methodology to employ an analytic form for the POD is essentially identical to that used to simulate indications for evaluating the probability of burst and leak. The process is repeated so that each simulation of all of the indications in a SG is independent of the other simulations of all of the indications in the SG. In this manner, thousands of variations of the possible levels of degradation within the SG are considered. The determination of the probability of burst and the potential leak rate during a postulated steam line break event then proceeds according the methodology outlined in NRC GL 95-05.

For each of the Monte Carlo simulations of a SG, the elements of the population variance-covariance matrix for the parameters of the loglogistic equation are found using the estimated values from the regression analysis and a random value from the Chi-Square distribution corresponding to the degrees of freedom associated with the regression analysis. Once the population values for the variance-covariance matrix have been calculated, population parameters of the POD equation, β_0 and β_1 corresponding to b_0 and b_1, can be calculated using two random values from the standardized normal distribution based on the assumption that they are bivariate normally distributed. Given the population parameters, the POD for any indication voltage, V_i, with a bin can be calculated as,

$$P_i = \left\{1 + \exp\left[-\beta_0 - \beta_1 \log(V_i)\right]\right\}^{-1} \tag{4}$$

where the β values are the estimated population parameters corresponding to the regression parameters b_0 and b_1. Whether or not a specific indication is detected during a simulation of the SG is determined by making a random draw from a uniform distribution. If the value obtained from the uniform distribution is greater than the POD the indication is not detected and if the value is less than the POD the indication is detected and included in the analysis to determine the probability of burst and potential total leak rate for that simulation of the SG.

Current POPCD Issues

In a telephone conference between the industry and the NRC on September 5, 2000, the NRC identified several issues that were required to be resolved before generic approval of the POPCD method could occur. These issues included: 1) treatment of uncertainties, 2) the effect of uncertainties in the upper voltage range, 3) characteristics of noise for the POPCD database plants, and 4) benchmarking of POPCD in comparison with the approved POD. These issues are addressed in the sections given below for both the industry and DCPP POPCD databases in order to permit comparisons of the DCPP POPCD with the industry database POPCD. Due to the incorporation of uncertainties in this assessment, the industry database of EPRI Topical Report NP 7480-L, Addendum 5, has been expanded to include data at higher voltages, that was indicated in the footnotes of Tables 7-1 and 7-2 of NP 7480-L, Addendum 5, to improve the assessment of POPCD in the upper voltage range. Also included is a comparison of the DCPP POPCD results with the POD versus volts results obtained by ANL based on round-robin testing of non-destructive examination analysts for indications in a SG mock-up (Reference 5).

Issue 1 - Treatment of Uncertainties

POPCD Evaluation for the Industry Database

The POPCD industry database was updated in EPRI Topical Report NP 7480-L, Addendum 5 (Reference 3). The POPCD data are given in Table 1 for the combined data from 37 inspections in plants with 7/8" and 3/4" tubing including 4 inspections from the DCPP units. The tabulated data of NP 7480-L, Addendum 5, Table 7-3 were extended in Table 1 to include indications above 3.5 volts, which are only noted in footnotes to Tables 7-1 and 7-2 of NP 7480-L, Addendum 5. The prior cycle volts for Table 1 include plants that used voltages reported in the prior cycle and plants that routinely reevaluated prior cycle volts based on the last cycle indications. The footnote in Table 7-2 of NP 7480-L, Addendum 5, notes that one indication above 3.5 volts was not reported in the prior cycle. However, the reevaluation of the initial field prior cycle voltage for this indication, as described in Section 3.5 of Reference 7, led to an indication less than 2 volts (applied in Table 1) based on the initial conservative evaluation including the TSP residual in the analysis. The RPC confirmed plus not inspected data of Table 1 are used to define the POPCD distribution since the RPC confirmed columns do not include indications not inspected by an RPC probe.

The median column of Table 1 provides the median rank or 50th percentile of the POPCD ratio values (fraction column in Table 1) based on applying binomial statistics to the number of detected and non-detected indications. A few of the voltage bins show a decrease in POPCD from one bin to the next higher voltage bin, which can be expected to occur due to a limited number of specimens in a bin characteristic of fewer indications at higher voltage levels. Since the POD can be expected to increase progressively with voltage, the median values are adjusted in the last column of Table 1 to maintain a constant or increasing POD as voltage increases. The mid-range voltage and adjusted median data are used to develop the loglogistic POPCD distribution. An exception from application of the mid-range voltage is made for the lowest voltage bin in Table 1, which ranges from > 0 to 0.2 volts. Most of the indications in this bin are between 0.1 and 0.2 volts so a mid-range value of 0.15 volts is assigned to the lowest voltage bin data for fitting the loglogistic function to the data.

Figure 1 shows the adjusted median POPCD data for the industry database and the resulting loglogistic fit to the data including the lower 90 percent confidence bound on the POPCD distribution. The 90 percent lower bound confidence limit on probability of detection is consistent with the EPRI SG Examination Guidelines (Reference 8) and associated Examination Technique Specification Sheets. The loglogistic function provides a very good fit to the POPCD data. The lower 90 percent confidence bound shows only a small reduction relative to the nominal fit, which supports small uncertainties for the industry POPCD distribution based on the large number of data available. The uncertainties in the upper voltage range above about 3 volts are further discussed in the section below on the "Effect of Uncertainties in the Upper Voltage Range."

POPCD Evaluation for the DCPP Database

DCPP POPCD are available from five cycles based on the inspections at Unit 1 refueling outages 10 and 11 and Unit 2 refueling outages 9, 10, and 11. The combined data for the five outages are given in Table 2 for which data in the median and adjusted median columns were obtained as described above for the industry database. There are 4472 indications in the DCPP POPCD database of which 2189 are detected indications (RPC confirmed plus not detected added to the RPC confirmed and plugged). For POPCD evaluations, all new indications are conservatively assumed to have been undetected at the prior inspection although a significant fraction of the indications may have initiated during the cycle.

Figure 2 shows the DCPP POPCD data and the resulting loglogistic fit to the adjusted median data including the lower 90 percent confidence bound on the POPCD distribution. As found for the industry database in Figure 1, the 90 percent confidence bound supports small uncertainties for the DCPP POPCD distribution. The DCPP POPCD data were also evaluated using the median values of Table 2 with the data from 1.8 to 5.0 volts combined as a single bin to obtain a median value of 0.984. The resulting POPCD distribution was nearly identical to Figure 2 with a very slight increase above 1 volt with a corresponding slight decrease below 1 volt. The industry and DCPP POPCD distributions are compared in Figure 3. Below about 1 volt, the industry data show a moderately higher POD while the DCPP POD is slightly better than the industry database above 1 volt. The lower DCPP POD below 1 volt reflects more new indications than the industry average and may not be indicative of more undetected indications. The DCPP POPCD is about 0.99 at 4 volts, which is essentially unity relative to having negligible impact on operational assessments. The uncertainties in the upper voltage range above about 3 volts are further discussed in the section below on the "Effect of Uncertainties in the Upper Voltage Range."

Issue 2 - Effect of Uncertainties in the Upper Voltage Range

Both the industry and DCPP POPCD databases are well defined relative to the number of indications in the databases up to about 3 volts. From Tables 1 and 2, all indications above 3.2 volts for the industry database and above 1.6 volts for the DCPP database are detected. However, the limited number of indications above these voltages lead to a reduction in the POD below unity as seen by the DCPP reduction from 1.0 for the fraction detected to 0.968 for the adjusted median in Table 2. The undetected indications in the industry POPCD database above approximately 1.5 volts are dominated by the data from two units (9 of the 37 inspections or 24 percent, SGs with 7/8 inch tubing since replaced) that had very high noise levels at the TSP intersections. The 9 inspections in these two units account for 70 percent of the new indications (POPCD assumption of missed indications) above 1.6 volts in Table 1 including 4 of the 5 new indications above 2.5 volts. The DCPP SG noise levels are small compared to these two units. For the SGs still operating, the industry database is therefore very conservative above about 1.6 volts. This difference above about 1.6 volts is seen in the NP 7480-L, Addendum 5, POPCD data by comparing the NP 7480-L, Addendum 5, figures for 3/4 inch plants with modest noise levels (Figure 7-1) and the 7/8 inch plants including the two units with high noise levels (Figure 7-2). Overall, it is concluded that the upper voltage range (above 2 volts) uncertainty is adequately addressed by the statistical applications defining the 50^{th} percentile, which provides the input to the loglogistic fits.

PG&E will use a lower 90 percent loglogistic confidence bound in the DCPP plant specific POPCD analyses to support the Operational Assessment for Unit 2 cycle 12. The statistical applications in developing the DCPP POPCD distribution together with accounting for POD uncertainties in the operational assessments adequately address uncertainties in the upper voltage range.

Issue 3 - Characteristics of Noise for the POPCD Database Plants

As noted above, 70 percent of the missed indications above 1.6 volts in the Table 1 industry database occurred in two units (SGs since replaced) that represent only 24 percent of the 37 inspections in the database. These units had high noise levels at TSP intersections compared to the currently operating SGs and, particularly, in comparison with the DCPP SGs. Although not numerically demonstrated by noise analyses, the noise levels for the industry POPCD database can be expected to bracket current ARC applications. However, the question of noise levels for the industry POPCD database compared to plants applying the ARC is not applicable to the proposed DCPP application of POPCD. DCPP will apply the POPCD distributions from only the DCPP inspection results. The DCPP database includes three consecutive inspections from Unit 2 and two consecutive inspections from Unit 1. Noise analyses performed for the two DCPP units (Reference 9, for example at dented TSP intersections) did not show any significant differences in noise levels at TSP intersections between the two units. Since only DCPP data are applied for the proposed POPCD applications, the noise data in the DCPP POPCD database directly applies for ARC applications.

The POPCD approach to detection probabilities has built-in checks on the potential for missing indications that might challenge structural or leakage integrity. The database includes successive inspections such as three consecutive inspections for DCPP and as many as five consecutive inspections for one of the units in the industry database with high noise levels. If a large indication was missed in one inspection, it would continue to grow until finally detected in a later inspection. The POPCD methodology includes all new indications as assumed missed indications and large new indications found in an inspection are reevaluated at the prior outage to define the undetected indication voltages for a POPCD cycle. As noted above and in Table 1, no new indications throughout the industry were found to have a prior inspection voltage greater than 3.2 volts, which is well below an indication of about 9.6 volts challenging structural integrity and would have a leakage probability of only about 20 percent based on NP 7480-L, Addendum 5, data. For DCPP, no new indications were found to have a prior inspection voltage greater than 1.6 volts. All large voltage indications challenging structural or leakage integrity found in ARC inspections, including DCPP Unit 2 refueling outage 11, can be traced to large growth rates and not to missed indications.

Issue 4 - Benchmarking of POPCD in Comparison with the Approved POD

In January, 1999, the NRC issued a request for additional information (Reference 10) requesting supplemental information in support of NP 7480-L, Addendum 1. Question 9, Part 2 requested an assessment of the ability of the POPCD approach to conservatively project the EOC voltage distribution. The response to this request for additional information (Reference 11) provided extensive benchmarking of POPCD analyses as described below. In addition, the DCPP POPCD distribution for the last operating cycle has been benchmarked against the inspection results at Unit 2 refueling outage 11 as described below.

Reference 11 provided a response to an NRC request for additional information on benchmarking operational assessments using POPCD for detection rather than POD = 0.6. The response included Monte Carlo analyses for 32 cases including 18 SGs with 7/8 inch tubing and 14 SGs with 3/4 inch tubing together with an additional 17 sensitivity cases. The analyses compared EOC voltages with the projected values in addition to comparisons of burst probabilities and leak rates based on projected and actual (inspection results) voltage distributions. With a leak rate methods acceptance basis for POPCD projections being greater than or within 0.25 gpm (typically <5 percent of allowable limits) of the leak rate obtained from the EOC voltage distributions, the POPCD projections were in agreement with the actual EOC voltage distribution for 31 of the 32 SGs analyzed. The only exception was a case of an indication found at EOC with a very high voltage growth that could not be predicted or accommodated using either POPCD or a 0.6 POD for the projections. With a burst probability methods acceptance basis for POPCD projections being greater than or within 5×10^{-4} (5 percent of the 10^{-2} reporting requirement) of the burst probability obtained from the EOC actual voltages, the POPCD projections were in agreement with the actual EOC voltage distribution for 30 of the 32 SGs analyzed. One exception required a methods update included in Addendum 2 for deplugged tube growth rates and the second exception was the high voltage growth indication that also lead to the leakage under prediction. The two exceptions could not be predicted or accommodated using either POPCD or a 0.6 POD for the projections. These benchmark analyses strongly support the use of POPCD for ARC analyses.

A DCPP benchmarking analysis was performed to show the adequacy of using a DCPP POPCD distribution. Monte Carlo projections were performed for the 2R11 cycle using the DCPP POPCD and a POD of 0.6. The growth rates for these analyses were obtained from the 2R11 inspection results as this evaluation is intended to assess POPCD and a POD of 0.6 rather than the accuracy of the growth distribution as known at the Unit 2 refueling outage 10 inspection. Actual voltage dependent growth rates were included in this calculation. The projected steam line break (SLB) leak rate and burst probability are then compared with the results obtained using the 2R11 EOC as found voltage distribution (i.e., condition monitoring assessment). Table 3 provides the analysis results. The results of Table 3 show that the use of the DCPP POPCD results in accurate (within approximately 9 percent) EOC projections while the use of POD = 0.6 results in excessively conservative projections. The difference between the calculated POPCD POB and the condition monitoring POB is accounted for by the application of percentage based non-destructive examination uncertainties to the 21.5 volt flaw in the condition monitoring calculation. These results support the adequacy of the DCPP POPCD distribution for ARC applications.

Comparisons of DCPP POPCD with ANL POD from Round Robin Testing

As discussed above, substantial industry benchmarking has been performed to support POPCD applications. An independent POD assessment that supports the POPCD results and elimination of the 0.6 POD for ARC applications is described in the ANL study (Reference 5) under work sponsored by the NRC. The ANL POD results were obtained from round-robin non-destructive examination analyses of data from a SG mock-up. The ANL results discussed in this section were obtained from Figures 2.54 and 2.55 of Reference 5, which are based on test results for axial ODSCC at TSP intersections. POD distributions as a function of bobbin coil voltage are described in the report. The Reference 5 figures are shown in Figure 4 of this letter.

Figure 5 shows a comparison of the DCPP POPCD, industry POPCD and ANL POD binned data where only the nominal results are shown for simplicity in the comparison. The ANL binned data above about 0.8 volts are generally consistent with the results of the DCPP and industry POPCD data as shown in Figure 5. Below about 0.8 volts, the ANL results show a lower POD than POPCD but it is not known if this may be due to a small number of samples in the ANL SG mock-up.

Based on the methods applied in this report, the ANL logistic fit shown in the lower part of Figure 4 appears to represent too high of a POD. For example, the nominal fit approaches unity near 2 volts for comparable detection to that of POPCD, which requires about 4 volts for the POD to be near unity. To permit an equivalent comparison of POD curves between the DCPP and ANL data, the ANL bin data from the upper graph in Figure 4 (also Figure 5) were processed in the same manner as the DCPP and industry POPCD data described above to obtain a loglogistic fit to the ANL data. Figure 6 compares the DCPP and ANL loglogistic POD nominal and lower 90 percent confidence curves. The comparisons show that the DCPP POPCD results are higher than the ANL results by about 0.1 below 1 volt and both are near unity above 4 volts. The trends of POD with increasing voltage are essential the same for both distributions.

EPRI also conducted blind testing of ANL analysts to develop a POD versus voltage curve. The resulting POD distribution developed in Reference 6 is also reported in NP 7480-L, Addendum 5, as the EPRI POD curve. Figure 7 provides a comparison of the DCPP POPCD, industry POPCD, ANL logistic, and EPRI POD curves. The comparison shows consistent high detectability for bobbin indications above one volt at TSP intersections independent of the methods used to develop the POD distributions. Below about two volts, the ANL results show a lower POD than POPCD and the EPRI POD. The POPCD results are based on the conservative assumption that all new indications in the inspection outage were not detected in the prior outage. For POPCD, "truth" as an indication is defined as inspection results for RPC confirmed plus not inspected indications. The EPRI POD is based on testing analysts against field data for about 5726 TSP intersections from three plants with 3/4 inch tubing. The definition of "truth" (flaws in the population) for the EPRI POD is based on 890 indications confirmed by RPC, 222 indications not confirmed by RPC or not RPC inspected and 251 added indications based on expert opinion. The ANL mock-up uses laboratory grown cracks that were reviewed by a NDE Task Group and judged to be prototypical of field indications although no destructive examinations have been performed to confirm the prototypicality of the specimens relative to pulled tube indications.

Conclusions

The current licensed DCPP methodology of using a uniform POD value of 0.6, based on GL 95-05, results in an overly conservative and counter intuitive estimate of the number and severity of indications remaining in the SGs following the inspection. Results of both the DCPP and industry POPCD evaluations support a high probability of detection for bobbin indications above about 1 volt and lead to near unity for POD above 4 volts, which is consistent with the ANL round-robin results for industry performance. The DCPP POPCD results are independently supported, with minor differences between POD distributions, by the ANL round-robin results, the EPRI POD study, and the industry POPCD results and provide a conservative POD for application to ARC operational assessments. All results show that use of a constant POD of 0.6 is non-conservative below about 0.5 volts and excessively conservative above 1 volt. POD uncertainties are adequately accounted for in DCPP POPCD applications through the statistical methods applied and the allowances for uncertainties included in operational assessments. Therefore, the application of the POPCD method for DCPP Unit 2 Cycle 12, using plant specific inspection results, is justified and appropriate for ARC analyses. Subject to NRC approval to use the POPCD method for DCPP Unit 2 Cycle 12, PG&E will apply a lower 90 percent loglogistic confidence bound in the DCPP plant specific POPCD analyses to support the Operational Assessment for Unit 2 cycle 12.

References

1. PG&E letter DCL-97-034, "License Amendment Request 97-03, Voltage-Based Alternate Steam Generator Tube Repair Limit for Outside Diameter Stress Corrosion Cracking at Tube Support Plate Intersections," dated February 26, 1997.
2. Diablo Canyon Power Plant (DCPP) Units 1 and 2 Amendments Nos. 124 and 122, dated March 12, 1998.
3. EPRI Topical Report NP 7480-L, Addendum 5, "Steam Generator Tubing Outside Diameter Stress Corrosion Cracking at Tube Support Plates Database for Alternate Repair Limits, Update 2002," dated January 2003.
4. EPRI Topical Report NP 7480-L, Addendum 1, "Steam Generator Tubing Outside Diameter Stress Corrosion Cracking at Tube Support Plates Database for Alternate Repair Limits 1996 Database Update," dated November 1996.
5. NUREG/CR-6791, ANL-02/07, "Evaluation Current Reliability Results from the Steam Generator Mock-Up Analysis Round-Robin", Published November 2002, Argonne National Laboratory.
6. Jackson, P. S., EPRI Project 6424/RP-3580, Tetra Eng. Group, Inc., TR-95-001, "Probability of Detection by Bobbin Inspection", February 6, 1995.
7. SG-99-03-001, "Farley Unit-1 1999 Voltage Based Repair Criteria 90 Day Report", March 1999, Westinghouse Electric Company.
8. EPRI Report 1003138, "Pressurized Water Reactor Steam Generator Examination Guidelines: Revision 6", Final Report, October 2002.
9. WCAP-15573, Revision 1, "Depth-Based Tube Repair Criteria for Axial PWSCC at Dented TSP Intersections – Alternate Burst Pressure Calculation", October, 2001, Westinghouse Electric Company.
10. NRC Letter, S. L. Magruder (NRC) to D. Modeen (NEI), "Request for Additional Information Regarding NP 7480-L, Addendum 1, Steam Generator Tubing Outside Diameter Stress Corrosion Cracking at Tube Support Plates, Database for Alternate Repair Limits, 1996 Database Update, November 1996", January 24, 1997.
11. Nuclear Energy Institute Letter, D. Modeen (NEI) to Document Control Desk (NRC), "Steam Generator Degradation Specific Management Database, Addendum 2 and Responses to NRC Requests for Additional Information (RAI)," dated September 14, 1998.
12. Nuclear Energy Institute Letter, A. Marion (NEI) to Document Control Desk (NRC), "Steam Generator Degradation Specific Management Database, Addendum 5," dated February 13, 2003.

Table 1. Industry NP 7480-L Addendum 5 Combined POPCD Data for 7/8 and 3/4 inch tubes (Post-1992 Inspections)

Voltage Bin	New Indications		Bobbin Call in Both Inspections		Prior Insp.	POPCD					
						RPC Confirmed		RPC Confirmed Plus Not Inspected			
	RPC Confirmed	RPC Confirmed Plus Not Inspected	RPC Confirmed	RPC Confirmed Plus Not Inspected	Last Insp. Confirmed and Plugged	Frac.	Count	Frac.	Count	Median	Adjusted Median (Note 1)
>0 - 0.2	301	3184	21	1725	43	0	64/365	0.357	1768/4952	0.357	0.357
0.2 - 0.4	348	9649	161	10044	422	0.626	583/931	0.520	10466/20115	0.520	0.520
0.4 - 0.6	343	6156	402	12035	493	0.723	895/1238	0.671	12528/18684	0.670	0.670
0.6 -0 .8	254	2724	703	9107	370	0.809	1073/1327	0.777	9477/12201	0.777	0.777
0.8 - 1.0	199	1157	902	5753	270	0.855	1172/1371	0.839	6023/7180	0.839	0.839
1.0 - 1.2	120	478	645	2849	1032	0.933	1677/1797	0.890	3881/4359	0.890	0.890
1.2 - 1.4	51	208	504	1419	597	0.956	1101/1152	0.906	2016/2224	0.906	0.906
1.4 - 1.6	55	117	414	806	337	0.932	751/806	0.907	1143/1260	0.907	0.907
1.6 - 1.8	26	47	225	364	190	0.941	415/441	0.922	554/601	0.921	0.921
1.8 - 2.0	15	30	111	143	127	0.941	238/253	0.900	270/300	0.898	0.921
2.0 - 2.2	9	9	31	31	128	0.946	159/168	0.946	159/168	0.943	0.943
2.2 - 2.5	9	10	17	17	110	0.934	127/136	0.927	127/137	0.922	0.943
2.5 - 3.2	5	5	15	15	124	0.965	139/144	0.965	139/144	0.961	0.961
3.2 - 3.5	0	0	0	0	8	1.000	8/8	1.000	8/8	0.917	0.961
3.5 - 5.0	0	0	0	0	40	1.000	40/40	1.000	40/40	0.983	0.983
5.0 - 11.0	0	0	0	0	17	1.000	17/17	1.000	17/17	0.960	0.983
Sum 3.2-11.0	0	0	0	0	65	1.000	65/65	1.000	65/65	0.989	0.989
TOTAL	1735	23774	4151	44308	4308						

Note 1: Median adjusted to maintain POD constant or increasing based on expected POD behavior rather than statistical lower bound

Table 2. DCPP POPCD Data - Combined 1R10, 1R11, 2R9, 2R10 and 2R11 Data

Voltage Bin	New Indications		Bobbin Call in Both Inspections		Prior Insp.	POPCD					
						RPC Confirmed		RPC Conf + Not Inspected			
	RPC Confirmed	RPC Confirmed Plus Not Inspected	RPC Confirmed	RPC Confirmed Plus Not Inspected	RPC Confirmed and Plugged	Frac.	Count	Frac.	Count	Median (50%)	Adjusted Median (Note 1)
0.01-0.20	61	525	15	61	3	0.228	18/79	0.109	64/589	0.108	0.108
0.21-0.40	163	1136	87	602	20	0.396	107/270	0.354	622/1758	0.354	0.354
0.41-0.60	100	415	131	621	15	0.593	146/246	0.605	636/1051	0.605	0.605
0.61-0.80	47	139	122	374	7	0.733	129/176	0.733	381/520	0.732	0.732
0.81-1.00	19	39	95	203	3	0.838	98/117	0.841	206/245	0.838	0.838
1.01-1.20	9	19	53	91	3	0.862	56/65	0.832	94/113	0.826	0.838
1.21-1.40	4	9	51	80	0	0.927	51/55	0.899	80/89	0.892	0.892
1.41-1.60	1	1	22	33	1	0.958	23/24	0.971	34/35	0.953	0.953
1.61-1.80	0	0	19	21	0	1.000	19/19	1.000	21/21	0.968	0.968
1.81-2.00	0	0	18	19	0	1.000	18/18	1.000	19/19	0.964	0.968
2.01-2.20	0	0	0	0	5	1.000	5/5	1.000	5/5	0.871	0.968
2.21-2.50	0	0	0	0	5	1.000	5/5	1.000	5/5	0.871	0.968
2.51-3.20	0	0	0	0	10	1.000	10/10	1.000	10/10	0.933	0.968
3.21-3.50	0	0	0	0	3	1.000	3/3	1.000	3/3	0.794	0.968
3.51-5.00	0	0	0	0	6	1.000	6/6	1.000	6/6	0.891	0.968
>5.00	0	0	0	0	3	1.000	3/3	1.000	3/3	0.794	0.968
Sum > 2.00	0	0	0	0	32	1.000	32/32	1.000	32/32	0.979	0.979
Total	404	2283	613	2105	84						

Note 1: Median adjusted to maintain POD constant or increasing based on expected POD behavior rather than statistical lower bound

Table 3. DCPP Unit 2 Cycle 11 SLB Leak Rate and Burst Probability for Unit 2 SG 4

Description of Calculation	SLB Leak Rate (gpm)	SLB Probability of Burst
Condition Monitoring Results Based on 2R11 As-Found Voltage Distribution	3.76	0.0251
Cycle 11 Recalculation Applying the Actual Cycle 11 Voltage Dependent Growth Distributions		
• POPCD	3.98	0.0229*
• POD = 0.6	6.42	0.0396

* The difference between the calculated POPCD probability of burst and the condition monitoring probability of burst is accounted for by the application of percentage based non-destructive examination uncertainties to the 21.5 volt flaw in the condition monitoring calculation.

Figure 1

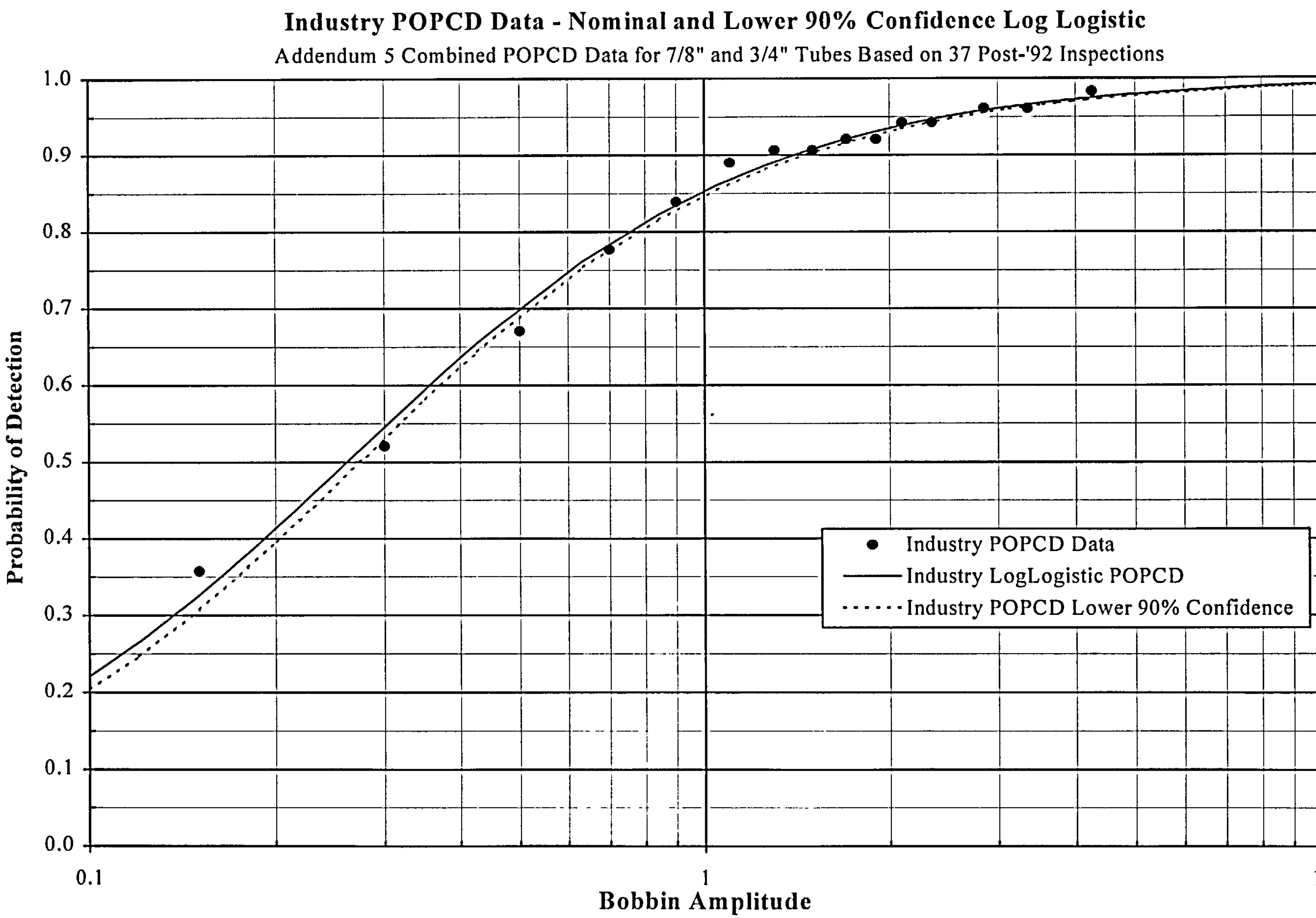
Industry POPCD Data - Nominal and Lower 90% Confidence Log Logistic
Addendum 5 Combined POPCD Data for 7/8" and 3/4" Tubes Based on 37 Post-'92 Inspections
Probability of Detection
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0.1
1
10
Bobbin Amplitude
Industry POPCD Data
Industry LogLogistic POPCD
Industry POPCD Lower 90% Confidence

Figure 2

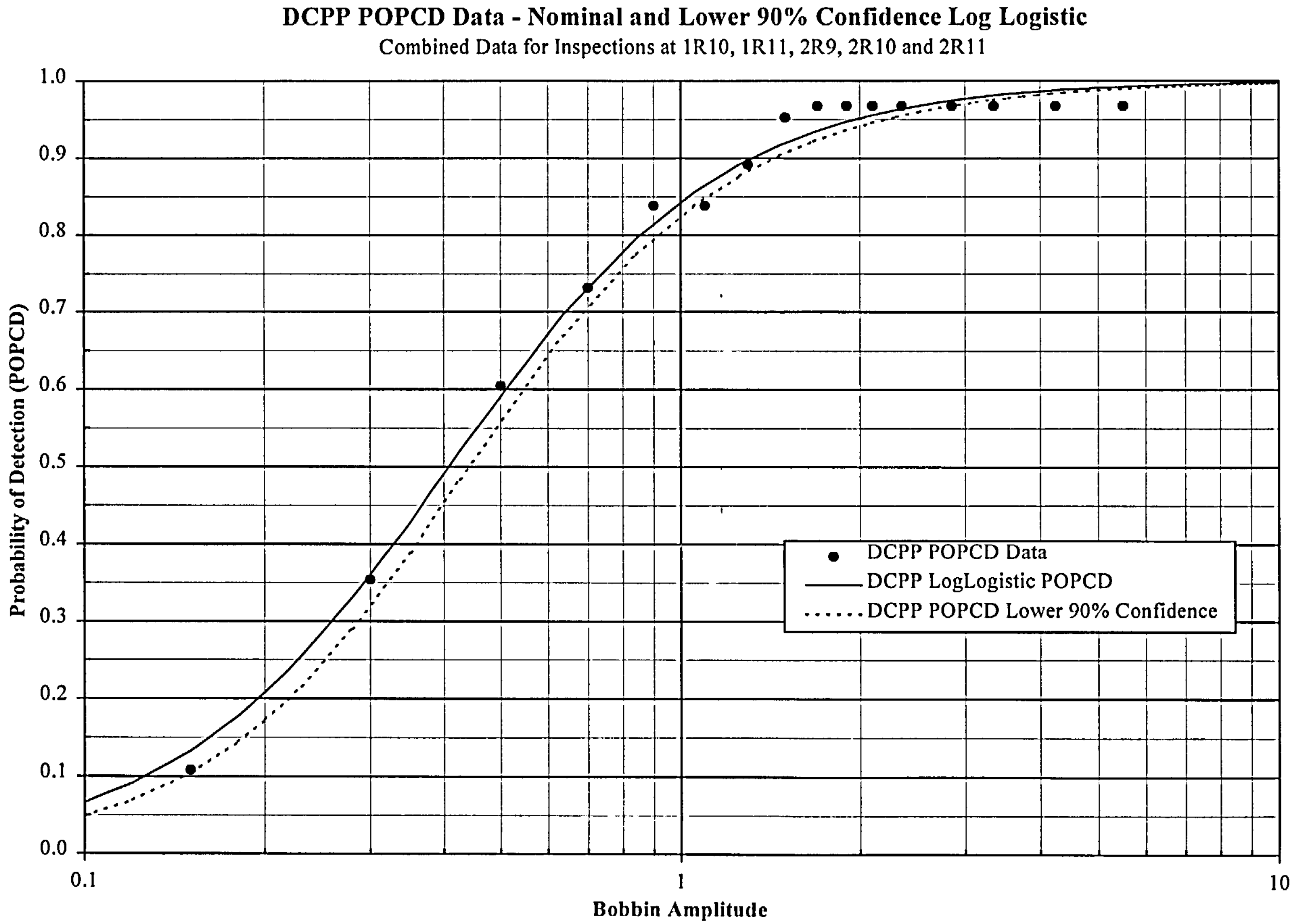
DCPP POPCD Data - Nominal and Lower 90% Confidence Log Logistic
Combined Data for Inspections at 1R10, 1R11, 2R9, 2R10 and 2R11
Probability of Detection (POPCD)
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0.1
1
10
Bobbin Amplitude
DCPP POPCD Data
DCPP LogLogistic POPCD
DCPP POPCD Lower 90% Confidence

Figure 3

Comparison of LogLogistic DCPP POPCD and Industry POPCD

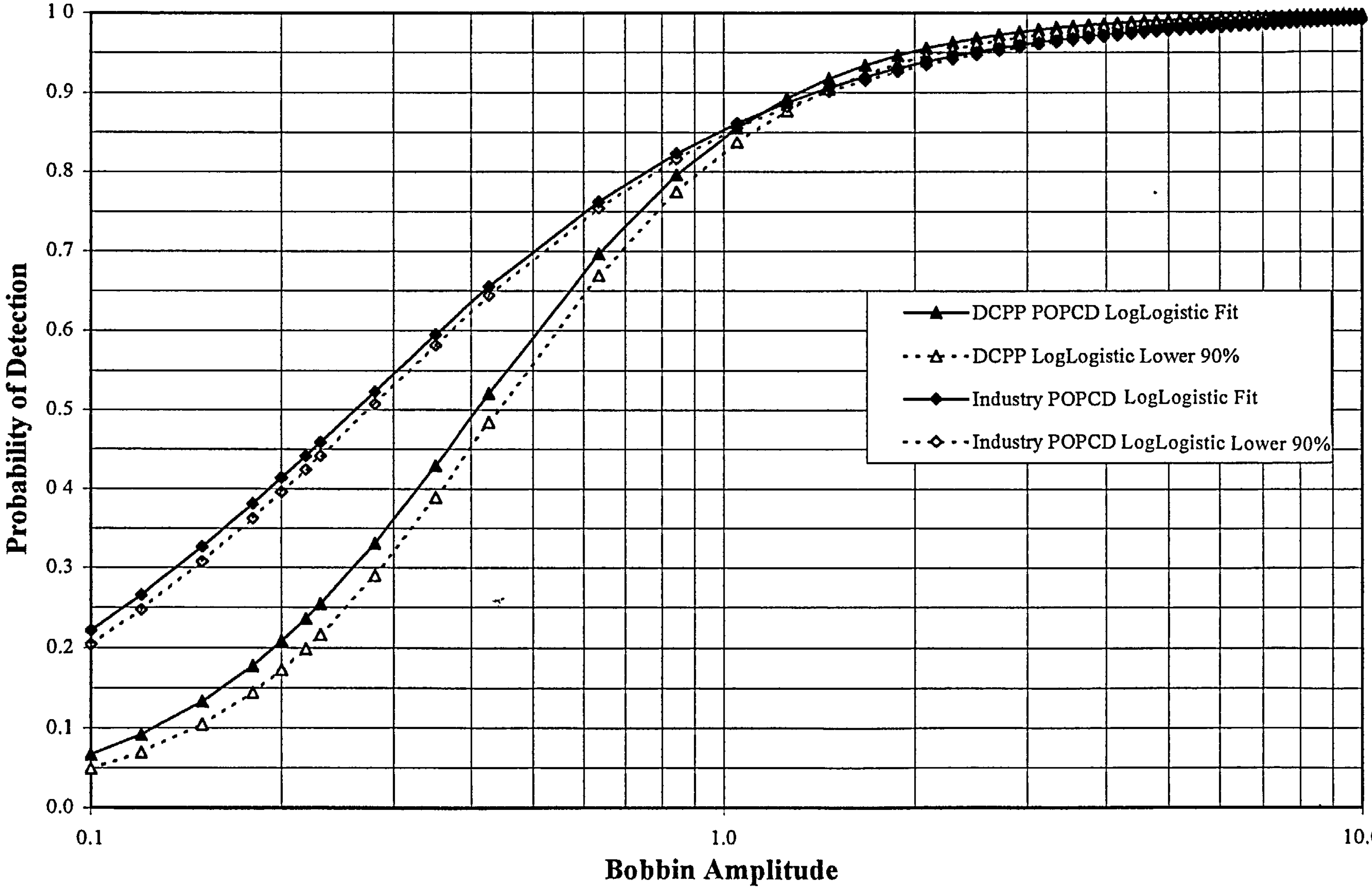

Figure 4

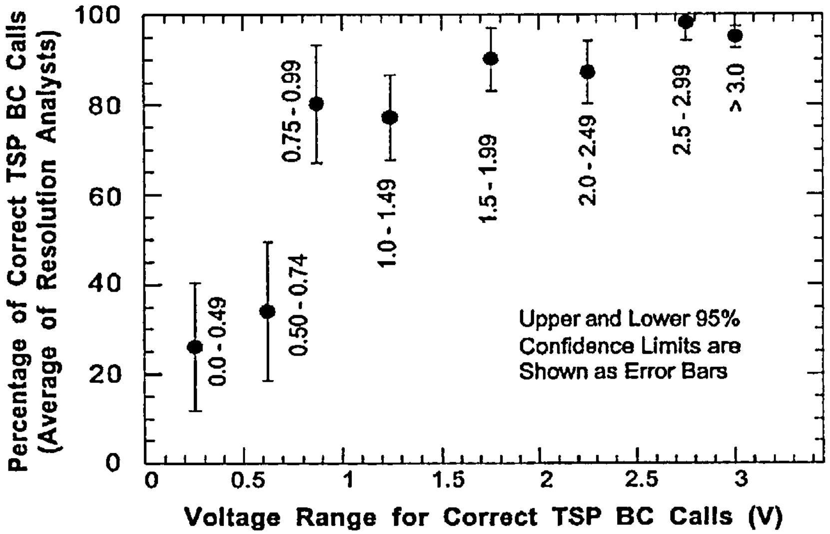

Figure 4 (Percent of Correct TSP BC Calls) Results as a function of BC voltage for TSP crack. The BC POD has been evaluated for LODSCC at the TSP. Depths are determined with the mulitparameter algorithm.

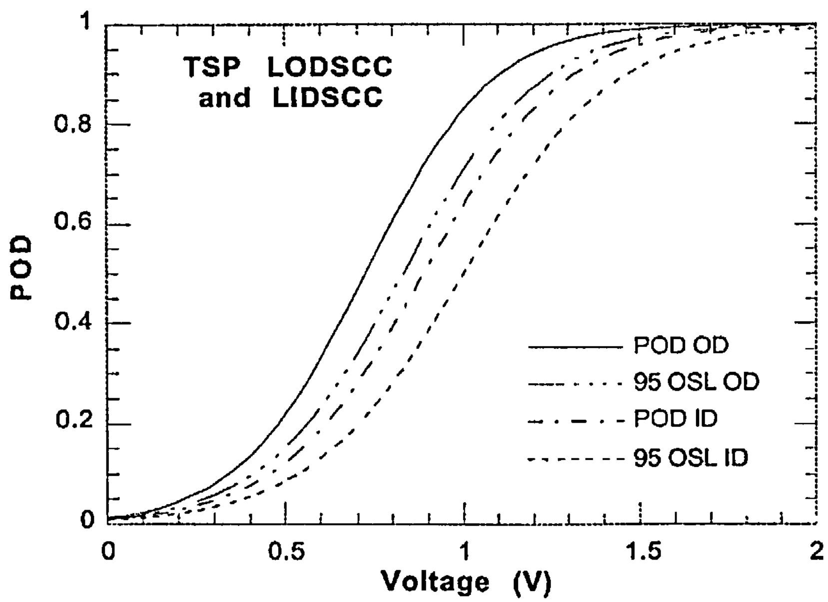

Figure 4 (POD) Logistic fit curves for BC POD as a function of voltage for LODSCC and LIDSCC in TSP.

Figure 5

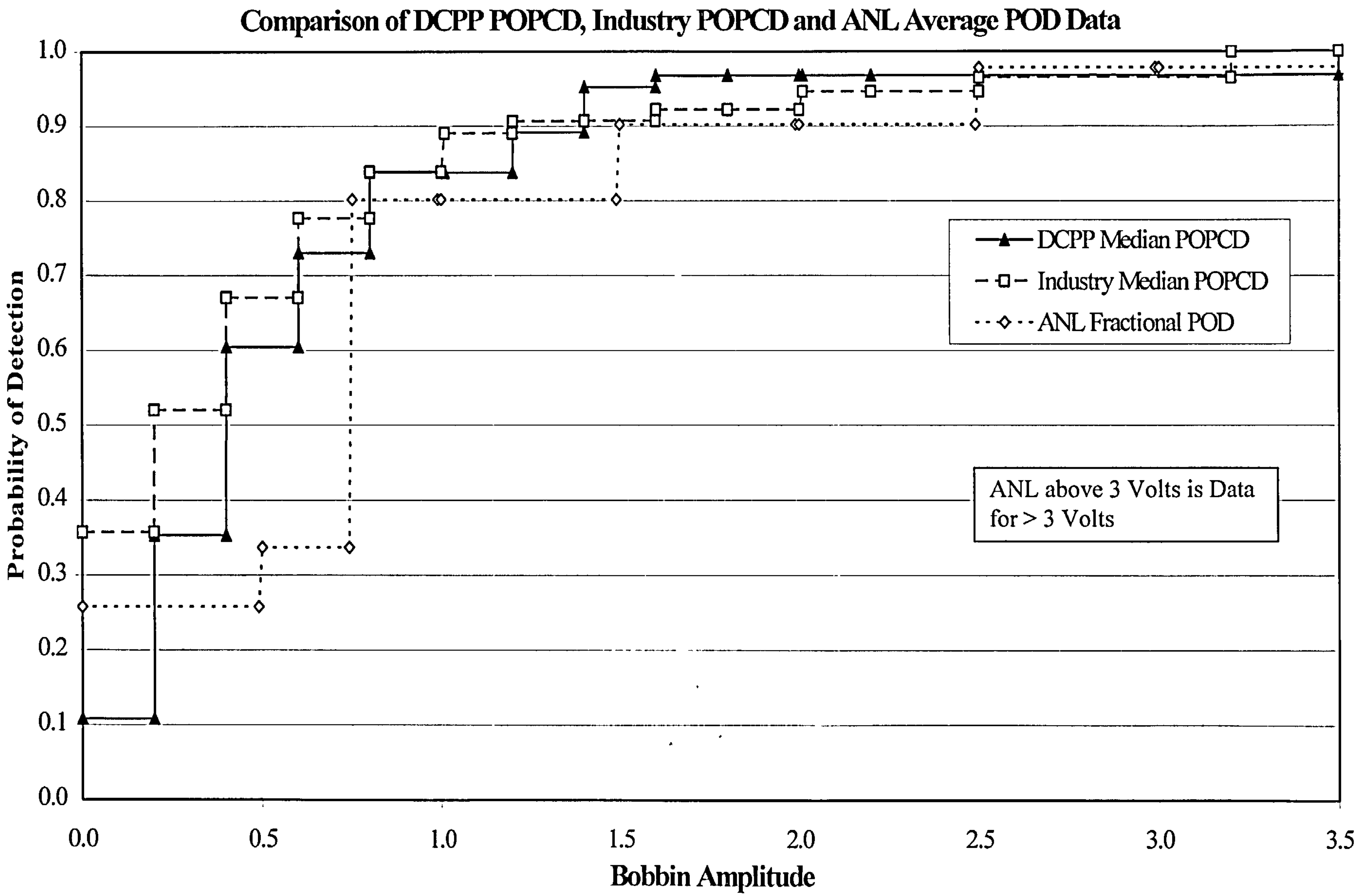
Comparison of DCPP POPCD, Industry POPCD and ANL Average POD Data
Probability of Detection
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
Bobbin Amplitude
DCPP Median POPCD
Industry Median POPCD
ANL Fractional POD
ANL above 3 Volts is Data for > 3 Volts

Figure 6

Comparison of LogLogistic DCPP POPCD and ANL POD

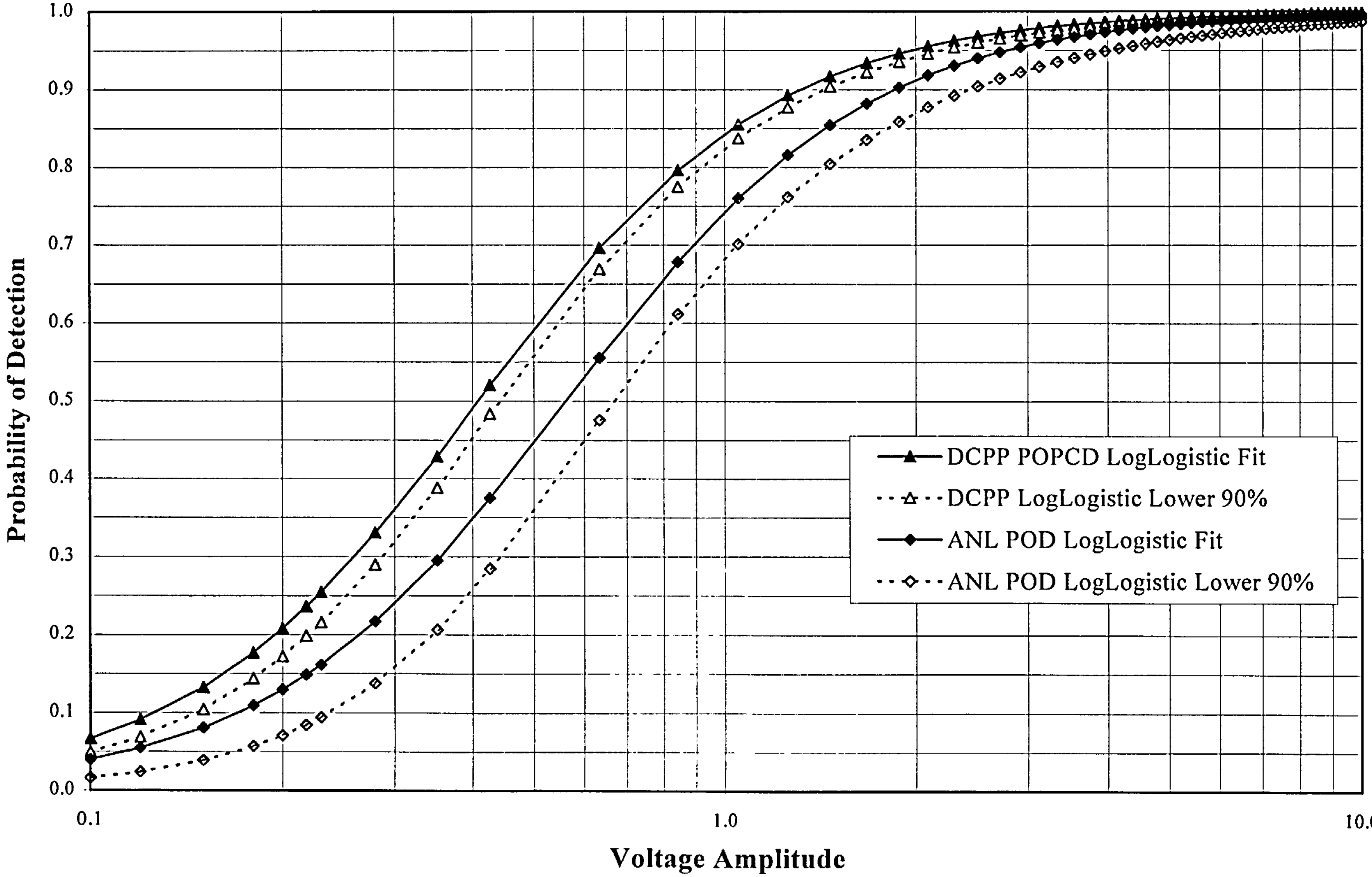

Figure 7

Comparison of LogLogistic DCPP POPCD, Industry POPCD and ANL POD