SPECIAL REPORT 03-02

W* ALTERNATE REPAIR CRITERIA 90 DAY REPORT

DIABLO CANYON POWER PLANT UNIT 2 ELEVENTH REFUELING OUTAGE

NRC Reporting Requirements

Diablo Canyon Power Plant (DCPP) Technical Specification (TS) 5.6.10.e requires that the results of the inspection of Wstar (W*) tubes be reported to the Commission pursuant to 10 CFR 50.4 within 90 days following return to service of the steam generators (SGs). The report shall include:

1. Identification of W* tubes. Per TS 5.5.9.d.1.k, a W* tube is a tube left in service with degradation within or below the W* length.
2. W* inspection distance measured with respect to the Bottom of the WEXTEX Transition (BWT) or the top of tubesheet, whichever is lower.
3. Elevation and length of axial indications within the flexible W* distance and the angle of inclination of clearly skewed axial cracks (if applicable).
4. The total steam line break leakage for the limiting SG per WCAP-14797 Revision 1 ("Generic W* Tube Plugging Criteria for 51 Series Steam Generator Tubesheet Region WEXTEX Expansions").

DCPP TS 5.6.10.f requires that the aggregate calculated steam line break leakage from application of all alternate repair criteria (ARC) be reported to the Commission pursuant to 10 CFR 50.4 within 90 days following return to service of the SGs.

W* Inspections and Results

This report implements the DCPP TS reporting criteria. W* ARC was implemented for the third time in DCPP Unit 2 during the Unit 2 eleventh refueling outage (2R11). Following 2R11 SG inspections and repairs completed in March 2003, the SGs were returned to service.

One hundred percent of the SG tubes were inspected by bobbin from tube end to tube end. One hundred percent of the hot leg top of tubesheet (TTS) WEXTEX region was inspected by Plus Point in each SG. Even though cold leg inspections were not required in accordance with the EPRI PWR SG Examination Guidelines, Revision 5, 100 percent of the cold leg TTS region was inspected by Plus Point in SG 2-4, and 20 percent of the cold leg TTS region was inspected by Plus Point in SGs 2-1, 2-2, and 2-3 (biased to the center of the bundle).

Table 1 provides a comprehensive list of axial primary water stress corrosion cracking (PWSCC) indications detected in the hot leg WEXTEX region during 2R11 Plus Point inspections. No indications were detected in the cold leg WEXTEX region. The following TS-required reporting information is extracted from Table 1:

1. *Identification of W* tubes*. See "W* Tube" column in Table 1. A total of 66 tubes with 76 axial PWSCC indications in the hot leg WEXTEX region are identified in Table 1. 63 tubes, containing a total of 73 single axial PWSCC indications (SAI), are categorized as W* tubes. A description of tubes plugged due to degradation in the WEXTEX region is described below.

   - Three repeat W* tubes were plugged (total of 8 indications) due to reasons other than failing the W* ARC, as follows: SG 2-3 R28C12 because of greater than 40% cold leg thinning at a cold leg support plate, SG 2-4 R2C29 because it was in situ leak tested to ΔP_{SLB}, and SG 2-2 R28C15 as a preventive repair because of multiple axial indications above the tube end.

   - One repeat W* tube was plugged due to failure of W* ARC (UCT above BWT). SG 2-3 R17C72 axial PWSCC indication extended from 1.0 inch (lower crack tip, LCT) to 0.53 inch (upper crack tip, UCT) below the TTS. The BWT was measured as 0.29 inch below the TTS. After addition of NDE uncertainty in locating the UCT relative to BWT as required by the W* methodology, the 2R11 UCT is located just slightly above the BWT (by 0.04 inch), requiring the tube to be plugged. The prior cycle OA projected the UCT to be located 0.16 inch above BWT, so the prior cycle OA methodology was conservative. The calculated crack length growth rate was 0.067 inch/EFPY, reflecting slow growth. This growth rate is less than the growth rate used in the prior cycle OA.

   - One tube with a new axial PWSCC indication was plugged due to failure of W* ARC (UCT above BWT). SG 2-1 R45C59 axial PWSCC indication extended from 0.55 inch (LCT) to 0.38 inch (UCT) below the TTS. The BWT was measured as 0.46 inch below the TTS. The 2R11 UCT is located above the BWT, requiring the tube to be plugged. The maximum depth of the indication was 53% through-wall as measured by Plus Point. The indication was detectable in 2R10 based on a lookup review, and had a crack length growth rate of 0.024 inch/EFPY, reflecting slow growth.

   - One tube with a new axial PWSCC indication was plugged because the entire crack length was located in the WEXTEX transition region, above BWT. Axial PWSCC located entirely in the transition region is not applicable to W* ARC. SG 2-4 R4C18 axial PWSCC indication extended from 0.27 inch (LCT) to 0.09 inch (UCT) below the TTS. The BWT was measured as 0.41 inch below the TTS. The 2R11 UCT is located above the BWT, requiring the tube to be plugged. The indication was not detectable in 2R10 based on a lookup review. Because W* ARC is not applicable to indications in the transition, the W* leakage model is not

applied. Because the flaw was located entirely below the top of tubesheet, the tubesheet provides burst restraint. Structural and SLB leakage integrity are also supported for this indication because of its small voltage (0.47 volts) and shallow depth (40%) as measured by Plus Point. The basis for these numbers are contained in draft EPRI Report 1007904, Steam Generator In Situ Pressure Test Guidelines, May 6, 2003, which demonstrates that axial PWSCC indications in explosive transitions less than 2.5 volts Plus Point have no SLB leakage potential, and degradation less than 0.5 volts Plus Point has no burst potential at 3 times normal operation differential pressure. For operational assessment, it is assumed this flaw size is the largest undetected flaw in the transition. Applying the PWSCC ARC operational assessment methodology to this flaw results in a projected EOC 12 burst pressure in excess of 6100 psi (default value in software output), and no leakage at SLB conditions. Therefore, no axial PWSCC indications in the transition region are expected that would challenge structural performance criteria at EOC 12, and no leakage is postulated in a faulted SG following a SLB at EOC 12.

- One tube with a circumferential ODSCC indication at the hot leg top of tubesheet (SG 2-1 R20C45) was plugged. Circumferential indications located in the transition region are not applicable to W* ARC. This indication is not listed in Table 1 and is not assessed in the W* ARC report. It is assessed in Enclosure 3.

2. *W* inspection distance measured with respect to BWT or TTS, whichever is lower.* For the one hundred percent Plus Point hot leg TTS exam, the inspection extent relative to the TTS was specified as +2/-8.5 inches. Assuming no degradation in the W* length, 8.5 inches below the TTS constitutes the W* inspection distance. This distance bounds W* lengths for hot leg Zone A and Zone B (5.2 inch and 7.0 inch, respectively, relative to BWT) and cold leg Zone A and Zone B (5.5 inch and 7.5 inch, respectively, relative to BWT), and includes margin for a nominal distance from BWT to TTS plus nondestructive examination (NDE) uncertainty in measuring W* length. If degradation is detected in the W* region, the inspection extent must bound the calculated flexible W* length. The "W* Inspect Dist" column in Table 1 lists the W* inspection distances measured with respect to BWT for tubes in which axial PWSCC was detected (in all cases, BWT was lower than the TTS). The W* inspection distance must be greater than or equal to the W* flexible length.

3. *Elevation and length of axial indications within the flexible W* distance.* See "LCT", "UCT" and "Crack Length" columns in Table 1 for elevation of the upper crack tip, elevation of the lower crack tip, and crack length of the axial indications. The elevations of the UCT and LCT are relative to the TTS.

4. *Angle of inclination of clearly skewed axial cracks (if applicable).* None of the axial indications were skewed, so this reporting requirement is not applicable.

5. *The total steam line break leakage for the limiting SG per WCAP-14797.* Steam line break (SLB) leakage attributed to each W* indication at end of the cycle (EOC) 11 (condition monitoring) and projected EOC 12 (operational assessment) are listed in "CM Leak Rate" and "OA Leak Rate" columns in Table 1. The W* leakage model conservatively assumes all W* indications are throughwall cracks. The total SLB leakage for each SG is provided in Tables 3 and 4, and reflects the sum of the individual leak rates listed in Table 1. Note that SG 2-4 R2C29 (two indications) was in situ leak tested at ΔP_{SLB} conditions, and no leakage was detected. The CM leak rates for these two indications are listed in Table 1 for information only and are based on the leakage model in WCAP-14797 Revision 1. However, when calculating the total SG 2-4 leak rate in Table 3, no CM leakage was assigned to these two indications based on the results of the in situ leak test.

Table 3 and Table 4 reports the following SLB leak rates for condition monitoring and operational assessment, pursuant to TS 5.6.10.e.4 and 5.6.10.f. For W* ARC, the SLB differential pressure is conservatively assumed to be 2560 psi. For PWSCC ARC and voltage-based ARC, the SLB differential pressure is assumed to be 2405 psi.

1. Total W* ARC SLB leakage for each SG at EOC 11 (condition monitoring). The maximum leak rate is 0.585 gpm (at room temperature) in SG 2-3.

2. Total W* ARC SLB leakage for each SG at EOC 12 (operational assessment). The maximum leak rate is 0.702 gpm (at room temperature) in SG 2-3.

3. The aggregate calculated EOC 11 (condition monitoring) SLB leakage from application of voltage-based ARC, PWSCC ARC, W* ARC, and non-ARC degradation. The maximum leak rate is 3.614 gpm (at room temperature) in SG 2-4.

4. The aggregate calculated EOC 12 (operational assessment) SLB leakage from application of voltage-based ARC, PWSCC ARC, W* ARC, and non-ARC degradation. The maximum leak rate is 3.319 gpm (at room temperature) in SG 2-4, based on voltage-based ARC application of voltage-dependent growth and DCPP Units 1 and 2 probability of prior cycle detection (POPCD) probability of detection (POD). Application of POPCD is pending NRC approval. The maximum leak rate is 10.089 gpm (at room temperature) in SG 2-4, based on worse case SLB leakage from voltage-based ARC (application of voltage-dependent growth, POD of 1.0 for SG 2-4 R44C45 2H indication, and POD of 0.6 for other indications).

Table 5 reports the projected EOC 11 leak rates from the prior cycle operational assessment, submitted in Enclosure 1 to PG&E letter DCL-01-086 dated August 21, 2001, for comparison with the as-found leak rates listed in Table 3. The projected leak rates are higher than the as-found leak rates in all SGs, except for SG 2-1, reflecting the conservatism of the ARC methodology. The reason for the slightly non-conservative leak rate projection in SG 2-1 (0.053 gpm under prediction) is due to three

new axial PWSCC indications within the W* length that account for 0.107 gpm. The W* ARC methodology does not require that potential new indications be accounted for in operational assessments on the basis that new indications are not likely to be through-wall. The Plus Point voltages for these three indications range from 0.24 to 0.28 volt for which leakage would not be expected.

Axial PWSCC Growth Rates

Of the 76 axial PWSCC indications in the hot leg WEXTEX region that were detected in 2R11, 9 were new indications and 67 were repeat W* indications that had been left in service in the prior inspection. All repeat indications were detected in 2R11. Based on a 2R10 lookup review of the 9 new indications, 7 were detectable, 1 was not detectable due to data quality, and 1 was not inspected because the new indication was located below the 2R10 inspection extent. As a result, 74 additional growth rate data points were available for evaluation, and their average growth rate was 0.042 inch per EFPY at Thot of 603 degrees F.

After addition of the cycle 11 data points, the updated W* growth rate distribution now consists of 182 data points from DCPP Units 1 and 2. The updated growth rate at 95 percent cumulative probability is 0.115 inch per EFPY at 603 degrees F, compared to the pre-2R11 growth rate of 0.069 inch per EFPY. The updated growth rate value of 0.115 inch per EFPY is used in the operational assessment for DCPP Unit 2 Cycle 12. Because there are less than 200 data points in the growth rate distribution, no data points are excluded.

The actual length of Unit 2 Cycle 11 was 1.64 EFPY. The projected length of Unit 2 Cycle 12 is 1.54 EFPY.

In Situ Leak Testing

In Situ Test Screening Methodology

In support of W* leak rate model validation, PG&E letter DCL-01-095 dated September 13, 2001, defined a four step sequential screening process for determining the need for in situ leak testing of axial PWSCC indications in the WEXTEX region. The screening criteria are described below. PG&E's assessment of the 76 axial PWSCC indications detected in 2R11 with respect to the screening criteria is tabulated in Table 2, and is also summarized below.

- Step 1: Prior leak tested W* indications with maximum Plus Point voltages greater than or equal to 1.25 times the prior leak test voltage are carried to Step 2. W* indications with no prior leak test are also carried to step 2.

  PG&E evaluation: Seven W* indications had been leak tested in prior outages and for one of these indications (SG 2-4 R2C29 crack 2), the Plus Point voltage

increased by 30% (more than 25% threshold), so this indication was carried to step 2. The 69 indications with no prior in situ test were also carried to step 2.

- Step 2: Indications with maximum Plus Point voltages exceeding the critical voltage (V_{crit}) are leak tested independent of other parameters. V_{crit} equals 4.0 volts for nondeplugged indications and 6.0 volts for deplugged indications. Indications with maximum Plus Point voltages less than V_{crit} are carried to Step 3.

  PG&E evaluation: 42 of the 70 indications carried to step 2 had been deplugged in a prior outage, and 28 had not been deplugged. None of the deplugged indications exceeded 6.0 volts Plus Point, and none of the nondeplugged indications exceeded 4.0 volts Plus Point. As such, none of the indications required in situ testing due to exceeding V_{crit}. Therefore, all 70 indications were carried to step 3.

- Step 3: Indications with maximum Plus Point voltages exceeding V_{thr} are carried to the Step 4 depth evaluation. A minimum of the five largest voltage indications are carried to the depth evaluation if less than five indications exceed the voltage threshold. V_{thr} equals 2.5 volts for nondeplugged indications and 4.0 volts for deplugged indications.

  PG&E evaluation: For the 28 nondeplugged axial PWSCC indications, none of maximum Plus Point voltages exceeded the 2.5 volt V_{thr} threshold value. The maximum Plus Point voltage of 2 of the 42 deplugged axial PWSCC indications exceeded the 4.0 volt V_{thr} threshold value (SG 2-2 R28C15 cracks 4 and 5). This tube had been deplugged and returned to service in 2R9. The 2R11 Plus Point voltages of these two indications were 4.7 and 5.4, reflecting an increase from the 2R10 voltage measurements of 2.9 and 3.9, respectively. These 2 indications are carried to the step 4 depth evaluation.

  The remaining 68 indications were ranked from highest to lowest Plus Point voltage. The 5 highest voltages were carried to step 4, in addition to SG 2-2 R28C15 cracks 4 and 5, to ensure that a minimum of 5 largest voltages are carried to step 4.

- Step 4 (depth evaluation): Indications with maximum depths exceeding the maximum depth leakage threshold (MD_{L-thr}) over lengths greater than the deep crack length threshold (L_{L-min}) are leak tested. MD_{L-thr} equals 80% and L_{L-min} equals 0.1 inch.

  PG&E evaluation: All axial PWSCC indications in the WEXTEX region were depth profiled using the same techniques as axial PWSCC at dented TSP intersections. For each indication, the flaw length exceeding 80% maximum depth is listed in Table 2.

2R11 In Situ Testing of W Indications*

Only 2 of the 7 indications had maximum depths exceeding 80% maximum depth over greater than 0.1 inch (SG 2-2 R28C15 cracks 4 and 5). Therefore, these indications required in situ leak testing. However, in situ testing was not performed because the location of the indications precluded an effective test. These indications were located between approximately 0.5 inches to 2 inches above the tube end (below the shop roll and within the tubesheet). This location is where the in situ testing tool head would seat/seal, so the test would not have been capable of pressurizing the indication. In addition, because the location of the indication is well below the W* length, tests results would not provide meaningful data for validation of the W* leakage model. R18C25 was subsequently plugged. In summary, none of the seven indications carried to step 4 were in situ tested.

The SG 2-4 R2C29 crack 1 and crack 2 UCT locations were 3.61 and 1.78 inches below the TTS (within the W* length), had Plus Point voltages of 5.25 volts and 1.22 volts, and had greater than 80% maximum depth lengths of 0.97 inch and 0.12 inch. The indications did not require in situ testing based on the screening methodology described above. However, 2R11 in situ testing was performed on these indications because visual examination of the R2C29 tube end showed some evidence of moisture during secondary side pressure testing. The indications were subsequently in situ tested (full tube length test) up to ΔP_{SLB} conditions, and no leakage was detected. The test was then terminated and the tube was plugged. Based on the in situ test results, the total SG leak rate assumes no leakage from R2C29 indications. The R2C29 indications were previously in situ tested in 2R10, with no in situ leakage detected up to normal operating dP, and were returned to service in 2R10 because they had satisfied W* ARC criteria.

<u>Tube Integrity Performance Monitoring</u>

Condition Monitoring Performance Criteria to Limit Free Span Cracking: The upper crack tip (UCT) of W* indications returned to service under W* ARC in the prior inspection (EOC 10) shall remain below the TTS at EOC 11 by at least the NDE uncertainty on locating the crack tip relative to the TTS. The "UCT adj" column in Table 1 provides the EOC 11 elevation of the upper crack tip relative to the top of tubesheet, accounting for NDE uncertainty in locating the crack relative to the top of tubesheet. In all cases, the EOC 11 crack tip for indications returned to service at EOC 10 is below the top of tubesheet, as indicated by "Yes" in the column "UCT below TTS?" Therefore, the performance criterion was satisfied for condition monitoring at EOC 11.

Accident-Induced Leakage Performance Criteria: W* leak rates under postulated SLB conditions, when combined with SLB leak rates from application of GL 95-05 voltage-based ARC and PWSCC ARC, and SLB leak rates from non-ARC degradation mechanisms, shall not exceed 10.5 gpm (at room temperature) in the faulted SG for condition monitoring and operational assessment. The 10.5 gpm limit was approved by the NRC as requested in PG&E license amendment request (LAR) 01-05. The aggregate calculated SLB leakage at EOC 11 is 3.614 gpm for the limiting SG. The

aggregate calculated SLB leakage at EOC 12 is 10.089 gpm for the limiting SG, based on worst case SLB leakage from voltage based ARC (application of voltage dependent growth, POD of 1.0 for SG 2-4 R44C45 2H indication, and POD of 0.6 for other indications). In both assessments, SLB leakage is less than the allowable limit. Therefore, the performance criterion has been satisfied for condition monitoring at EOC 11 and operational assessment at EOC 12.

Table 1 - 2R11 Axial PWSCC Indications in Hot Leg WEXTEX Tubesheet Region

SG	Row	Col	PP Volts	Crack No	LCT	UCT	Crack Length	UCT adj	UCT below TTS	W* Zone	W* Length	BWT	UCT to BWT	UCT Below W*	UCT Below BWT	EOC (N+1) UCT to TTS	EOC (N+1) UCT Below TTS	W* Tube	Inspect Extent	W* Inspect Dist	Flex W* Length	CM Leak Rate	EOC (N+1) UCT to BWT	OA Leak Rate	Prev W* Tube	Tube Plugged
21	3	59	4.95	1	-1.48	-0.76	0.72	-0.54	Yes	B1	7.12	-0.42	0.06	No	Yes	-0.36	Yes	Yes	-10.66	10.15	7.88	0.043	-0.34	0.045	Repeat	No
21	6	77	0.86	1	-1.4	-1.23	0.17	-1.01	Yes	B4	7.12	-0.40	0.55	No	Yes	-0.83	Yes	Yes	-10.94	10.45	7.33	0.026	0.15	0.040	Repeat	No
21	7	24	0.19	1	-1.98	-1.87	0.11	-1.65	Yes	B3	7.12	-0.37	1.22	No	Yes	-1.47	Yes	Yes	-10.97	10.51	7.27	0.015	0.82	0.021	Repeat	No
21	7	62	3.58	1	-2.34	-1.44	0.90	-1.22	Yes	B2	7.12	-1.06	0.10	No	Yes	-1.04	Yes	Yes	-21.4	20.25	8.06	0.042	-0.30	0.045	Repeat	No
21	8	32	0.39	1	-2.13	-1.98	0.15	-1.76	Yes	B2	7.12	-0.39	1.31	No	Yes	-1.58	Yes	Yes	-10.8	10.32	7.31	0.015	0.91	0.020	Repeat	No
21	9	49	0.49	1	-2.16	-1.96	0.20	-1.74	Yes	B1	7.12	-0.36	1.32	No	Yes	-1.56	Yes	Yes	-10.93	10.48	7.36	0.015	0.92	0.020	Repeat	No
21	10	49	0.25	1	-0.94	-0.80	0.14	-0.58	Yes	B1	7.12	-0.30	0.22	No	Yes	-0.40	Yes	Yes	-10.76	10.37	7.30	0.037	-0.18	0.045		No
21	11	37	0.42	1	-7.54	-7.43	0.11	-7.21	Yes	B2	7.12	-0.41	6.74	No	Yes	-7.03	Yes	Yes	-10.63	10.13	7.27	0.001	6.34	0.001	Repeat	No
21	11	37	0.64	2	-6.65	-6.48	0.17	-6.26	Yes	B2	7.12	-0.41	5.79	No	Yes	-6.08	Yes	Yes	-10.63	10.13	7.33	0.001	5.39	0.001	Repeat	No
21	11	37	0.31	3	-2.11	-1.85	0.26	-1.63	Yes	B2	7.12	-0.41	1.16	No	Yes	-1.45	Yes	Yes	-10.63	10.13	7.42	0.017	0.76	0.022	Repeat	No
21	11	39	1.3	1	-1.93	-1.61	0.32	-1.39	Yes	B1	7.12	-0.42	0.91	No	Yes	-1.21	Yes	Yes	-10.92	10.41	7.48	0.020	0.51	0.027	Repeat	No
21	11	40	0.37	1	-0.97	-0.83	0.14	-0.61	Yes	B1	7.12	-0.49	0.06	No	Yes	-0.43	Yes	Yes	-10.94	10.36	7.30	0.043	-0.34	0.045	Repeat	No
21	11	48	1.99	1	-4.84	-4.39	0.45	-4.17	Yes	B1	7.12	-0.42	3.69	No	Yes	-3.99	Yes	Yes	-10.54	10.03	7.61	0.006	3.29	0.007	Repeat	No
21	13	49	0.28	1	-1.68	-1.54	0.14	-1.32	Yes	B1	7.12	-0.66	0.60	No	Yes	-1.14	Yes	Yes	-11.53	10.78	7.30	0.025	0.20	0.037		No
21	23	70	0.95	1	-1.66	-1.27	0.39	-1.05	Yes	A	5.32	-0.22	0.77	No	Yes	-0.87	Yes	Yes	-10.9	10.59	5.75	0.018	0.37	0.031	Repeat	No
21	30	59	2.43	1	-10.13	-9.82	0.31	-9.60	Yes	B4	7.12	-0.15	9.39	Yes	Yes	-9.42	Yes	Yes	-21.4	21.16	7.12	0.000	8.99	0.000		No
21	45	59	0.24	1	-0.55	-0.38	0.17	-0.16	Yes	A	5.32	-0.46	-0.36	No	No	0.02	No	No	-11.11	10.56	5.53	0.045	NA	0.000		Yes
22	28	15	0.51	1	-2.3	-2.16	0.14	-1.94	Yes	A	5.32	-0.45	1.43	No	Yes	-1.76	Yes	Yes	-21.4	20.86	5.50	0.006	NA	0.000	Repeat	Yes
22	28	15	0.5	2	-1.89	-1.69	0.20	-1.47	Yes	A	5.32	-0.45	0.96	No	Yes	-1.29	Yes	Yes	-21.4	20.86	5.56	0.011	NA	0.000	Repeat	Yes
22	28	15	0.83	3	-11.11	-10.82	0.29	-10.6	Yes	A	5.32	-0.45	10.09	Yes	Yes	-10.42	Yes	Yes	-21.4	20.86	5.32	0.000	NA	0.000	Repeat	Yes
22	28	15	5.4	4	-20.88	-19.38	1.50	-19.16	Yes	A	5.32	-0.45	18.65	Yes	Yes	-18.98	Yes	Yes	-21.4	20.86	5.32	0.000	NA	0.000	Repeat	Yes
22	28	15	4.7	5	-21.01	-19.29	1.72	-19.07	Yes	A	5.32	-0.45	18.56	Yes	Yes	-18.89	Yes	Yes	-21.4	20.86	5.32	0.000	NA	0.000	Repeat	Yes
22	5	18	0.66	1	-1.24	-0.99	0.25	-0.77	Yes	B4	7.12	-0.24	0.47	No	Yes	-0.59	Yes	Yes	-10.03	9.70	7.41	0.028	0.07	0.043	Repeat	No
22	31	25	4.05	1	-2.18	-1.59	0.59	-1.37	Yes	A	5.32	-0.55	0.76	No	Yes	-1.19	Yes	Yes	-9.57	8.93	5.95	0.018	0.36	0.031	Repeat	No
22	13	43	0.73	1	-1.42	-1.23	0.19	-1.01	Yes	B1	7.12	-0.45	0.50	No	Yes	-0.83	Yes	Yes	-10.38	9.84	7.35	0.027	0.10	0.042	Repeat	No
22	10	48	0.42	1	-3.04	-2.9	0.14	-2.68	Yes	B1	7.12	-0.09	2.53	No	Yes	-2.50	Yes	Yes	-10.16	9.98	7.30	0.008	2.13	0.009	Repeat	No
22	10	56	0.88	1	-1.07	-0.9	0.17	-0.68	Yes	B1	7.12	-0.58	0.04	No	Yes	-0.50	Yes	Yes	-10.46	9.79	7.33	0.044	-0.36	0.045	Repeat	No
23	28	12	2.37	1	-2.1	-1.51	0.59	-1.29	Yes	A	5.32	-0.54	0.69	No	Yes	-1.11	Yes	Yes	-12.19	11.56	5.95	0.02	NA	0.00	Repeat	Yes
23	14	24	0.35	1	-1.91	-1.76	0.15	-1.54	Yes	B4	7.12	-0.16	1.32	No	Yes	-1.36	Yes	Yes	-11.65	11.40	7.31	0.010	0.92	0.016	Repeat	No

Table 1 - 2R11 Axial PWSCC Indications in Hot Leg WEXTEX Tubesheet Region

SG	Row	Col	PP Volts	Crack No	LCT	UCT	Crack Length	UCT adj	UCT below TTS	W* Zone	W* Length	BWT	UCT to BWT	UCT Below W*	UCT Below BWT	EOC (N+1) UCT to TTS	EOC (N+1) UCT Below TTS	W* Tube	Inspect Extent	W* Inspect Dist	Flex W* Length	CM Leak Rate	EOC (N+1) UCT to BWT	OA Leak Rate	Prev W* Tube	Tube Plugged
23	16	24	0.25	1	-1.38	-1.23	0.15	-1.01	Yes	B4	7.12	-0.16	0.79	No	Yes	-0.83	Yes	Yes	-11.85	11.60	7.31	0.019	0.39	0.031	Repeat	No
23	25	37	1.87	1	-1.29	-0.88	0.41	-0.66	Yes	B4	7.12	-0.31	0.29	No	Yes	-0.48	Yes	Yes	-11.57	11.17	7.57	0.034	-0.11	0.045	Repeat	No
23	45	37	1.50	1	-1.56	-1.22	0.34	-1.00	Yes	A	5.32	-0.28	0.66	No	Yes	-0.82	Yes	Yes	-12.04	11.67	5.70	0.022	0.26	0.035	Repeat	No
23	21	38	0.54	1	-1.52	-1.02	0.50	-0.80	Yes	B3	7.12	-0.33	0.41	No	Yes	-0.62	Yes	Yes	-11.57	11.15	7.66	0.030	0.01	0.045	Repeat	No
23	12	48	0.29	1	-1.99	-1.87	0.12	-1.65	Yes	B1	7.12	-0.29	1.30	No	Yes	-1.47	Yes	Yes	-11.58	11.20	7.28	0.015	0.90	0.020	Repeat	No
23	5	51	0.51	1	-2.12	-2.01	0.11	-1.79	Yes	B1	7.12	-0.24	1.49	No	Yes	-1.61	Yes	Yes	-11.64	11.31	7.27	0.013	1.09	0.017	Repeat	No
23	7	52	4.21	1	-1.53	-0.79	0.74	-0.57	Yes	B1	7.12	-0.28	0.23	No	Yes	-0.39	Yes	Yes	-11.99	11.62	7.90	0.036	-0.17	0.045	Repeat	No
23	5	55	1.13	1	-2.2	-1.93	0.27	-1.71	Yes	B1	7.12	-0.19	1.46	No	Yes	-1.53	Yes	Yes	-11.89	11.61	7.43	0.014	1.06	0.018	Repeat	No
23	32	55	1.21	1	-1.3	-0.9	0.40	-0.68	Yes	A	5.32	-0.37	0.25	No	Yes	-0.50	Yes	Yes	-11.55	11.09	5.76	0.035	-0.15	0.045	Repeat	No
23	7	59	1.50	1	-1.88	-1.44	0.44	-1.22	Yes	B1	7.12	-0.31	0.85	No	Yes	-1.04	Yes	Yes	-11.84	11.44	7.60	0.021	0.45	0.029	Repeat	No
23	9	63	0.40	1	-1.29	-1.13	0.16	-0.91	Yes	B2	7.12	-0.38	0.47	No	Yes	-0.73	Yes	Yes	-11.62	11.15	7.32	0.028	0.07	0.043	Repeat	No
23	3	69	0.94	1	-1.22	-0.88	0.34	-0.66	Yes	B2	7.12	-0.34	0.26	No	Yes	-0.48	Yes	Yes	-11.42	10.99	7.50	0.035	-0.14	0.045	Repeat	No
23	19	71	1.08	1	-2.14	-1.8	0.34	-1.58	Yes	A	5.32	-0.38	1.14	No	Yes	-1.40	Yes	Yes	-11.40	10.93	5.70	0.008	0.74	0.019	Repeat	No
23	17	72	1.67	1	-1	-0.53	0.47	-0.31	Yes	A	5.32	-0.29	-0.04	No	No	-0.13	Yes	No	-13.38	13.00	5.83	0.045	NA	0.00	Repeat	Yes
23	6	77	0.26	1	-1.78	-1.66	0.12	-1.44	Yes	B4	7.12	-0.42	0.96	No	Yes	-1.26	Yes	Yes	-11.96	11.45	7.28	0.015	0.56	0.026	Repeat	No
23	21	83	0.94	1	-1.16	-0.85	0.31	-0.63	Yes	A	5.32	-0.31	0.26	No	Yes	-0.45	Yes	Yes	-11.92	11.52	5.67	0.035	-0.14	0.045	Repeat	No
23	4	90	0.33	1	-1.11	-0.97	0.14	-0.75	Yes	A	5.32	-0.19	0.50	No	Yes	-0.57	Yes	Yes	-10.12	9.84	5.50	0.027	0.10	0.042		No
23	2	91	0.62	1	-0.95	-0.6	0.35	-0.38	Yes	A	5.32	-0.23	0.09	No	Yes	-0.20	Yes	Yes	-11.92	11.60	5.71	0.042	-0.31	0.045	Repeat	No
23	7	92	0.92	1	-1.15	-0.81	0.34	-0.59	Yes	A	5.32	-0.24	0.29	No	Yes	-0.41	Yes	Yes	-13.61	13.28	5.70	0.034	-0.11	0.045	Repeat	No
23	8	93	1.22	1	-0.8	-0.57	0.23	-0.35	Yes	A	5.32	-0.26	0.03	No	Yes	-0.17	Yes	Yes	-12.08	11.73	5.59	0.044	-0.37	0.045	Repeat	No
24	2	10	0.43	1	-1.46	-1.33	0.13	-1.11	Yes	A	5.32	-0.20	0.85	No	Yes	-0.93	Yes	Yes	-11.37	11.08	5.49	0.015	0.45	0.029	Repeat	No
24	2	29	5.25	1	-4.58	-3.61	0.97	-3.39	Yes	B2	7.12	-0.29	3.04	No	Yes	-3.21	Yes	Yes	-10.77	10.39	8.13	0.006 Note 1	NA	0.000	Repeat	Yes
24	2	29	1.22	2	-2.42	-1.78	0.64	-1.56	Yes	B2	7.12	-0.29	1.21	No	Yes	-1.38	Yes	Yes	-10.77	10.39	7.80	0.016 Note 1	NA	0.000	Repeat	Yes
24	3	5	1.77	1	-1.85	-0.85	1.00	-0.63	Yes	A	5.32	-0.29	0.28	No	Yes	-0.45	Yes	Yes	-11.29	10.91	6.36	0.034	-0.12	0.045	Repeat	No
24	3	12	0.44	1	-2.81	-2.69	0.12	-2.47	Yes	A	5.32	-0.28	2.13	No	Yes	-2.29	Yes	Yes	-11.28	10.91	5.48	0.004	1.73	0.005	Repeat	No
24	3	12	0.94	2	-2.49	-2.28	0.21	-2.06	Yes	A	5.32	-0.28	1.72	No	Yes	-1.88	Yes	Yes	-11.28	10.91	5.57	0.005	1.32	0.007	Repeat	No
24	3	17	0.39	1	-3.59	-3.38	0.21	-3.16	Yes	B4	7.12	-0.60	2.50	No	Yes	-2.98	Yes	Yes	-10.91	10.22	7.37	0.004	2.10	0.005		No

Table 1 - 2R11 Axial PWSCC Indications in Hot Leg WEXTEX Tubesheet Region

SG	Row	Col	PP Volts	Crack No	LCT	UCT	Crack Length	UCT adj	UCT below TTS	W* Zone	W* Length	BWT	UCT to BWT	UCT Below W*	UCT Below BWT	EOC (N+1) UCT to TTS	EOC (N+1) UCT Below TTS	W* Tube	Inspect Extent	W* Inspect Dist	Flex W* Length	CM Leak Rate	EOC (N+1) UCT to BWT	OA Leak Rate	Prev W* Tube	Tube Plugged
24	4	18	0.47	1	-0.27	-0.09	0.18	0.13	No	B4	7.12	-0.41	-0.60	No	No	0.31	No	No	-11.46	10.96	7.34	NA Note 2	NA	NA		Yes
24	4	35	1.07	1	-1.58	-1.37	0.21	-1.15	Yes	B1	7.12	-0.25	0.84	No	Yes	-0.97	Yes	Yes	-11.14	10.8	7.37	0.021	0.44	0.029	Repeat	No
24	5	31	0.61	1	-1.03	-0.83	0.20	-0.61	Yes	B2	7.12	-0.33	0.22	No	Yes	-0.43	Yes	Yes	-8.88	8.46	7.36	0.037	-0.18	0.045		No
24	5	36	0.4	1	-1.91	-1.76	0.15	-1.54	Yes	B1	7.12	-0.14	1.34	No	Yes	-1.36	Yes	Yes	-11.24	11.01	7.31	0.015	0.94	0.019	Repeat	No
24	5	37	1.54	2	-4.07	-3.63	0.44	-3.41	Yes	B1	7.12	-0.28	3.07	No	Yes	-3.23	Yes	Yes	-11.21	10.84	7.60	0.007	2.67	0.008	Repeat	No
24	5	37	0.27	1	-4.25	-4.10	0.15	-3.88	Yes	B1	7.12	-0.28	3.54	No	Yes	-3.70	Yes	Yes	-11.21	10.84	7.31	0.006	3.14	0.007	Repeat	No
24	5	53	1.78	1	-1.96	-1.54	0.42	-1.32	Yes	B1	7.12	-0.26	1.00	No	Yes	-1.14	Yes	Yes	-10.62	10.27	7.58	0.018	0.60	0.025	Repeat	No
24	6	33	0.87	1	-2.84	-2.61	0.23	-2.39	Yes	B2	7.12	-0.16	2.17	No	Yes	-2.21	Yes	Yes	-10.83	10.58	7.39	0.008	1.77	0.011	Repeat	No
24	7	4	0.62	1	-1.25	-1.06	0.19	-0.84	Yes	A	5.32	-0.21	0.57	No	Yes	-0.66	Yes	Yes	-11.5	11.2	5.55	0.025	0.17	0.039	Repeat	No
24	7	38	1.98	1	-6.70	-6.31	0.39	-6.09	Yes	B1	7.12	-0.25	5.78	No	Yes	-5.91	Yes	Yes	-11.13	10.79	7.55	0.001	5.38	0.002	Repeat	No
24	7	38	1.71	2	-4.33	-3.71	0.62	-3.49	Yes	B1	7.12	-0.25	3.18	No	Yes	-3.31	Yes	Yes	-11.13	10.79	7.78	0.007	2.78	0.008	Repeat	No
24	7	53	0.3	1	-2.71	-2.53	0.18	-2.31	Yes	B1	7.12	-0.34	1.91	No	Yes	-2.13	Yes	Yes	-10.94	10.51	7.34	0.010	1.51	0.013		No
24	13	4	0.42	1	-1.32	-1.20	0.12	-0.98	Yes	A	5.32	-0.23	0.69	No	Yes	-0.80	Yes	Yes	-11.50	11.18	5.48	0.021	0.29	0.034	Repeat	No
24	13	40	1.65	1	-1.90	-1.51	0.39	-1.29	Yes	B2	7.12	-0.21	1.02	No	Yes	-1.11	Yes	Yes	-11.43	11.13	7.55	0.018	0.62	0.024	Repeat	No
24	15	10	0.34	1	-1.04	-0.83	0.21	-0.61	Yes	A	5.32	-0.21	0.34	No	Yes	-0.43	Yes	Yes	-11.44	11.14	5.57	0.032	-0.06	0.045	Repeat	No
24	16	10	2.23	1	-2.36	-1.86	0.50	-1.64	Yes	A	5.32	-0.29	1.29	No	Yes	-1.46	Yes	Yes	-11.43	11.05	5.86	0.007	0.89	0.013	Repeat	No
24	20	47	1.79	1	-1.69	-1.25	0.44	-1.03	Yes	B2	7.12	-0.25	0.72	No	Yes	-0.85	Yes	Yes	-11.14	10.80	7.60	0.023	0.32	0.033	Repeat	No
24	24	26	1.17	1	-2.01	-1.69	0.32	-1.47	Yes	A	5.32	-0.32	1.09	No	Yes	-1.29	Yes	Yes	-11.58	11.17	5.68	0.009	0.69	0.021	Repeat	No
24	25	64	1.64	1	-1.52	-1.20	0.32	-0.98	Yes	B4	7.12	-0.35	0.57	No	Yes	-0.80	Yes	Yes	-9.34	8.90	7.48	0.025	0.17	0.039	Repeat	No
24	26	45	1.12	1	-3.83	-3.50	0.33	-3.28	Yes	B4	7.12	-0.23	2.99	No	Yes	-3.10	Yes	Yes	-11.10	10.78	7.49	0.003	2.59	0.004	Repeat	No

Note 1: SG 24 R2C29 was in situ tested to SLB conditions, and no leakage was detected. The leak rates listed for these indications are for information only and are based on W* ARC leak rate model. The total SG leak rate assumes no leakage from R2C29 indications.
Note 2: SG 24 R4C18 is located in the WEXTEX transition and is not applicable to W* ARC.

Table 2 - 2R11 In Situ Screening of W* Indications

SG	Row	Col	PP Volts	Crack No	LCT	UCT	Deplugged	Prior In Situ Voltage	Vcrit	Vthr	Step 1	Step 2	Step 3	Voltage Rank	Top 5 Voltage Rank	L >80% TW MD	Step 4	In situ Req'd
21	3	59	4.95	1	-1.48	-0.76	Yes	4.67	6	4	Stop					0.6		No
21	6	77	0.86	1	-1.4	-1.23	Yes		6	4	Go to Step 2	Go to Step 3	Rank	32		0		No
21	7	24	0.19	1	-1.98	-1.87	Yes		6	4	Go to Step 2	Go to Step 3	Rank	68		0.03		No
21	7	62	3.58	1	-2.34	-1.44	Yes	4.08	6	4	Stop					0.11		No
21	8	32	0.39	1	-2.13	-1.98			4	2.5	Go to Step 2	Go to Step 3	Rank	53		0		No
21	9	49	0.49	1	-2.16	-1.96			4	2.5	Go to Step 2	Go to Step 3	Rank	44		0		No
21	10	49	0.25	1	-0.94	-0.80			4	2.5	Go to Step 2	Go to Step 3	Rank	65		0		No
21	11	37	0.42	1	-7.54	-7.43			4	2.5	Go to Step 2	Go to Step 3	Rank	48		0		No
21	11	37	0.64	2	-6.65	-6.48			4	2.5	Go to Step 2	Go to Step 3	Rank	36		0		No
21	11	37	0.31	3	-2.11	-1.85			4	2.5	Go to Step 2	Go to Step 3	Rank	59		0		No
21	11	39	1.3	1	-1.93	-1.61	Yes		6	4	Go to Step 2	Go to Step 3	Rank	16		0		No
21	11	40	0.37	1	-0.97	-0.83			4	2.5	Go to Step 2	Go to Step 3	Rank	55		0		No
21	11	48	1.99	1	-4.84	-4.39			4	2.5	Go to Step 2	Go to Step 3	Rank	4	Go to Step 4	0.06	Stop	No
21	13	49	0.28	1	-1.68	-1.54			4	2.5	Go to Step 2	Go to Step 3	Rank	62		0		No
21	23	70	0.95	1	-1.66	-1.27	Yes		6	4	Go to Step 2	Go to Step 3	Rank	25		0		No
21	30	59	2.43	1	-10.13	-9.82			4	2.5	Go to Step 2	Go to Step 3	Rank	1	Go to Step 4	0	Stop	No
21	45	59	0.24	1	-0.55	-0.38			4	2.5	Go to Step 2	Go to Step 3	Rank	67		0		No
22	28	15	0.51	1	-2.3	-2.16	Yes		6	4	Go to Step 2	Go to Step 3	Rank	41		0		No
22	28	15	0.5	2	-1.89	-1.69	Yes		6	4	Go to Step 2	Go to Step 3	Rank	43		0		No
22	28	15	0.83	3	-11.11	-10.82	Yes		6	4	Go to Step 2	Go to Step 3	Rank	33		0		No
22	28	15	5.4	4	-20.88	-19.38	Yes		6	4	Go to Step 2	Go to Step 3	Go to Step 4			1.3	Test	Yes
22	28	15	4.7	5	-21.01	-19.29	Yes		6	4	Go to Step 2	Go to Step 3	Go to Step 4			1.2	Test	Yes
22	5	18	0.66	1	-1.24	-0.99			4	2.5	Go to Step 2	Go to Step 3	Rank	35		0		No
22	31	25	4.05	1	-2.18	-1.59	Yes	3.82	6	4	Stop					0		No
22	13	43	0.73	1	-1.42	-1.23	Yes		6	4	Go to Step 2	Go to Step 3	Rank	34		0		No
22	10	48	0.42	1	-3.04	-2.9			4	2.5	Go to Step 2	Go to Step 3	Rank	48		0		No
22	10	56	0.88	1	-1.07	-0.9	Yes		6	4	Go to Step 2	Go to Step 3	Rank	30		0		No
23	28	12	2.37	1	-2.1	-1.51			4	2.5	Go to Step 2	Go to Step 3	Rank	2	Go to Step 4	0.01	Stop	No

Table 2 - 2R11 In Situ Screening of W* Indications																		
SG	Row	Col	PP Volts	Crack No	LCT	UCT	Deplugged	Prior In Situ Voltage	Vcrit	Vthr	Step 1	Step 2	Step 3	Voltage Rank	Top 5 Voltage Rank	L >80% TW MD	Step 4	In situ Req'd
23	14	24	0.35	1	-1.91	-1.76	Yes		6	4	Go to Step 2	Go to Step 3	Rank	56		0		No
23	16	24	0.25	1	-1.38	-1.23	Yes		6	4	Go to Step 2	Go to Step 3	Rank	65		0		No
23	25	37	1.87	1	-1.29	-0.88	Yes		6	4	Go to Step 2	Go to Step 3	Rank	6		0		No
23	45	37	1.50	1	-1.56	-1.22	Yes		6	4	Go to Step 2	Go to Step 3	Rank	14		0		No
23	21	38	0.54	1	-1.52	-1.02	Yes		6	4	Go to Step 2	Go to Step 3	Rank	40		0		No
23	12	48	0.29	1	-1.99	-1.87	Yes		6	4	Go to Step 2	Go to Step 3	Rank	61		0		No
23	5	51	0.51	1	-2.12	-2.01	Yes		6	4	Go to Step 2	Go to Step 3	Rank	41		0		No
23	7	52	4.21	1	-1.53	-0.79	Yes	3.9	6	4	Stop					0.33		No
23	5	55	1.13	1	-2.2	-1.93			4	2.5	Go to Step 2	Go to Step 3	Rank	21		0		No
23	32	55	1.21	1	-1.3	-0.9	Yes		6	4	Go to Step 2	Go to Step 3	Rank	19		0		No
23	7	59	1.50	1	-1.88	-1.44	Yes		6	4	Go to Step 2	Go to Step 3	Rank	14		0		No
23	9	63	0.40	1	-1.29	-1.13			4	2.5	Go to Step 2	Go to Step 3	Rank	51		0		No
23	3	69	0.94	1	-1.22	-0.88			4	2.5	Go to Step 2	Go to Step 3	Rank	26		0		No
23	19	71	1.08	1	-2.14	-1.8	Yes		6	4	Go to Step 2	Go to Step 3	Rank	23		0		No
23	17	72	1.67	1	-1	-0.53	Yes		6	4	Go to Step 2	Go to Step 3	Rank	10		0		No
23	6	77	0.26	1	-1.78	-1.66	Yes		6	4	Go to Step 2	Go to Step 3	Rank	64		0		No
23	21	83	0.94	1	-1.16	-0.85	Yes		6	4	Go to Step 2	Go to Step 3	Rank	26		0		No
23	4	90	0.33	1	-1.11	-0.97			4	2.5	Go to Step 2	Go to Step 3	Rank	58		0		No
23	2	91	0.62	1	-0.95	-0.6	Yes		6	4	Go to Step 2	Go to Step 3	Rank	37		0		No
23	7	92	0.92	1	-1.15	-0.81	Yes		6	4	Go to Step 2	Go to Step 3	Rank	29		0		No
23	8	93	1.22	1	-0.8	-0.57	Yes		6	4	Go to Step 2	Go to Step 3	Rank	17		0		No
24	2	10	0.43	1	-1.46	-1.33	Yes		6	4	Go to Step 2	Go to Step 3	Rank	47		0		No
24	2	29	5.25	1	-4.58	-3.61	Yes	4.45	6	4	Stop					0.97		No
24	2	29	1.22	2	-2.42	-1.78	Yes	0.94	6	4	Go to Step 2	Go to Step 3	Rank	17		0.12		No
24	3	5	1.77	1	-1.85	-0.85	Yes	1.51	6	4	Stop					0.725		No
24	3	12	0.44	1	-2.81	-2.69	Yes		6	4	Go to Step 2	Go to Step 3	Rank	46		0		No
24	3	12	0.94	2	-2.49	-2.28	Yes		6	4	Go to Step 2	Go to Step 3	Rank	26		0		No
24	3	17	0.39	1	-3.59	-3.38			4	2.5	Go to Step 2	Go to Step 3	Rank	53		0		No

Table 2 - 2R11 In Situ Screening of W* Indications

SG	Row	Col	PP Volts	Crack No	LCT	UCT	Deplugged	Prior In Situ Voltage	Vcrit	Vthr	Step 1	Step 2	Step 3	Voltage Rank	Top 5 Voltage Rank	L >80% TW MD	Step 4	In situ Req'd
24	4	18	0.47	1	-0.27	-0.09			4	2.5	Go to Step 2	Go to Step 3	Rank	45		0		No
24	4	35	1.07	1	-1.58	-1.37	Yes		6	4	Go to Step 2	Go to Step 3	Rank	24		0		No
24	5	31	0.61	1	-1.03	-0.83			4	2.5	Go to Step 2	Go to Step 3	Rank	39		0		No
24	5	36	0.4	1	-1.91	-1.76			4	2.5	Go to Step 2	Go to Step 3	Rank	51		0		No
24	5	37	1.54	2	-4.07	-3.63	Yes		6	4	Go to Step 2	Go to Step 3	Rank	13		0.365		No
24	5	37	0.27	1	-4.25	-4.10	Yes		6	4	Go to Step 2	Go to Step 3	Rank	63		0		No
24	5	53	1.78	1	-1.96	-1.54			4	2.5	Go to Step 2	Go to Step 3	Rank	8		0		No
24	6	33	0.87	1	-2.84	-2.61			4	2.5	Go to Step 2	Go to Step 3	Rank	31		0		No
24	7	4	0.62	1	-1.25	-1.06	Yes		6	4	Go to Step 2	Go to Step 3	Rank	37		0		No
24	7	38	1.98	1	-6.70	-6.31	Yes		6	4	Go to Step 2	Go to Step 3	Rank	5	Go to Step 4	0	Stop	No
24	7	38	1.71	2	-4.33	-3.71	Yes		6	4	Go to Step 2	Go to Step 3	Rank	9		0		No
24	7	53	0.3	1	-2.71	-2.53			4	2.5	Go to Step 2	Go to Step 3	Rank	60		0		No
24	13	4	0.42	1	-1.32	-1.20			4	2.5	Go to Step 2	Go to Step 3	Rank	48		0		No
24	13	40	1.65	1	-1.90	-1.51	Yes		6	4	Go to Step 2	Go to Step 3	Rank	11		0.03		No
24	15	10	0.34	1	-1.04	-0.83	Yes		6	4	Go to Step 2	Go to Step 3	Rank	57		0		No
24	16	10	2.23	1	-2.36	-1.86	Yes		6	4	Go to Step 2	Go to Step 3	Rank	3	Go to Step 4	0	Stop	No
24	20	47	1.79	1	-1.69	-1.25	Yes		6	4	Go to Step 2	Go to Step 3	Rank	7		0		No
24	24	26	1.17	1	-2.01	-1.69			4	2.5	Go to Step 2	Go to Step 3	Rank	20		0.17		No
24	25	64	1.64	1	-1.52	-1.20	Yes		6	4	Go to Step 2	Go to Step 3	Rank	12		0		No
24	26	45	1.12	1	-3.83	-3.50			4	2.5	Go to Step 2	Go to Step 3	Rank	22		0		No

Column – Tables 1 and 2	Legend and Notes for Tables 1 and 2
SG	Steam generator
Row	Tube Row
Col	Tube Column
PP Volts	Peak voltage from Plus Point coil
Crack No	Crack number
LCT	Elevation (inch) of lower crack tip (LCT), relative to the top of tubesheet (TTS).
UCT	Elevation (inch) of upper crack tip (UCT), relative to the TTS.
Crack length	Length of crack (inch)
UCT adj	Adjusted elevation (inch) of the UCT relative to TTS, including $\Delta NDE_{CT\text{-}TTS}$ (Plus Point NDE uncertainty on locating the crack tip relative to the TTS).
UCT below TTS?	If the adjusted elevation of the UCT (including NDE uncertainty) is located below TTS, then the tube is a W* candidate.
W* Zone	W* tubesheet zone based on crack location.
W* Length	W* length is 7.12 inch for hot leg Zone B and 5.32 inch for hot leg Zone A, and includes ΔNDE_W (NDE uncertainty in measuring the W* depth).
BWT	Elevation of the bottom of the WEXTEX transition (BWT), inch, measured by bobbin relative to the TTS.
UCT to BWT	Distance (inch) from the UCT to BWT, minus $\Delta NDE_{CT\text{-}BWT}$ (Plus Point NDE uncertainty on locating the crack tip relative to the BWT).
UCT below W*?	If the UCT is located below the W* length, then the tube is a W* tube. Any type of degradation below the W* length is acceptable.
UCT below BWT?	If the UCT is located below BWT, then the tube is a W* candidate.
EOC (n+1) UCT to TTS	Elevation (inch) of UCT relative to TTS at the end of the next operating cycle, based on growing the UCT at 0.115 inch/EFPY.
EOC (n+1) UCT below TTS?	If the UCT is below TTS at the end of the next cycle, a free span indication is precluded and the tube is a W* candidate.
W* Tube?	If the UCT is below BWT and the EOC (n+1) UCT is projected to be below TTS at the end of the next cycle, then the tube is a W* tube.
Inspect Extent	Elevation of Plus Point inspection relative to TTS (inch).
W* Inspect Dist	W* inspection distance (inch). This is the Plus Point inspection extent relative to BWT. The W* inspection distance below BWT is equal to the Plus Point inspection extent below TTS, plus measured distance from BWT to TTS, plus bobbin NDE uncertainty in locating BWT relative to TTS. The W* inspection distance must be greater than or equal to the flexible W* length.
Flex W* Length	Flexible W* length relative to BWT (inch), equal to W* Length + $\sum Cl_i$ (total axial crack length) + $N_{CL}*\Delta NDE_{CL}$ (number of indications times Plus Point NDE uncertainty with measuring length of axial cracks) + $N_{CL}*\Delta CG$ (number of indications times crack growth, 0.115 inch/EFPY)
CM Leak Rate	Condition monitoring SLB leak rate, gpm at room temperature, based on distance of UCT to BWT, using Figure 6.4-3 of WCAP-14797 Rev 1. No accident leakage is assigned to indications with UCT below W* length.
EOC (n+1) UCT to BWT	Distance (inch) of the UCT relative to BWT at end of the next cycle, minus $\Delta NDE_{CT\text{-}BWT}$ (Plus Point NDE uncertainty on locating the crack tip relative to the BWT), based on growing the UCT at 0.115 inch/EFPY. This entry is not applicable to indications that are plugged.
OA Leak Rate	Operational assessment leak rate, gpm at room temperature, at end of next cycle based on distance of EOC (n+1) UCT to BWT, using Figure 6.4-3 of WCAP-14797 Rev 1. No accident leakage is assigned to an indication with UCT below W* length.
Previous W* Tube?	If the indication was left in service in the prior cycle, it is classified as a repeat. Otherwise, the indication is new.
Tube Plugged?	Tube was plugged during the current outage.
MD	Maximum depth, percent through-wall, using TSP axial PWSCC depth sizing technique.
Deplugged?	Tube was deplugged in a prior outage.
Prior In situ Voltage	If prior in situ testing was performed, the Plus Point voltage of the indication in the outage that in situ leak testing was performed.
Vcrit	Critical voltage for determining need for in situ testing
Vthr	Threshold voltage for determining need for in situ testing
Steps 1 through 4	Logical steps used for screening indications for in situ testing
Voltage rank	Plus Point voltage ranking of indications as required by in situ screening Step 3
Top 5 Voltage Rank	Five largest Plus Point voltages are identified for further screening
L >80% TW MD	The length of the indication that exceeds 80% maximum depth, based on Plus Point line by line sizing.
In situ Req'd?	Identifies indications that require in situ leak testing based on the four step screening logic

Table 3
DCPP Unit 2 Condition Monitoring Steam Line Break Leak Rates for Alternate Repair Criteria

EOC 11 Condition Monitoring Leak Rate (gpm at room temperature)	SG 2-1	SG 2-2	SG 2-3	SG 2-4
W* ARC	0.367	0.144	0.585	0.401
Voltage-Based ARC (Note 1)	0.682	0.362	0.211	3.21
PWSCC ARC	0	0	0	0
Non-ARC degradation (Note 2)	0	0	0	0.003
Aggregate ARC	1.049	0.506	0.796	3.614

Note 1: Voltage-based ARC leak rates are described in Enclosure 4.
Note 2: Non-ARC degradation leak rate of 0.003 gpm based on in situ leak test result for SG 2-4 R5C62 circumferential PWSCC in U-bend region (Enclosure 4).

Table 4
DCPP Unit 2 Operational Assessment Steam Line Break Leak Rates for Alternate Repair Criteria

EOC 12 Operational Assessment Leak Rate (gpm at room temperature)	SG 2-1	SG 2-2	SG 2-3	SG 2-4
W* ARC	0.407	0.171	0.702	0.509
Voltage-Based ARC (note 1)	0.72	0.60	0.48	2.81
Voltage-Based ARC (note 2)	1.95	1.41	1.16	9.58
PWSCC ARC	0	0	0	0
Non-ARC degradation	0	0	0	0
Aggregate ARC (note 1)	1.127	0.771	1.182	3.319
Aggregate ARC (note 2)	2.357	1.581	1.862	10.089

Note 1: Leak rates calculated using DCPP Units 1 and 2 POPCD and voltage dependent growth for voltage-based ARC (Enclosure 4).
Note 2: Worst case leak rates calculated using POD of 0.6 (POD of 1.0 for SG 2-4 R44C45) and voltage dependent growth for voltage-based ARC (Enclosure 4).

Table 5
DCPP Unit 2 Prior Cycle W* ARC Leak Rate Predictions

Predicted EOC 11 Leak Rate (from prior cycle OA) (gpm at room temperature)	SG 2-1	SG 2-2	SG 2-3	SG 2-4
W* ARC	0.314	0.176	0.661	0.457

Note: Leak rates do not include leakage contribution of potential new flaws at EOC 11, in accordance with W* ARC criteria.

SPECIAL REPORT 03-02

TSP PWSCC ALTERNATE REPAIR CRITERIA 120 DAY REPORT

DIABLO CANYON POWER PLANT UNIT 2 ELEVENTH REFUELING OUTAGE

NRC Reporting Requirements

PWSCC alternate repair criteria (ARC) for axial PWSCC at dented tube support plates (TSP) was implemented for the first time in DCPP Unit 2 during 2R11. 2R11 SG inspections and repairs were completed in March 2003.

For implementation of ARC for axial PWSCC at dented TSPs, DCPP TS 5.6.10.h requires that the results of the condition monitoring and operational assessments be reported to the NRC within 120 days following completion of the inspection. This report implements the DCPP TS reporting criteria.

To satisfy the TS, this report includes the following:

- Tabulations of indications found in the inspection, tubes repaired, and tubes left in service under the ARC.
- Growth rate distributions for indications found in the inspection and growth rate distributions used to establish the tube repair limits.
- Plus Point confirmation rates for bobbin detected indications when bobbin is relied upon for detection of axial PWSCC in less than or equal to 2 volt dents.
- For condition monitoring, an evaluation of any indications that satisfy burst margin requirements based on the Westinghouse burst pressure model, but do not satisfy burst margin requirements based on the combined Argonne National Laboratory (ANL) ligament tearing and throughwall burst pressure model.
- Performance evaluation of the operational assessment methodology for prediction of flaw distributions as a function of flaw size.
- Evaluation results of number and size of previously reported versus new PWSCC indications found in the inspection, and the potential need to account for new indications in the operational assessment burst evaluation.
- Identification of mixed mode (axial PWSCC and circumferential) indications found in the inspection and an evaluation of the mixed mode indications for potential impact on the axial indication burst pressures or leakage. In addition, as committed in DCL-02-045, performance of a trending analysis to assess the potential for increasing mixed mode affects over time.
- Any corrective actions found necessary in the event that condition monitoring requirements are not met.

Tubes were pulled in 2R11 to satisfy voltage-based ARC requirements for axial ODSCC at TSPs. As committed in PG&E letter DCL-02-045 and as noted in the NRC safety evaluation in NRC letter to PG&E dated May 1, 2002, Attachment 1 of this enclosure provides an evaluation of ligament tearing following the SLB leak test in the laboratory.

Dented TSP Plus Point Inspection Scope

The 2R11 Plus Point dent inspection scope was based on greater than 2 volt dents called in the prior 2R10 outage, plus previously unidentified greater than 2 volt dents called in 2R11. The greater than 2 volt dent population and number of greater than 2 volt dents inspected by Plus Point in 2R11 is provided in Table 1.

The dented TSP inspection criteria and expansion plan criteria described below are based on PG&E letter to the NRC dated April 16, 2001, and WCAP-15573, Revision 1, "Depth-Based SG Tube Repair Criteria for Axial PWSCC at Dented TSP Intersections – Alternate Burst Pressure Calculation."

Plus Point inspection criteria for axial PWSCC left in service

Plus Point inspections shall be conducted on 100 percent of axial PWSCC indications at dented TSP intersections that were left in service in Unit 2 Cycle 11. Thirty five axial PWSCC indications had been left in service in Cycle 11 that were less than 40 percent maximum depth.

Plus Point inspection criteria for >2 and <5 volt dents and for ≥ 5 volt dents

On a SG-specific basis, Plus Point inspections shall be conducted on 100 percent of ≥ 5 volt dented intersections up to and including the highest hot leg TSP elevation where PWSCC (at any size dent), circumferential indications (at any size dent), or axial ODSCC not detected by bobbin (AONDB) (at ≥ 5 volt dent) have been previously detected in that SG in the prior two outages, or current outage (expansion required), plus 20 percent of ≥ 5 volt dents at the next higher TSP elevation. In each SG where 100 percent hot leg TSP Plus Point inspections are not required, Plus Point inspections shall be conducted on 20 percent of ≥ 5 volt dents at each hot leg TSP. For any 20 percent sample, a minimum of 50 ≥ 5 volt dents shall be inspected. If the population of ≥ 5 volt dents at that TSP elevation is less than 50, then 100 percent of the ≥ 5 volt dents at that TSP shall be inspected.

On a SG-specific basis, Plus Point inspections shall be conducted on 100 percent of > 2 and < 5 volt dented intersections up to and including the highest hot leg TSP elevation where PWSCC (at any size dent), circumferential indications (at any size dent), or ≥ 2 inferred volt AONDB (at > 2 and < 5 volt dent) have been previously detected in that SG in the prior two outages, or current outage (expansion required), plus 20 percent of > 2 and < 5 volt dent at the next higher TSP elevation. If a SG is free from PWSCC (at any size dent), circumferential indications (at any size dent) and ≥ 2

inferred volt AONDB (at > 2 and < 5 volt dent), then Plus Point inspections shall be conducted on 20 percent of > 2 and < 5 volt dents at 1H. For any 20 percent sample, a minimum of 50 > 2 and < 5 volt dents shall be inspected. If the population of > 2 and < 5 volt dents at that TSP elevation is less than 50, then 100 percent of the > 2 and < 5 volt dents at that TSP shall be inspected.

The highest TSP where PWSCC or circumferential indications have been found in the prior two outages in Unit 2 is 5H for SG 2-2, 3H for SG 2-3, and 3H for SG 2-4. In SG 2-1, no PWSCC or circumferential indications have been detected. Because all inferred bobbin voltages for AONDB indications have been less than 2 volts, AONDB indications do not factor into the inspection scope. Based on this information, the following Plus Point dent inspection criteria was implemented to meet the requirements specified above.

≥ 5 volt dents:

- 100% in all SGs, both hot leg and cold leg.

> 2 and < 5 volt dents:

- SG 2-1: 20% at 1H
- SG 2-2: 100% from 1H to 5H, 20% at 6H
- SG 2-3, 2-4: 100% from 1H to 3H, 20% at 4H

In 2R11, no axial PWSCC was detected in SG 2-1, no axial PWSCC was detected above 5H in SG 2-2, and no axial PWSCC was detected above 3H in SGs 2-3 and 2-4. Therefore, no expansion of the Plus Point dent inspection program was required.

Plus Point inspection for less than or equal to 2 volt dents

One hundred percent of the tubes were inspected by bobbin coil, and the bobbin coil was relied upon for detection of axial PWSCC in ≤ 2 volt dents. As a result, Plus Point inspection of ≤ 2 volt dents was only required if the bobbin coil detected a distorted ID support signal (DIS) at a dented TSP intersection. One hundred percent of DIS indications were inspected by Plus Point.

Plus Point inspection criteria for detection of circumferential indications at dents

On a SG-specific basis, if a circumferential indication or ≥ 2 inferred volt AONDB is detected in a dent of "x" volts in the prior two outages, or current outage (expansion required), then Plus Point inspections shall be conducted on 100 percent of dents greater than "x - 0.3" volts up to the affected TSP, plus 20 percent of dents greater than "x – 0.3" volts at the next higher TSP. "X" is defined as the lowest dent voltage where a circumferential crack or ≥ 2 inferred volt AONDB was detected in that SG. For any 20 percent sample, a minimum of 50 "x – 0.3" volt dents shall be inspected. If the

population of "x – 0.3" volt dents at that TSP elevation is less than 50, then 100 percent of the "x – 0.3" volt dents at that TSP shall be inspected.

The smallest dent in which a Unit 2 circumferential crack has been detected in the prior two outages was 3.1 volts (2R9 circumferential indication in SG 2-2). Thus, "x" = 3.1 volts, and "x – 0.3" = 2.8 volts. Since 2.8 volts is greater than 2 volts, the 2 volt dent cutoff for 2R11 Plus Point inspection was sufficient. In 2R11, six circumferential indications at dented TSPs were detected, and the associated dent voltages were greater than 5 volts. Therefore, no Plus Point expansion was necessary.

Tabulations of indications found in the inspection, tubes repaired, and tubes left in service under the ARC.

62 axial PWSCC indications at dented TSP intersections were detected in 2R11. Table 5 provides a tabulation of indications, including the following information:

- For plugged indications, the reason for plugging
- Identifies the indication as repeat, new, or deplugged
- Adjusted NDE measurements of length, maximum depth, average depth, voltage, and crack location relative to the TSP centerline.
- Operational assessment burst pressure (free span and total length) using the ANL and Electric Power Research Institute (EPRI) burst model. A burst pressure of 6100 psi in Table 5 represents a predicted burst pressure $\geq$ 6100 psi since all pressures predicted to exceed 6100 psi are grouped at 6100 psi to reduce computer storage requirements in the analysis.
- Operational assessment SLB leak rate (free span and total length) using the ANL ligament tearing model.

The PWSCC ARC allows axial PWSCC indications to remain in service at dented TSP intersections if the following PWSCC ARC conditions are satisfied for each indication:

- OA free span burst pressure (based on the combined ANL ligament tearing and EPRI throughwall burst pressure model) exceeds $3\Delta P_{NO}$. The $3\Delta P_{NO}$ burst pressure is equal to 4419 psi.
- OA total length burst pressure (based on the combined ANL ligament tearing and EPRI throughwall burst pressure model) exceeds $1.4\Delta P_{SLB}$. The $1.4\Delta P_{SLB}$ burst pressure is equal to 3367 psi, based on a ΔP_{SLB} of 2405 psi (pressurizer PORV setpoint plus uncertainty).

- OA free span leak rate, when combined with free span leak rates from other degradation mechanisms, is less than 1 gpm (0.7 gpm at room temperature) in a faulted SG.

- OA total length leak rate, when combined with leak rates from other degradation mechanisms, is less than 10.5 gpm (room temperature) in a faulted SG.

- The indication is less than 40% through-wall outside the TSP crevice.

In addition to the above PWSCC ARC conditions, axial PWSCC indications must satisfy the following exclusion criteria in order to remain in service:

- The indication is not located at a TSP intersection located in the wedge region or 7H/7C high bending stress region.

- The indication is not located at a TSP intersection that contains cracked or missing TSP ligaments.

- The indication is not located at a TSP intersection that contains another degradation mechanism.

- The indication is not located in a tube that contains another repairable indication.

Thirty-five axial PWSCC indications at dented TSPs had been left in service following 2R10 because they were less than 40% maximum depth in 2R10. Following 2R11 Plus Point inspection, sizing, and application of PWSCC ARC requirements, 3 of the 35 repeat axial PWSCC indications were plugged. One indication was plugged due to excessive Plus Point probe noise in the U-bend region. Two indications were plugged due to combined ID and OD cracking at the same TSP location.

In 2R11, 27 new axial PWSCC indications at dented TSPs were detected, sized by Plus Point, and applied to PWSCC ARC requirements. Twelve of these 27 axial PWSCC indications were subsequently plugged. Four indications were plugged due to maximum depths greater than or equal to 40% outside the TSP region. Five indications were plugged due to combined ID and OD cracking at the same TSP location. Three indications were plugged due to pluggable indications located elsewhere in the tubes (i.e., the TSPs with axial PWSCC indications were acceptable for continued service): two indications (one tube) were plugged due to circumferential PWSCC in the U-bend, and one indication was plugged due to axial PWSCC in the tubesheet region that did not meet W* ARC.

The indications that were located outside the TSP region were reviewed to determine the need for in situ pressure testing in accordance with the criteria in WCAP-15128 Revision 1. Namely, if condition monitoring for axial PWSCC at dented TSPs predicts free span leakage or free span burst pressures less than $3\Delta P_{NO}$, then in situ pressure

testing is required. These conditions were not predicted by condition monitoring, and therefore no in situ pressure testing of axial PWSCC at dents was required nor performed.

In summary, 47 axial PWSCC indications at dented TSPs were returned to service in 2R11: 32 repeat indications and 15 new indications.

Growth rate distributions for indications used to establish the tube repair limits.

The growth rate distribution used to establish the tube repair limits was based on prior outage growth data. The methodology for establishing the growth rate was established in WCAP-15573, Revision 1 as further explained in PG&E letters DCL-02-023 and DCL-02-045. The methodology is summarized below:

- If there are at least 200 points in each of the last two cycles on the unit being inspected, the most conservative growth distribution from the last two cycles shall be used.
- If there are at least 200 points over the last two cycles on the unit being inspected, the growth distribution to be used is the more conservative of the combined data or either of the two cycles.
- If there are less than 200 points over the last two cycles on the unit being inspected, the growth distribution to be used shall contain data from both units over the last two (or three if necessary) cycles of each unit until 200 data points are obtained. The data from each cycle is compared for consistency in growth magnitude. If a given cycle has lower growth rates than other cycles, it is not included in the growth distribution.

For 2R11, the third bullet applies. There are 262 data points over the last two cycles from each unit representing data from 2R9 (15), 1R10 (83), 2R10 (45), and 1R11 (119). The oldest growth data, that is, data from 1R8, 2R8, and 1R9 (total of 76 growth rate data points), does not require evaluation and is excluded per the above methodology because over 200 data points are already available from the more recent inspections. For each remaining data set (2R9, 1R10, 2R10, and 1R11), cumulative growth distributions were developed and compared for length, maximum depth, and average depth. The prior cycle growth rate cumulative probability distributions (CPD) are provided in Table 2, and depicted in Figures 1, 2, and 3. For length, the 1R11 growth rates were the lowest. For MD and AD, the 1R10 and 1R11 growth rates were the lowest. Per the ARC methodology, these data sets were evaluated for exclusion. PG&E determined that exclusion of these Unit 1 data sets would result in minimal number of Unit 1 data points remaining in the growth distributions. Therefore, instead of excluding any data, a lower bound growth distribution of all data sets was applied, which is more conservative than excluding data. The lower bound CPD distribution was obtained as the point-by-point lower bound for each of the four CPDs. The cumulative

combined growth rate CPD is provided in Table 2 (and Figures 4, 5, and 6), and was used in the 2R11 Monte Carlo operational assessment calculations for determining the need for tube repair.

The average Thot in Unit 2 Cycle 11 was 603 degrees F. The average Thot in Unit 1 Cycle 11 was 604 degrees F and the 1R11 growth rates were adjusted using the Arrhenius equation to account for differences in Thot between Unit 1 and Unit 2.

Growth rate distributions for indications found in the inspection

In accordance with WCAP-15573, Revision 1, growth rates that could impact the upper tail of the growth distribution were evaluated during 2R11. The methodology requires that if new growth data cause the growth distribution above 90 percent probability to be more conservative, the new data is added to the growth distribution for the operational assessment.

Forty-nine additional growth rate data points were established in 2R11, 35 from repeat indications and 14 from new indications. The CPD of the 2R11 growth data is provided in Table 2 and in Figures 4, 5, and 6. The growth rates used in the OA bound the 2R11 growth rates, and shown in Figures 4, 5, and 6.

Table 3 provides the 90 percentile growth values per EFPY at 603 degrees F for 2R9, 1R10, 2R10, 1R11, 2R11, and lower bound 2R9 to 1R11 (the data set used in the 2R11 Monte Carlo OA calculations). The 90 percentile values of the 2R11 growth rates were significantly less than the values used in the OA data set, such that adding the 2R11 growth data to the OA data set was not required.

Plus Point confirmation rates for bobbin detected indications when bobbin is relied upon for detection of axial PWSCC in less than or equal to 2 volt dents.

In 2R11, the bobbin coil was relied upon for detection of axial PWSCC in less than or equal to 2 volt dents. As identified in Table 4, there were 525 DIS indications detected by bobbin at TSP intersections with non-repeat PWSCC indications. Tracking of Plus Point confirmation rates for repeat PWSCC indications tubes is not required because these known flaws are inspected by Plus Point regardless of the bobbin call.

All DIS indications were inspected by Plus Point. Only 14 of the 525 DIS indications were confirmed as PWSCC by Plus Point, for a Plus Point confirmation rate of 2.7 percent, or a 97.3 percent bobbin overcall rate. The high bobbin overcall rate is greater than the approximately 90% overcall rate generated during the bobbin coil performance test documented in WCAP-15573, Revision 1. The high bobbin overcall rate is overly conservative to establish a high probability of detecting significant axial PWSCC indications in less than or equal to 2 volt dents.

For condition monitoring, an evaluation of any indications that satisfy burst margin

requirements based on the Westinghouse burst pressure model, but do not satisfy burst margin requirements based on the combined ANL ligament tearing and throughwall burst pressure model.

This item is not applicable, because all indications satisfied condition monitoring burst margin requirements based on the combined ANL ligament tearing and EPRI throughwall burst pressure model as shown in Table 5. The total length condition monitoring burst requirement for EOC 11 was 3367 psi at 1.4 ΔP_{SLB}, based on ΔP_{SLB} of 2405 psi (pressurizer PORV setpoint plus uncertainty). The free span length condition monitoring burst requirement for EOC 11 was 4419 psi, based on 3 times the normal operating pressure differential.

Performance evaluation of the operational assessment methodology for prediction of flaw distributions as a function of flaw size.

Even though the ARC was not in effect in Unit 2 Cycle 11, benchmarking was performed of the 35 repeat indications that had been left in service in Unit 2 Cycle 11 because they were less than 40 percent maximum depth in 2R10. All projected EOC 11 burst pressures for these indications exceeded the default free span and total length burst pressure of 6100 psi, using the ANL/EPRI model. No SLB leakage was projected at EOC 11 for any of these indications, using the ANL ligament tearing leakage model. The EOC 11 projections used all DCPP Units 1 and 2 growth rate data through 2R10 (219 data points). The actual EOC 11 condition monitoring burst pressure of these 35 indications also exceeded the default free span and total length burst pressure of 6100 psi using the ANL/EPRI model, and had no SLB leakage using the ANL ligament tearing leakage model. Based on this performance evaluation via benchmarking, the operational assessment methodology is determined to be adequately conservative.

Evaluation results of number and size of previously reported versus new PWSCC indications found in the inspection, and the potential need to account for new indications in the operational assessment burst evaluation.

As discussed above, there were 62 axial PWSCC indications detected in 2R11: 35 repeat indications and 27 new indications. Seventeen of the new indications had prior Plus Point inspections in 2R10, of which 14 were detectable based on a lookup of the 2R10 data. Ten of the new indications had no prior Plus Point inspection. Because the number of new flaws is relatively small and all new indications have OA burst pressures well in excess of burst margin requirements, there is no need to account for new indications in the OA burst evaluation.

Identification of mixed mode (axial PWSCC and circumferential) indications found in the inspection and an evaluation of the mixed mode indications for potential impact on the axial indication burst pressures or leakage. In addition, performance of a trending analysis to assess the potential for increasing mixed mode affects (e.g., circumferential

crack depths, burst pressure reductions, increased leakage rates) over time.

For PWSCC ARC, a mixed mode indication is defined as an axial PWSCC indication and a circumferential indication (either PWSCC or ODSCC) occurring at the same dented TSP intersection. No mixed mode indications (axial PWSCC and circumferential PWSCC) were detected during 2R11. Because no mixed mode indications were detected, no actions are needed to adjust burst margin requirements or SLB leak rates. The following conditions require evaluation to determine the need for corrective actions.

- If an interacting mixed mode indication is found to have led to a reduction in the axial indication burst pressure by more than 10 percent and to less than 4000 psi, or to have caused an indication to not satisfy burst margin requirements, the burst margin requirements for implementation in the OA at the next and subsequent outages must be increased by the percentage reduction in the burst pressure found for the mixed mode indication. As discussed above, because no mixed mode indications were detected in 2R11, there are no corrective actions needed to adjust burst margin requirements for future operational assessments.

  As discussed above, because no mixed mode indications were detected in 2R11, there are no corrective actions needed to adjust burst margin requirements for future operational assessments.

- If an interacting mixed mode indication is found, and the axial indication condition monitoring predicts SLB leakage at 95/50, and the circumferential indication has > 50 percent average depth including NDE uncertainty, then the CM leak rate for the axial indication must be increased by a leakage factor. In addition, the OA SLB leak rate for each SG must be increased by a leakage factor. As discussed above, because no mixed mode indications were detected in 2R11, there are no corrective actions needed to adjust SLB leak rates for CM or OA.

  As discussed above, because no mixed mode indications were detected in 2R11, there are no corrective actions needed to adjust SLB leak rates for CM or OA.

- If a previously Plus Point inspected TSP intersection is found to have a circumferential indication with average depth > 80 percent after accounting for NDE uncertainty, then the OA SLB leak rate for each SG must be increased by a leakage factor.

  All circumferential indications detected in 2R11 were previously Plus Point inspected in 2R10. The deepest 2R11 circumferential indication (SG 2-2 R3C30 1H) was 53 percent average depth, including NDE uncertainty, less than the 80 percent average depth threshold. Therefore, no corrective actions are needed to adjust the OA SLB leak rates.

In response to NRC request for additional information, PG&E letter DCL-02-045 dated April 18, 2002, committed to perform a trending analysis in the 120 day report to assess the potential for increasing mixed mode affects (e.g., circumferential crack depths, burst pressure reductions, increased leakage rates) over time. Since no burst pressure reductions or leakage rate multipliers have been required, there is no data to trend for these parameters. Trending of circumferential depths and number of circumferential indications is provided in Figures 7, 8, and 9. Figure 7 provides all DCPP Units 1 and 2 TSP PWSCC and ODSCC circumferential indication measured "adjusted" average depths versus year detected. The adjustments do not include NDE uncertainty. The average depths show a fairly flat trend line. Figure 8 data is a subset of Figure 7, showing the mixed mode circumferential indication average depths versus year detected. Only one mixed mode circumferential indication has been detected in an axial PWSCC indication that had been returned to service (in 1R11, SG 1-2 R11C81). The Figure 8 average depths show a decreasing trend line. Figure 9 provides the cumulative distribution of the number of DCPP Units 1 and 2 TSP PWSCC and ODSCC circumferential indications detected over time. The trend does not indicate a large increase in the numbers of circumferential indications in recent inspections.

This trending assessment does not indicate a need to modify any mixed mode evaluation criteria such as applying the criteria that could lead to an increase in the burst margin requirements.

Any corrective actions found necessary in the event that condition monitoring requirements are not met.

This item is not applicable because condition monitoring requirements were satisfied.

Condition monitoring requirements for active tubes are satisfied for burst and leakage; therefore no corrective actions are required. All CM burst pressures for active tubes exceeded 5750 psi using the ANL/EPRI throughwall model, at 95 percent probability and 50 percent confidence (95/50). There was no CM SLB free span or total length leakage at 95/50 for active tubes.

Tube pull ligament tearing evaluation.

Tubes were pulled in 2R11 to satisfy TSP ODSCC ARC requirements. As committed in PG&E letter DCL-02-045 and as noted in the NRC safety evaluation in NRC letter to PG&E dated May 1, 2002, Attachment 1 to this Enclosure provides an evaluation of ligament tearing following the SLB leak test in the laboratory. The attachment results show that the ligament tearing model very conservatively over predicts the ligament tearing measured for the pulled tubes.

Table 1
> 2 Volt Dent Population and Number Plus Point Inspected in 2R11

2 to 5 volt Dents and Number Inspected (shaded)

TSP	SG 2-1	SG 2-2	SG 2-3	SG 2-4	Total Inspected
1H	4	87	7	1	99
2H	1	22	3	3	28
3H	2	2	8	28	38
4H	2	39	2	4	45
5H	3	2	1	2	2
6H	1	0	9	1	0
7H	17	12	10	38	0
TOTAL	30	164	40	77	212

>= 5 volt Dents and Number Inspected (shaded)

TSP	SG 2-1	SG 2-2	SG 2-3	SG 2-4	Total Inspected
1H	0	330	1	0	331
2H	0	7	0	1	8
3H	0	1	1	27	29
4H	0	87	1	1	89
5H	2	0	0	0	2
6H	0	0	0	0	0
7H	0	0	2	5	7
7C	0	0	1	0	1
6C	0	0	0	0	0
5C	0	0	0	0	0
4C	0	0	6	0	6
3C	0	0	0	0	0
2C	0	0	0	0	0
1C	0	0	0	1	1
TOTAL	2	425	12	35	474

Table 2
Axial PWSCC Cumulative Probability Distribution (CPD) Growth Rates per EFPY at 603F for Length, Maximum Depth, and Average Depth

	2R9 CPD	1R10 CPD	2R10 CPD	1R11 CPD	Lower Bound CPD (used for Cycle 12 OA)	2R11 CPD
Length Bin (inch)						
0	0.533	0.289	0.178	0.647	0.178	0.388
0.01	0.600	0.337	0.333	0.756	0.333	0.469
0.02	0.667	0.470	0.444	0.832	0.444	0.735
0.03	0.867	0.590	0.689	0.882	0.590	0.796
0.04	0.867	0.687	0.800	0.908	0.687	0.837
0.05	0.867	0.771	0.911	0.950	0.771	0.898
0.06	0.867	0.819	0.956	0.966	0.819	0.959
0.07	0.867	0.892	0.956	0.992	0.867	0.959
0.08	0.933	0.928	0.978	1.000	0.928	1.000
0.09	1.000	0.976	0.978	1.000	0.976	1.000
0.1	1.000	0.976	0.978	1.000	0.976	1.000
0.11	1.000	0.976	0.978	1.000	0.976	1.000
0.12	1.000	0.988	1.000	1.000	0.988	1.000
0.13	1.000	1.000	1.000	1.000	1.000	1.000
MD Bin (% TW fraction)						
0	0.333	0.554	0.311	0.496	0.311	0.612
0.01	0.400	0.651	0.333	0.571	0.333	0.633
0.02	0.400	0.723	0.378	0.672	0.378	0.673
0.03	0.467	0.783	0.422	0.748	0.422	0.673
0.04	0.467	0.843	0.422	0.782	0.422	0.714
0.05	0.600	0.880	0.489	0.824	0.489	0.816
0.06	0.600	0.904	0.511	0.857	0.511	0.837
0.07	0.667	0.952	0.644	0.899	0.644	0.898
0.08	0.800	0.964	0.733	0.916	0.733	0.939
0.09	0.867	0.976	0.800	0.958	0.800	0.959
0.1	0.867	0.976	0.822	0.975	0.822	0.980
0.11	0.933	0.988	0.867	0.983	0.867	1.000
0.12	0.933	0.988	0.911	0.992	0.911	1.000
0.13	0.933	0.988	0.911	0.992	0.911	1.000
0.14	0.933	0.988	0.933	1.000	0.933	1.000
0.15	0.933	1.000	0.956	1.000	0.933	1.000
0.16	0.933	1.000	0.956	1.000	0.933	1.000
0.17	0.933	1.000	0.978	1.000	0.933	1.000
0.18	1.000	1.000	0.978	1.000	0.978	1.000
0.19	1.000	1.000	1.000	1.000	1.000	1.000
AD Bin (% TW fraction)						
0	0.200	0.458	0.311	0.387	0.200	0.551
0.01	0.400	0.614	0.378	0.529	0.378	0.653
0.02	0.467	0.747	0.422	0.697	0.422	0.776
0.03	0.467	0.771	0.489	0.739	0.467	0.816
0.04	0.600	0.843	0.556	0.790	0.556	0.816
0.05	0.667	0.904	0.689	0.857	0.667	0.898
0.06	0.733	0.940	0.711	0.899	0.711	0.898
0.07	0.733	0.952	0.822	0.916	0.733	0.898
0.08	0.733	0.964	0.844	0.950	0.733	0.939
0.09	0.867	0.988	0.889	0.958	0.867	0.980
0.1	0.867	0.988	0.911	0.975	0.867	0.980
0.11	0.933	1.000	0.911	0.975	0.911	1.000
0.12	0.933	1.000	0.956	0.983	0.933	1.000
0.13	0.933	1.000	0.956	0.983	0.933	1.000
0.14	0.933	1.000	0.956	1.000	0.933	1.000
0.15	1.000	1.000	0.956	1.000	0.956	1.000
0.16	1.000	1.000	0.978	1.000	0.978	1.000
0.17	1.000	1.000	0.978	1.000	0.978	1.000
0.18	1.000	1.000	0.978	1.000	0.978	1.000
0.19	1.000	1.000	0.978	1.000	0.978	1.000
0.2	1.000	1.000	1.000	1.000	1.000	1.000

Table 3
90 Percentile Growth Rates per EFPY at 603F

Cycle	Data points	Length (inch)	MD %	AD %
2R9	15	0.07	11	11
1R10	83	0.07	6	5
2R10	45	0.05	12	10
1R11	119	0.04	7	6
Lower Bound 2R9 to 1R11 (OA data set)	262	0.08	12	11
2R11	49	0.05	7	7

Table 4
DIS Confirmation Rates

	SG 2-1	SG 2-2	SG 2-3	SG 2-4	Total
Number of bobbin DIS (excludes repeat PWSCC indications)	71	272	108	74	525
Number of new PWSCC indications confirmed by Plus Point	0	10	1	3	14
Plus Point confirmation rate	0%	3.7%	0.9%	4.1%	2.7%
Bobbin DIS overcall rate	100%	92.3%	99.1%	95.9%	97.3%

Table 5 - 2R11 Axial PWSCC Indications at Dented Tube Support Plate Intersections - Adjusted NDE PWSCC ARC Operational Assessment Burst and Leakage Monte Carlo Calculations (ANL/EPRI Burst Model)

SG	Row	Col	TSP	Crack No.	Cal. Num.	Type	Reason for 2R11 Plugging	Length (in.)	Max. Depth (%)	Avg. Depth (%)	Max. Volts	From	To	FS Burst Pressure psi	FS Leakage gpm	Total Length Burst Pressure psi	Total Length Leakage gpm
2	2	19	1H	1	51	new		0.12	37	24.5	0.54	0.06	0.18	6100	0.000	6100	0.000
2	2	23	1H	1	13	repeat	Ubend RMS noise	0.08	22	12.9	0.42	-0.01	0.07	6100	0.000	6100	0.000
2	2	41	1H	1	60	new		0.19	25	16.7	0.40	0.47	0.66	6100	0.000	6100	0.000
2	4	28	1H	1	13	repeat		0.24	30	21.7	0.74	-0.01	0.23	6100	0.000	6100	0.000
2	4	34	4H	1	13	repeat		0.12	36	21.2	0.24	0.09	0.21	6100	0.000	6100	0.000
2	5	3	1H	1	13	repeat		0.26	20	11.9	0.40	-0.24	0.02	6100	0.000	6100	0.000
2	5	26	1H	1	13	repeat		0.15	20	11.6	0.54	-0.33	-0.18	6100	0.000	6100	0.000
2	5	28	1H	1	51	new	>= 40% outside TSP	0.17	46	32.5	1.22	-0.51	-0.34	6100	0.000	6100	0.000
2	5	33	1H	1	13	repeat		0.12	22	12.5	0.65	-0.31	-0.19	6100	0.000	6100	0.000
2	6	24	1H	1	13	repeat		0.21	33	23.8	0.52	-0.35	-0.14	6100	0.000	6100	0.000
2	6	31	1H	1	13	repeat		0.12	30	17.8	0.35	-0.39	-0.27	6100	0.000	6100	0.000
2	6	36	1H	1	13	repeat		0.12	20	10.5	0.38	-0.21	-0.09	6100	0.000	6100	0.000
2	6	49	1H	1	50	new		0.08	53	33.6	0.37	-0.25	-0.17	6100	0.000	6100	0.000
2	7	5	1H	1	62	new		0.17	33	21.3	0.41	-0.08	0.09	6100	0.000	6100	0.000
2	7	27	1H	1	13	repeat		0.15	33	23.3	0.32	0.12	0.27	6100	0.000	6100	0.000
2	7	32	1H	1	13	repeat		0.18	28	17.6	0.69	-0.33	-0.15	6100	0.000	6100	0.000
2	8	17	1H	1	45	new	>= 40% outside TSP	0.17	45	34.7	0.74	-0.66	-0.49	6100	0.000	6100	0.000
2	8	36	1H	1	13	repeat		0.49	28	19.8	0.75	-0.27	0.22	6100	0.000	6100	0.000
2	8	43	4H	1	13	repeat		0.11	33	20.9	0.60	-0.09	0.02	6100	0.000	6100	0.000
2	8	52	1H	1	56	new		0.17	36	20.1	0.84	0.37	0.54	6100	0.000	6100	0.000
2	9	32	1H	1	13	repeat		0.10	39	21.5	0.59	-0.14	-0.04	6100	0.000	6100	0.000
2	10	19	4H	1	154	new	Ubend circ PWSCC	0.26	42	32.7	0.78	0.05	0.31	6100	0.000	5925	0.000
2	10	19	4H	2	154	new	Ubend circ PWSCC	0.18	42	22.0	0.29	0.18	0.36	6100	0.000	6100	0.000
2	10	21	4H	1	45	new		0.17	28	12.7	0.31	-0.29	-0.12	6100	0.000	6100	0.000
2	11	30	1H	1	40	new		0.17	29	18.5	0.47	-0.26	-0.09	6100	0.000	6100	0.000
2	12	39	1H	1	13	repeat		0.11	28	15.3	0.64	-0.19	-0.08	6100	0.000	6100	0.000

Table 5 - 2R11 Axial PWSCC Indications at Dented Tube Support Plate Intersections - Adjusted NDE PWSCC ARC Operational Assessment Burst and Leakage Monte Carlo Calculations (ANL/EPRI Burst Model)

SG	Row	Col	TSP	Crack No.	Cal. Num.	Type	Reason for 2R11 Plugging	Length (in.)	Max. Depth (%)	Avg. Depth (%)	Max. Volts	From	To	FS Burst Pressure psi	FS Leakage gpm	Total Length Burst Pressure psi	Total Length Leakage gpm
2	12	71	1H	1	21	new	ID/OD 1H	0.11	37	24.6	0.39	-0.23	-0.12	6100	0.000	6100	0.000
2	13	25	3H	1	13	repeat		0.13	39	25.8	0.53	-0.15	-0.02	6100	0.000	6100	0.000
2	13	41	1H	1	13	repeat		0.21	28	19.9	0.60	-0.17	0.04	6100	0.000	6100	0.000
2	14	45	1H	1	13	repeat		0.11	20	10.4	0.41	-0.11	0.00	6100	0.000	6100	0.000
2	15	22	1H	1	13	repeat		0.16	22	12.7	0.39	-0.09	0.07	6100	0.000	6100	0.000
2	15	42	1H	1	13	repeat		0.18	30	16.4	0.46	-0.05	0.13	6100	0.000	6100	0.000
2	15	51	1H	1	13	repeat		0.11	20	9.4	0.26	-0.18	-0.07	6100	0.000	6100	0.000
2	16	49	1H	1	13	repeat		0.17	25	17.1	0.71	-0.20	-0.03	6100	0.000	6100	0.000
2	17	12	1H	2	13	new		0.13	20	11.3	0.31	-0.14	-0.01	6100	0.000	6100	0.000
2	17	12	1H	1	13	repeat		0.12	28	17.2	0.58	0.11	0.23	6100	0.000	6100	0.000
2	19	15	1H	1	13	repeat		0.15	20	12.2	0.45	-0.07	0.08	6100	0.000	6100	0.000
2	19	17	1H	1	13	repeat		0.35	42	30.0	0.84	-0.50	-0.15	6100	0.000	5752	0.000
2	21	35	2H	1	62	new		0.33	23	12.5	0.55	-0.22	0.11	6100	0.000	6100	0.000
2	21	40	1H	1	13	repeat		0.19	20	10.9	0.59	-0.29	-0.10	6100	0.000	6100	0.000
2	21	41	1H	1	13	repeat		0.19	28	16.8	0.44	0.13	0.32	6100	0.000	6100	0.000
2	22	44	4H	1	13	repeat		0.14	20	10.3	0.40	-0.36	-0.22	6100	0.000	6100	0.000
2	22	55	1H	1	54	new		0.13	20	13.9	0.44	0.12	0.25	6100	0.000	6100	0.000
2	22	67	2H	1	63	new	ID/OD 2H	0.23	38	24.8	0.91	-0.17	0.06	6100	0.000	6100	0.000
2	24	58	2H	1	63	new	ID/OD 2H	0.07	20	12.8	0.29	-0.14	-0.07	6100	0.000	6100	0.000
2	25	44	5H	1	13	repeat		0.15	20	12.0	0.47	-0.12	0.03	6100	0.000	6100	0.000
2	26	38	1H	1	34	new	>= 40% outside TSP	0.20	40	25.6	0.81	0.40	0.60	6100	0.000	6100	0.000
2	28	38	1H	1	13	repeat	ID/OD 1H	0.16	33	17.6	0.44	-0.15	0.01	6100	0.000	6100	0.000
2	31	39	1H	1	39	new	>= 40% outside TSP	0.17	48	29.0	0.54	-0.64	-0.47	6100	0.000	6100	0.000
2	34	38	1H	1	38	new		0.12	32	17.8	0.50	0.41	0.53	6100	0.000	6100	0.000
3	8	66	1H	1	69	new	ID/OD 1H	0.11	20	14.5	0.43	-0.04	0.07	6100	0.000	6100	0.000
3	21	78	3H	1	17	repeat		0.28	20	14.5	0.88	-0.28	0.00	6100	0.000	6100	0.000
3	29	41	3H	1	69	new		0.12	20	11.0	0.45	-0.07	0.05	6100	0.000	6100	0.000

Table 5 - 2R11 Axial PWSCC Indications at Dented Tube Support Plate Intersections - Adjusted NDE PWSCC ARC Operational Assessment Burst and Leakage Monte Carlo Calculations (ANL/EPRI Burst Model)

SG	Row	Col	TSP	Crack No.	Cal. Num.	Type	Reason for 2R11 Plugging	Length (in.)	Max. Depth (%)	Avg. Depth (%)	Max. Volts	From	To	FS Burst Pressure psi	FS Leakage gpm	Total Length Burst Pressure psi	Total Length Leakage gpm
3	45	56	1H	1	17	repeat		0.12	20	8.9	0.49	0.17	0.29	6100	0.000	6100	0.000
4	3	12	3H	1	80	new		0.23	32	18.4	1.12	-0.20	0.03	6100	0.000	6100	0.000
4	4	18	3H	1	80	new	Tubesheet PWSCC	0.15	20	12.9	0.69	-0.09	0.06	6100	0.000	6100	0.000
4	5	15	1H	1	80	new		0.08	20	13.8	0.30	-0.04	0.04	6100	0.000	6100	0.000
4	6	38	3H	1	54	new		0.18	21	13.8	0.68	0.37	0.55	6100	0.000	6100	0.000
4	12	17	3H	1	29	repeat		0.08	20	10.0	0.66	0.14	0.22	6100	0.000	6100	0.000
4	14	53	3H	1	29	repeat		0.10	20	8.5	0.31	-0.03	0.07	6100	0.000	6100	0.000
4	16	11	3H	1	29	repeat	ID/OD 3H	0.26	30	17.2	0.72	-0.19	0.07	6100	0.000	6100	0.000
4	34	43	3H	1	44	new	ID/OD 3H, >2v DOS 2H	0.39	36	22.8	0.65	-0.30	0.09	6100	0.000	6100	0.000

Figure 1 - Comparison of Prior Cycle PWSCC Length Growth Rates

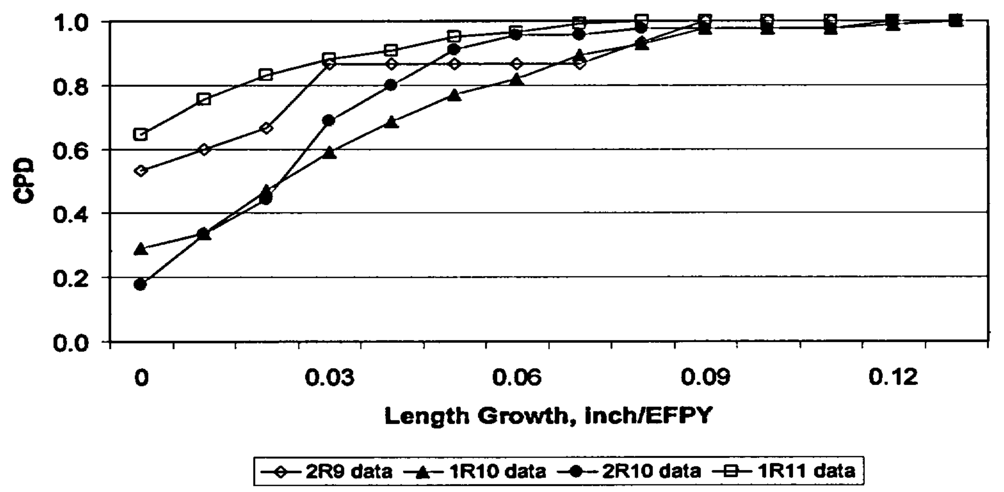
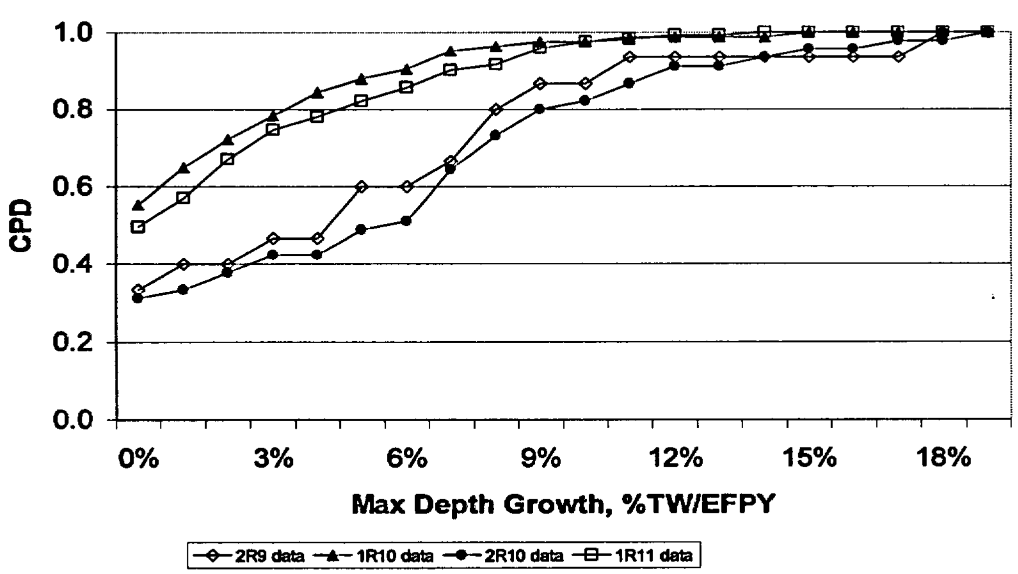


Figure 2 - Comparison of Prior Cycle PWSCC Maximum Depth Growth Rates



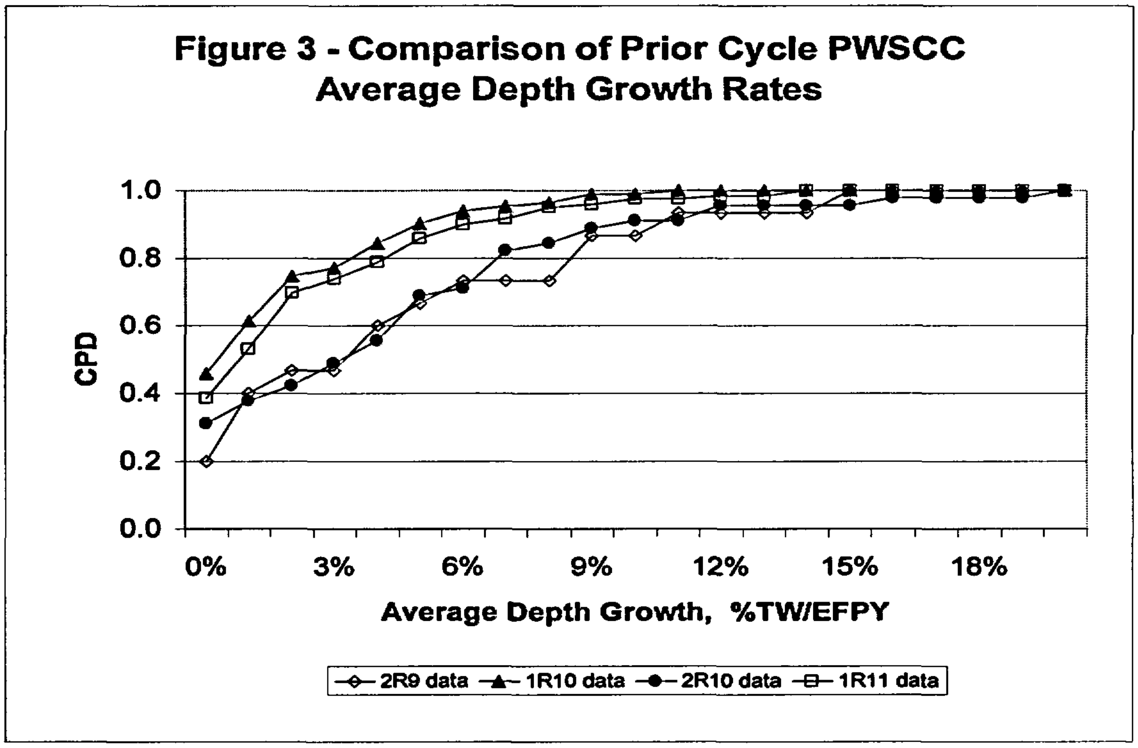


Figure 3 - Comparison of Prior Cycle PWSCC Average Depth Growth Rates
1.0
0.8
0.6
0.4
0.2
0.0
CPD
0%
3%
6%
9%
12%
15%
18%
Average Depth Growth, %TW/EFPY
2R9 data
1R10 data
2R10 data
1R11 data

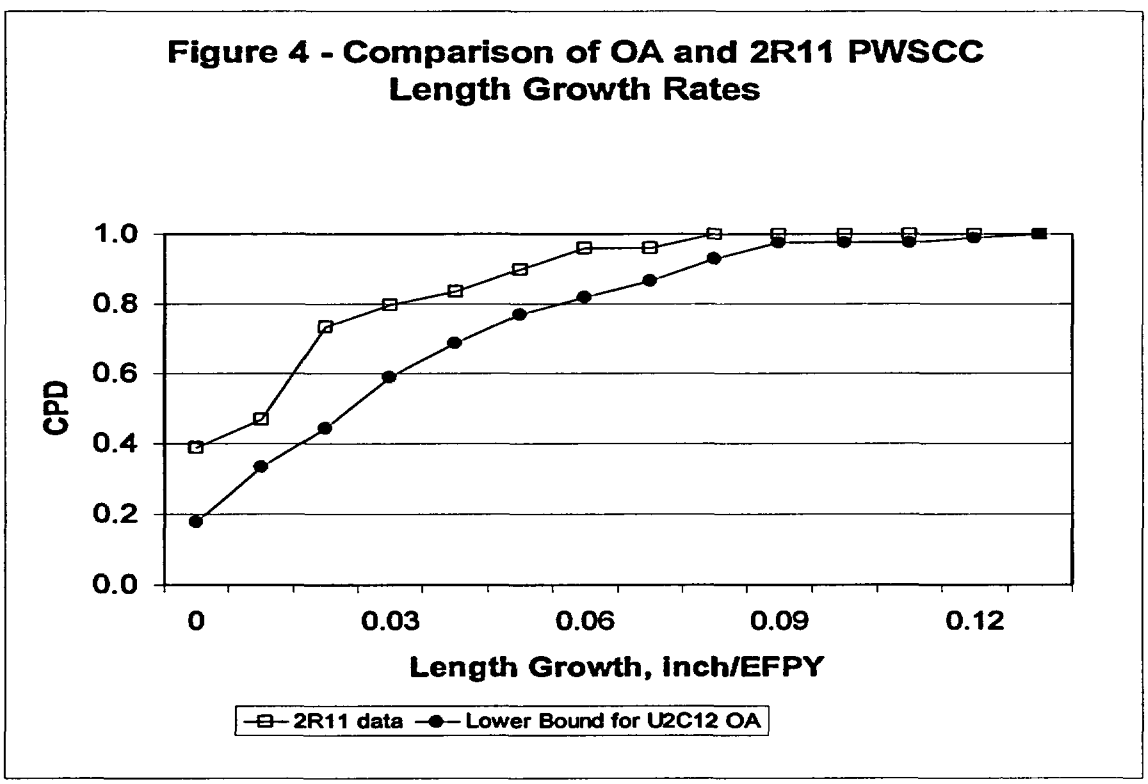


Figure 4 - Comparison of OA and 2R11 PWSCC Length Growth Rates
1.0
0.8
0.6
0.4
0.2
0.0
CPD
0
0.03
0.06
0.09
0.12
Length Growth, inch/EFPY
2R11 data
Lower Bound for U2C12 OA

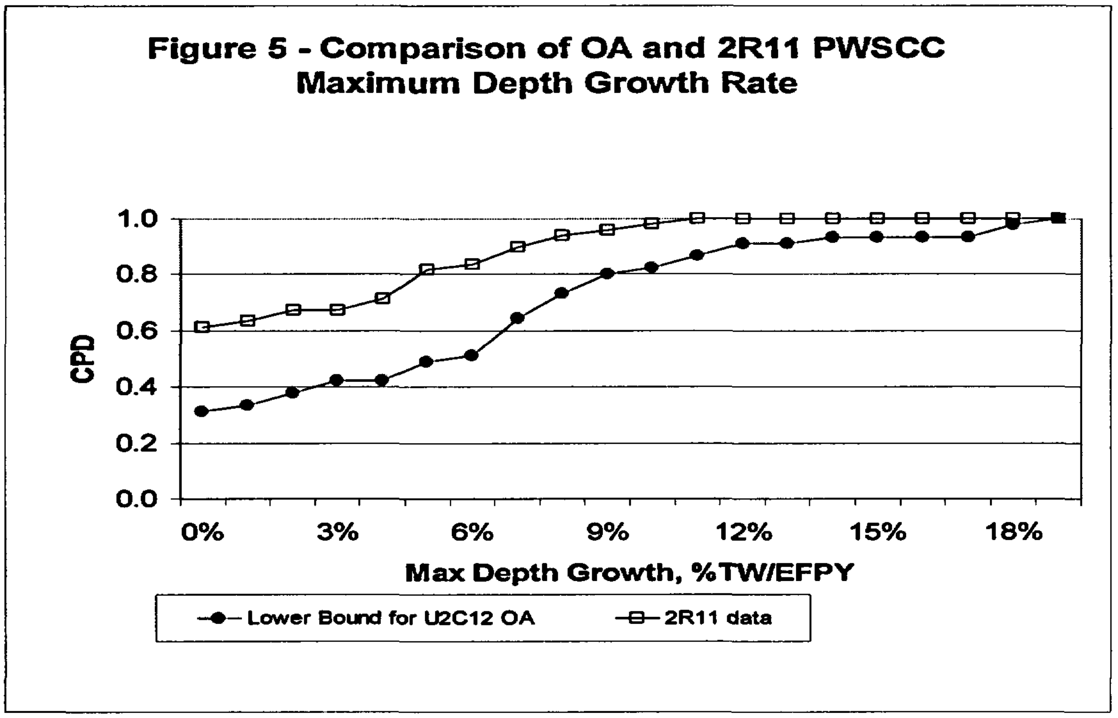


Figure 5 - Comparison of OA and 2R11 PWSCC
Maximum Depth Growth Rate
CPD
1.0
0.8
0.6
0.4
0.2
0.0
0%
3%
6%
9%
12%
15%
18%
Max Depth Growth, %TW/EFPY
Lower Bound for U2C12 OA
2R11 data

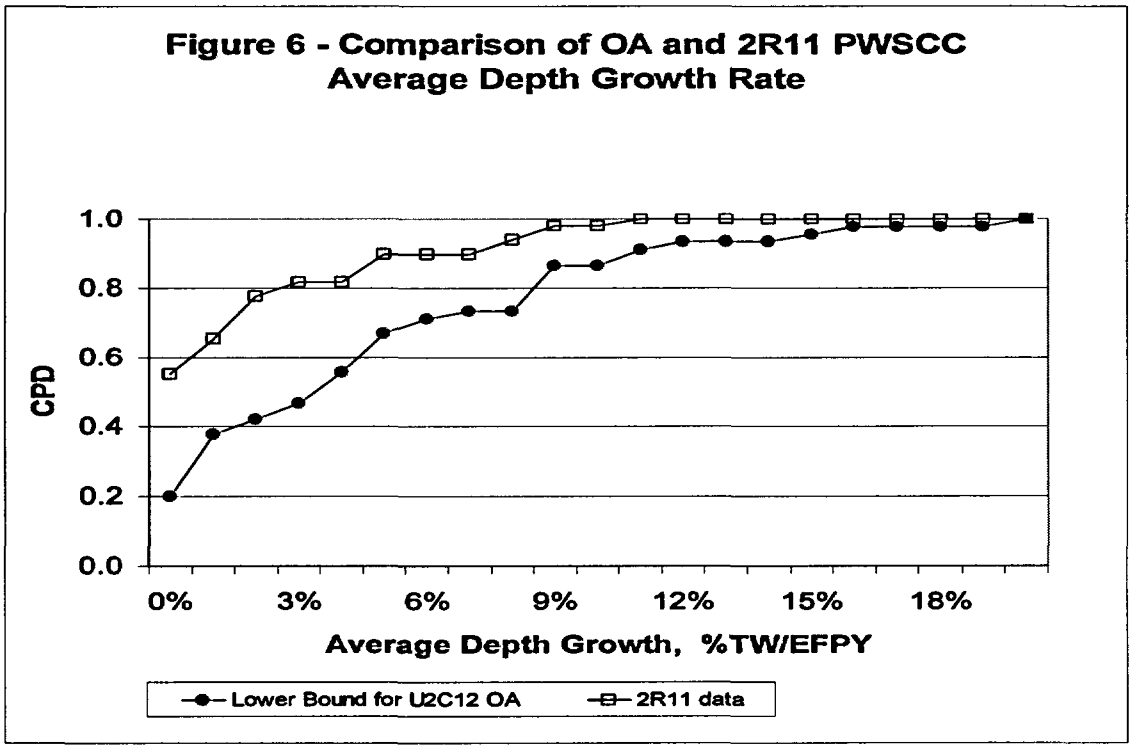


Figure 6 - Comparison of OA and 2R11 PWSCC
Average Depth Growth Rate
CPD
1.0
0.8
0.6
0.4
0.2
0.0
0%
3%
6%
9%
12%
15%
18%
Average Depth Growth, %TW/EFPY
Lower Bound for U2C12 OA
2R11 data

Figure 7

Circumferential Average Depth Trending

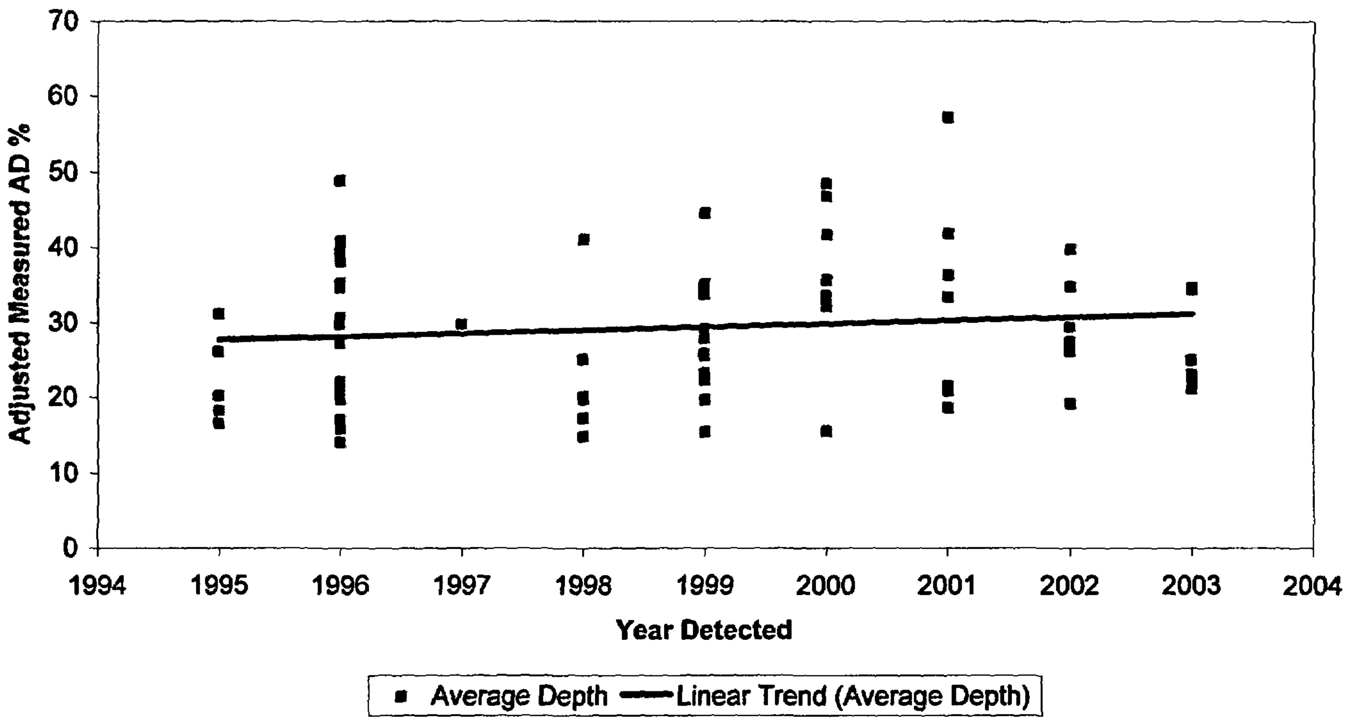


Figure 8

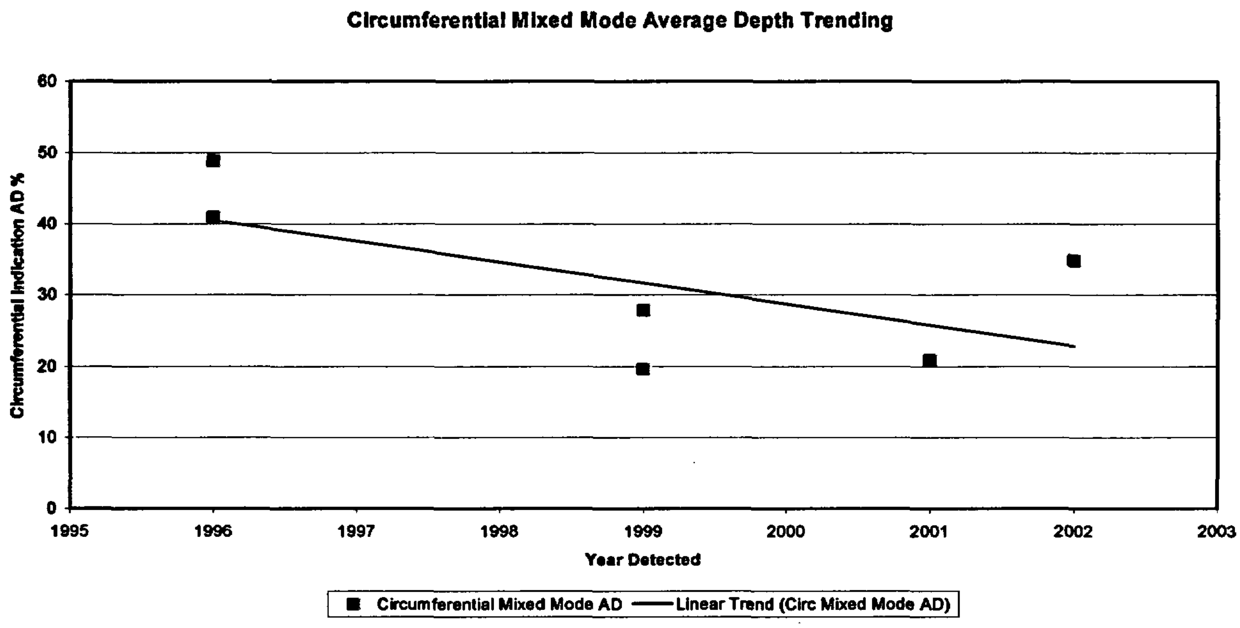
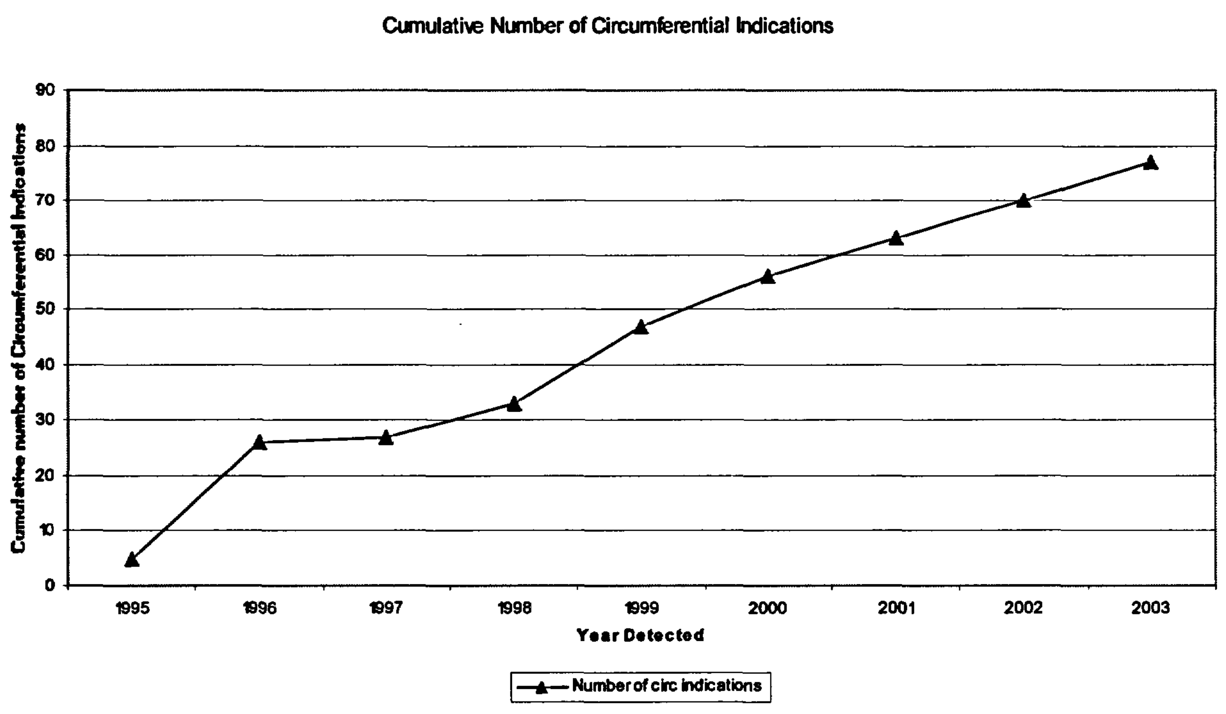


Figure 9



SPECIAL REPORT 03-02

ATTACHMENT 1 TO ENCLOSURE 2

WESTINGHOUSE REPORT
"DIABLO CANYON LIGAMENT TEARING AND LEAK RATE MODEL"

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Diablo Canyon Ligament Tearing & Leak Rate Model

1.0 Introduction

The Reference 1 report documented the development of depth based alternate repair criteria (ARC) for the disposition of axial primary water stress corrosion cracking (PWSCC) of steam generator (SG) tube indications at dented tube support plate (TSP) intersections in Westinghouse Model 51 SGs with drilled hole TSPs. The Reference 2 report provided information inclusive of and in addition to that of Reference 1 to support the technical bases for the use of the ARC in the presence of potential mixed mode indications. A significant feature of the ARC methodology is a model for predicting radial ligament tearing of the axial indications to obtain the associated leak rate during postulated steam line break (SLB) conditions. A proviso of the implementation of the ARC at the Diablo Canyon Nuclear Power Plant (DCPP) is the comparison of model predicted leak rates to those obtained by testing indications in tube sections removed from the DCPP SGs. Two tube sections were removed for examination and testing during the 2R11 outage at the DCPP. Destructive examination of the tubes was performed by Framatome ANP and the results of the examinations were provided to the Nuclear Services Division of the Westinghouse Electric Company for comparison with predictions from the analytic model.

2.0 Monte Carlo Simulation of Degradation Leak Rates

The following information is a repeat of the discussion of References 1 and 2 and is included herein to familiarize the reader with the features of the ligament tearing and leak rate models. A Monte Carlo simulation model is applied for estimating the leak rate through degraded tubes during a postulated steam line break (SLB) event. The Monte Carlo model uses the NDE crack profiles obtained for each indication including simulation sample adjustments for maximum depth and length NDE uncertainties for condition monitoring and maximum depth NDE uncertainties, length NDE uncertainties and maximum depth growth for operational assessments. Calculations may be performed to obtain the leakage distribution for a single indication or for the entire SG indication distribution. The Monte Carlo leakage model includes:

1. The crack profile is searched for the longest lengths that would be predicted to break through by ligament tearing at SLB conditions. The profile is evaluated three times. In general, the weakest ligament of the crack will be near the center of the crack. Once that torn length has been identified, the profile of the crack above and below the torn length is evaluated to determine if a second or third location is anticipated to tear.

2. The ANL (Argonne National Laboratories) model, Reference 5 for ligament tearing is used to estimate the throughwall length(s) of the indication, See Section 3.0.

3. The Westinghouse computer code CRACKFLO is used to calculate a model value of the leak rate using the throughwall length(s) calculated using the ANL tearing model.

4. The leak rate correlation is applied to calculate a random value of the leak rate distributed about the regression line.

5. The distribution of leak rates from each of the random samples is developed and evaluated at the required confidence level (See Section 7 of Reference 2 for ARC requirements on confidence levels) for the analysis.

6. The combined use of a ligament tearing model and CRACKFLO leak rates results in a conservative overestimate of the leak rate.

As described in Section 6.2.1 of Reference 2, the CRACKFLO crack opening model includes a calculation for crack extension at the crack tip, which is also effectively part of the ligament tearing effect. Leakage is therefore based on a longer length than that obtained only from the ligament tearing model and the predicted leak rates are inherently conservative. In addition, PWSCC cracks are initiated as multiple microcracks which grow to link up with other microcracks to form the overall macrocrack. Crack depths vary significantly between microcracks such that non-throughwall depths vary sharply over short spans. As a consequence, leak tests of corrosion induced cracks rarely show ligament tearing for more than about 2% of the wall thickness where the depth is the largest. The ligament tearing models are based on uniform average depths and typically predict breakthrough at shallower depths and longer lengths than found in tests of corrosion cracks. This effect adds further conservatism to the predicted leak rates. That is, leak rates would be over-predicted due to the CRACKFLO crack extension beyond that of the ANL ligament tearing model and due to the analytical models predicting more ligament tearing than indicated by leak tests of corrosion cracks with non-uniform depth profiles.

3.0 Ligament Tearing Model

The ligament tearing model for part-throughwall cracks is based on modifying the stress intensity magnification factor presented in Reference 3 to be used for predicting the burst pressure of SG tubes with axial, throughwall cracks. The pressure to cause burst of a tube with a single throughwall axial crack, P_B, is predicted by the following equation,

$$P_B = \frac{P_0}{m}, \tag{1}$$

where P_0 is the burst pressure of the non-degraded tube and m is referred to as the hoop stress or fracture mechanics stress intensity magnification factor. The factor m is also referred to as the bulging factor because it accounts for radial outward deformation of the crack flanks as a function of the crack length, L, the mean radius of the tube, R_m, and the thickness of the tube, t. Reference 3 reported m to be predicted by the following,

$$m = 0.614 + 0.386\,e^{-1.25\lambda} + 0.481\lambda, \tag{2}$$

where λ is the normalized crack length given by,

$$\lambda = \frac{0.9089\,L}{\sqrt{R_m\,t}}. \tag{3}$$

This expression for m was the result of a regression analysis of data obtained from numerical solutions of theoretical models of axial cracks. Hence, it represents a theoretical solution to the problem of burst of axially cracked tubes. The constant in the numerator is a function of the Poisson's ratio of the material.

3.1 Ligament Tearing Breakthrough Model

The authors of Reference 4 reported reviewing several models for predicting the pressure required for tearing the remaining ligament of a part-throughwall axially cracked tube based on modifying the above formulation to use a part-throughwall stress intensity magnification factor, m_p. The inverse of the stress intensity magnification factor is a failure or tearing pressure reduction factor, herein designated by ξ. Thus, the pressure required to tear the remaining radial ligament of a part-throughwall axial crack, P_T, is found as,

$$P_T = \frac{P_0}{m_p} = \xi P_0 . \tag{4}$$

Reference 4 also presented a review of various formulations for m_p and recommended a final expression for m_p as a function the relative depth of the crack, h (the ratio of the depth, d, to the thickness of the tube), and the throughwall axial crack magnification factor as,

$$m_p = \frac{1-\alpha \frac{h}{m}}{1-h}, \text{ where } \alpha = 1 + 0.852 h^2 \left(1 - \frac{1}{m}\right). \tag{5}$$

Reference 4 further designated this model as the ANL model. The coefficient of 0.852 used in Equation 5 was originally reported as 0.9 in Reference 5. Subsequent examination of the original calculation revealed that some minor changes in the computation were required to account for temperature affects on the material properties (the tensile tests were performed at room temperature and the burst tests at 600°F), the radius used for the normalized crack length, e.g., minimum or mean, the radius used for the non-degraded burst pressure, and the number of data for which ANL depth measurements were available. The revised coefficient was obtained via Reference 6. The non-degraded burst pressure is computed as,

$$P_0 = 0.595 \left(S_Y + S_U\right) \frac{t}{R_m}, \tag{6}$$

based on a large amount of Westinghouse and industry data, including the results used in the ANL computation, see Reference 7.

The limit of m_p as h goes to 1, i.e., corresponding to a throughwall crack, is infinity, and the ligament tearing pressure is then zero. Results obtained from the model for three different crack lengths are illustrated on Figure 3. For very long cracks, say greater than 1.5", the model is linear between the non-degraded burst pressure for zero depth and zero tearing pressure for 100% depth. For shorter cracks the shape of the curve becomes more and more convex as shown on Figure 3. As the length of the crack approaches zero, the location of the maximum rate of change of the

slope, i.e., the *knee* of the curve, tends to the non-degraded burst pressure as the depth approaches 100%.

The critical crack length as a function of crack depth for the postulated SLB differential pressure for nominal and 95/95 lower tolerance limit (LTL) material properties is presented on Figure 4. A curve for the critical crack length for ligament tearing under typical normal operating conditions is also presented. It may be concluded from the figure that the effect of material property variations is small for depths greater than about 90% throughwall.

The ligament tearing model was derived to predict the behavior of part-throughwall, rectangular shaped, axial cracks. The comments of Section 5 of Reference 2 regarding the shape of real cracks also apply to the prediction of the ligament failure pressure. The approach used to predict the ligament tearing pressure is the same as that used to predict the tube burst pressure, with the exception that the ANL model is used. Since the intent is to predict ligament tearing, no calculations of the burst pressure of the resulting 100% throughwall axial crack are performed for the leak rate evaluations. Following the naming of the burst pressure algorithm, the leak rate algorithm was designated as the *weak leak* model.

The end goal of the weak leak model is different from that of the burst pressure model. In order to estimate the leak rate, the likely throughwall crack length for a given applied pressure must be known. Hence, the model is applied to all possible sub-cracks from the original profile and the ligament tearing pressures are calculated. The length of the sub-crack with a ligament tearing pressure just less than (not more than) the SLB differential pressure may then be used for the leak rate calculation. Following identification of this longest throughwall length due to break through at SLB conditions, the crack profile is searched to identify the next two largest sub-lengths either above or below the longest throughwall length that would also be predicted to break through at SLB conditions. The lengths predicted to be throughwall are then included in the SLB leak rate analysis. Because the profile information is based on discrete increments, the appropriate sub-crack to evaluate is the one with the minimum tearing pressure that is greater than or equal to the given critical pressure. This means that the length returned is greater than or equal to that corresponding to the tearing pressure exactly matching the critical pressure. Because the leak rate from axial cracks varies approximately with the third to fourth power of the crack length, the subsequent leak rate calculation is conservative.

It is possible for multiple, distinct sub-cracks to exist with ligament tearing pressures equal to the SLB pressure. In this case the leak rate calculation would normally be performed for all such sub-cracks and the total leak rate found as the sum of the individual values. However, the presence of such cracks is judged to be a rare event although the model considers the longest and next two largest sub-cracks with a ligament tearing pressure nearest to, but greater than or equal to, the applied SLB pressure. For the rare case of two sub-cracks having the potential for ligament tearing, the longest sub-crack leak rate can be expected to be significantly higher than that of a shorter crack due to the leak rate dependence on throughwall crack length to a power of 3 to 4. Due to both low frequency of occurrence and lower leak rate of a second sub-crack with leakage, the leakage from a potential second sub-crack can be ignored. As discussed above in Section 6.4.1 of Reference 2, the leakage model already incorporates conservative leak rate predictions and efforts to calculate the breakthrough length for a second, shorter sub-crack are not necessary, but is included in the analysis.

3.2 Ligament Tearing Throughwall Model

The use of the ligament tearing model for throughwall cracks is inherently conservative because of the manner in which the model represents the crack as an equivalent rectangle. This is illustrated by considering the case where there is a 100% throughwall portion of the crack being evaluated as shown on the upper portion of Figure 2. One of the crack segments analyzed will consist only of the 100% throughwall region (the ligament tearing pressure will be zero in this case). The next segment analyzed will consist of the 100% throughwall length plus the inspection increment at one end of that segment, etc. Other segments analyzed will consist of the 100% throughwall length plus inspection increments at each end of the crack being analyzed as shown on the lower portion of Figure 2. To make a rectangular representation of the crack section being analyzed, the incremental material will be treated as being much narrower in order to extend it over the length of the rectangle while keeping the area of the crack constant. This means that the analysis will likely predict tearing of that incremental ligament even if it is quite wide.

The following example situation illustrates the foregoing discussion. The geometry considered is that of a 7/8" by 0.050" SG tube with a 0.3" long throughwall axial crack segment, an inspection increment of 0.030", and an adjacent crack depth of 50%. The geometry of the throughwall portion and the next increment will be that of a rectangle with a length of 0.33" and a depth of 95%. This is similar to the situation that develops as shown on Figure 2. It is very likely that such a narrow ligament would be predicted to tear at a significantly lower pressure than needed to actually extend the crack. This feature of the model is particularly relevant to the evaluation of the tube sections removed from the DCPP SG because they both contain throughwall segments.

In summary, the model provide a conservative, inaccurate prediction of the extension length of an existing throughwall crack, and would be expected to always over-predict the length associated with tearing in that case, because implementation involves averaging ligament material over a sub-length of the crack profile and the area of the material at the ends of the idealized rectangular profile is used to develop an average uniform depth that includes the throughwall portion of the crack.

4.0 Diablo Canyon Pulled Tubes' Evaluations

The destructive examination of the tube degradation consisted of the performance of leak rate tests up to a pressure of 2750 psi at room temperature which was commensurate with simulating the SLB pressure of 2405 psi at 603°F.[1] There was no perceived tearing of the crack in the R35C57 tube section and only miniscule tearing of the crack in the R44C45 tube segment. The results are discussed in the following two sections. Heat tinting was performed following the simulated SLB leak testing and prior to burst pressure testing to identify the various sections of the cracks. Any ductile tearing that occurred up to the SLB pressure was tinted to differentiate it from the ductile tearing that occurred during the burst testing.

The information used herein was obtained from References 8, 9 and 10. Reference 8 provides a complete description of the tube examination process and results. The information for the DE crack depth profiles and tube material strengths was also documented in Reference 9, including

crack depth and ligament tearing profiles in Excel™ format. Reference 10 documented the results from the leak rate tests performed in the laboratory. A summary of the examination results is provided in Table 1.

4.1 Examination Results for R35C57-2H

The profile obtained from the destructive examination of the R35C57 cracked tube section is illustrated on Figure 5. There was no ductile tearing in the radial, axial, or circumferential directions under SLB conditions; the only tearing occurred in the axial direction during the burst testing of the tube section. The initial throughwall portion of the crack was 0.217 inch long. The distribution of torn lengths resulting from the analysis using the ligament tearing model for the destructive examination profile is shown on Figure 6. The average of the simulated torn lengths was 0.338 inch even though no tearing occurred during the actual test of the tube section. The measured leak rate at a test pressure of 2750 psi at 70°F was found to be 0.0368 GPM. The adjusted value for the ODSCC ARC database was calculated to be 0.0023 GPM at a differential pressure of 2405 psi at 600°F when condensed to ambient conditions. The results from a simulation of ligament tearing and leak rate are shown on Figure 6 for the crack lengths and Figure 7 for the leak rates. The median, average, and 95th percentile leak rate values from the model of Reference 2 were 0.026, 0.060 and 0.204 GPM respectively.

The analysis was repeated using the profiles based on amplitude sizing of the information from the eddy current inspection. The NDE uncertainty values from Reference 2 were used for the simulations even though the cracks were ODSCC. There is a lack of ODSCC amplitude sizing information and the intent of the analysis was to simulate the level of uncertainty that would be associated with the application of the PWSCC ARC. A consequence of using the NDE uncertainties is that most of the simulations resulted in predicting that tearing of the remaining ligament would not occur. The intercept of the correlation of true depth to NDE depth is at about -1% and the slope of the regression line is 0.94. This means that the depth of the 100% portion of the profile will be ≤ 93% for 50% of the simulations. Because the associated lengths of the deepest portion of the profile are relatively short, ligament tearing is not predicted to occur for most of the simulations at a differential pressure of 2405 psi. One of the random simulated profiles is illustrated on Figure 8, a case that did not exhibit tearing at 2405 psi. However, the average torn length of the random indications that were predicted to exhibit tearing was calculated to be 0.402 inch. The simulated median, average and 95th percentile leak rates were 0.000, 0.087 and 0.400 GPM respectively. The distribution of torn lengths is illustrated on Figure 9 and the distribution of predicted SLB leak rates is shown on Figure 10. In summary, the leak rate used in the condition monitoring evaluation of the flaw, i.e., the 95th percentile leak rate from the NDE profile, was estimated to be 174 times greater than found from the destructive examination.

4.2 Examination Results for R44C45-2H

The destructive examination profile for the R44C45 tube degradation is shown of Figure 11. The following information was reported from the tube examination:

[1] The test pressure is increased by the ratio of the material strength properties at operating conditions to those at room temperature, usually about 10%, plus an allowance for potential measurement error.

1. Ductile tearing at SLB was essentially negligible. The sliver of ductile tearing is shown on Figure 11 is repeated singly on Figure 12 to focus on the small amount of tearing that occurred.
2. It was reported that neither the optical macrographs nor the SEM fractographs convey the true nature of the surface roughness both axially and through the wall thickness.
3. Individual crack segments are displaced by about 0.025 inch in the hoop direction.
4. Individual crack segments are about 0.10 inch in axial length.

Crack segments had joined together by intergranular cracking, consistent with the large jump in bobbin amplitude observed from EOC 10 to EOC 11. A small overall depth increase in the R44C45 crack led to a throughwall crack length of 0.378 inch. This, in combination with the loss of current paths from cracking of individual segment ligaments explains the large jump in bobbin and +Point voltages.

The leak rate reported in Reference 10 was 0.88 GPM for a differential pressure of 2750 psi at 70°F. The adjusted value for the ODSCC ARC database was calculated to be 0.277 GPM for a differential pressure of 2405 psi at 600°F when condensed to ambient conditions. The corresponding median, average and 95th percentile model predictions for SLB conditions were 0.41, 0.95 and 3.29 GPM respectively for the destructive examination profile. The average simulated length was 0.631 inch and the distribution of analysis-predicted torn lengths is shown on Figure 13 with the distribution of simulated leak rates is shown on Figure 14.

The analysis of the NDE profile yielded a mean torn length of 0.744 inch with median, average and 95th percentile leak rates of 0.121, 1.75 and 6.01 GPM respectively. A sample random analyzed profile is illustrated on Figure 15. The distribution of torn lengths from the Monte Carlo analysis is shown of Figure 16 and the attendant leak rates are shown on Figure 17. Thus, the leak rate expected from the condition monitoring evaluation of this flaw would be 21.7 times the value reported from the destructive examination testing.

5.0 Summary

Summary results from the analyses of the tube sections are provided in Table 1. The torn lengths from the SLB leak test were significantly less than that predicted by the ligament tearing analysis used in the leak rate model.

- There was no ligament tearing of the R35C57 crack during the SLB pressure testing. The original throughwall length was 0.217 inch and the predicted average ligament tearing length increase was 0.165 inch based on the analyses performed using the NDE profile. The predicted leak rate for the condition monitoring analysis using the NDE developed profile was more than 150 times the value observed during the SLB leak test.

- There was miniscule tearing of the R44C45 tube crack during the SLB testing, while significant tearing was predicted using the PWSCC ARC model using both the DE and NDE measured profiles, e.g., up about 0.370 inch of tearing versus about 0.004 inch from the test program. Moreover, the predicted leak rate for the condition monitoring analysis was about 22 times greater than the value observed during the testing.

In conclusion, the ligament tearing and leak rate model combination being used for the prediction of leak rates from PWSCC cracks yielded very conservative results relative those from the destructive examination.

6.0 References

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2. WCAP-15573, Revision 1, "Depth-Based SG Tube Repair Criteria for Axial PWSCC at Dented TSP Intersections – Alternate Burst Pressure Correlation," Westinghouse Electric Company, Nuclear Services Division, Madison, PA, October, 2001.
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4. Majumdar, Saurin, "Predictions of Structural Integrity of SG Tubes Under Normal, Operating, Accident, and Severe Accident Conditions," 24th Water Reactor Safety Meeting, October 21-26, 1996, Bethesda, MD, September, 1996.
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6. Personal communications on the *ANL Ligament Tearing Model*, W. Shack, Argonne National Laboratory, and R. Keating, Westinghouse Electric Company, February 15, 2000.
7. TR-105505, "Burst Pressure Correlation for Steam Generator Tubes with Throughwall Axial Cracks," EPRI, Palo Alto, CA, October, 1998.
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9. 51-5028414-01, "DCPP 2R11 DE Input Transmittal to Westinghouse," Framatome ANP, Lynchburg, VA, USA, May 30, 2003.
10. 51-5025756-00, "Diablo Canyon Unit 2 Tube Pull Leak Rate Test Results," Framatome ANP, Lynchburg, VA, USA, March 18, 2003.
11. NUREG/CR-6664, "Pressure and Leak-Rate Tests and Models for Predicting Failure of Flawed Steam Generator Tubes," United States Nuclear Regulatory Commission, Washington, DC, USA, August, 2000.

Table 1: Tearing and Leak Evaluations Data & Analysis Results Summary			
Category	Property	Tube	
		R35C57	R44C45 [1.]
Tube Properties	Diameter (inch)	0.875	
	Thickness (inch)	0.050	
	Elastic Modulus at 600°F (psi)	$28.7 \cdot 10^6$	
Laboratory Examination Results	Yield Strength (psi)	58,148	54,525
	Ultimate Strength (psi)	105,398	99,661
	Corrosion TW Length (inch)	0.217	0.374
	SLB Torn TW Length (inch)	0.217	0.378
	Leak Rate at 2750 psi & 70°F GPM)	0.0368	0.88
ARC Evaluation Results, 2405 psi			
ODSCC ARC	Leak at 600°F (GPM at 70°)	0.0023	0.277
Analysis of the Destructive Examination Profile	Average Torn Length (inch)	0.338	0.631
	ODSCC Median Leak (GPM)	0.026	0.41
	ODSCC Average Leak (GPM)	0.060	0.95
	ODSCC 95/50 Leak (GPM)	0.204	3.29
Analysis of the Nondestructive Examination Profile	NDE 100% TW Length (inch)	0.11	0.39
	Average Torn Length (inch) [2.]	0.403	0.744
	ODSCC Median Leak (GPM)	0.000	0.121
	ODSCC Average Leak (GPM)	0.087	1.75
	ODSCC 95/50 Leak (GPM)	0.400	6.01

Notes:

1. The second, smaller crack in this tube would not be predicted to exhibit any significant tearing or leak rate based on its size.
2. Of the simulated indications that tore.

Table 2: Crack Profile Data for R35C57 Intergranular Cracking	
Axial Distance	Depth %TW
0.000	0.0
0.007	23.4
0.012	27.7
0.014	32.0
0.021	36.8
0.029	42.4
0.031	45.0
0.040	61.5
0.054	74.0
0.073	77.9
0.094	83.1
0.116	84.4
0.127	86.1
0.149	100.0
0.158	100.0
0.176	100.0
0.195	100.0
0.224	100.0
0.249	100.0
0.276	100.0
0.301	100.0
0.329	100.0
0.351	100.0
0.366	100.0
0.378	85.0
0.386	79.2
0.402	58.4
0.429	44.2
0.438	37.2
0.447	30.1
0.465	14.2
0.472	18.6
0.479	13.3
0.492	11.1
0.501	7.1
0.514	7.5
0.519	0.0

Table 3: Crack Profile for Tube No. R44C45							
SLB Leak Path ≈ All Intergranular		High Shear Wall Intact at SLB		Intergranular Facet		Sliver of Ductile Tearing at SLB	
Axial Distance	Depth % TW	Axial Distance	Depth % TW	Axial Distance	Depth % TW	Axial Distance	Depth % TW
0.000	0.00	0.602	80.60	0.599	100.00	0.575	100.00
0.005	19.34	0.609	67.57	0.602	80.60	0.602	80.60
0.015	24.53	0.617	67.57	0.602	80.60	0.579	100.00
0.021	21.23	0.643	72.07	0.609	67.57		
0.026	29.25	0.655	67.57	0.617	67.57		
0.033	29.72			0.643	72.07		
0.047	29.72			0.655	67.57		
0.062	25.00			0.655	100.00		
0.074	49.06						
0.086	55.66						
0.095	68.87						
0.108	76.89						
0.131	73.11						
0.177	83.02						
0.201	100.00						
0.230	100.00						
0.266	100.00						
0.284	100.00						
0.299	100.00						
0.346	100.00						
0.353	100.00						
0.384	100.00						
0.410	100.00						
0.441	100.00						
0.464	100.00						
0.472	100.00						
0.498	100.00						
0.510	100.00						
0.528	100.00						
0.539	100.00						
0.556	100.00						
0.579	100.00						
0.602	80.60						
0.609	67.57						
0.617	67.57						
0.643	72.07						
0.655	67.57						
0.667	67.57						

Table 3: Crack Profile for Tube No. R44C45							
SLB Leak Path ≈ All Intergranular		High Shear Wall Intact at SLB		Intergranular Facet		Sliver of Ductile Tearing at SLB	
Axial Distance	Depth % TW	Axial Distance	Depth % TW	Axial Distance	Depth % TW	Axial Distance	Depth % TW
0.671	42.34						
0.672	18.02						
0.677	18.92						
0.687	9.91						
0.689	11.71						
0.695	10.81						
0.701	0.00						

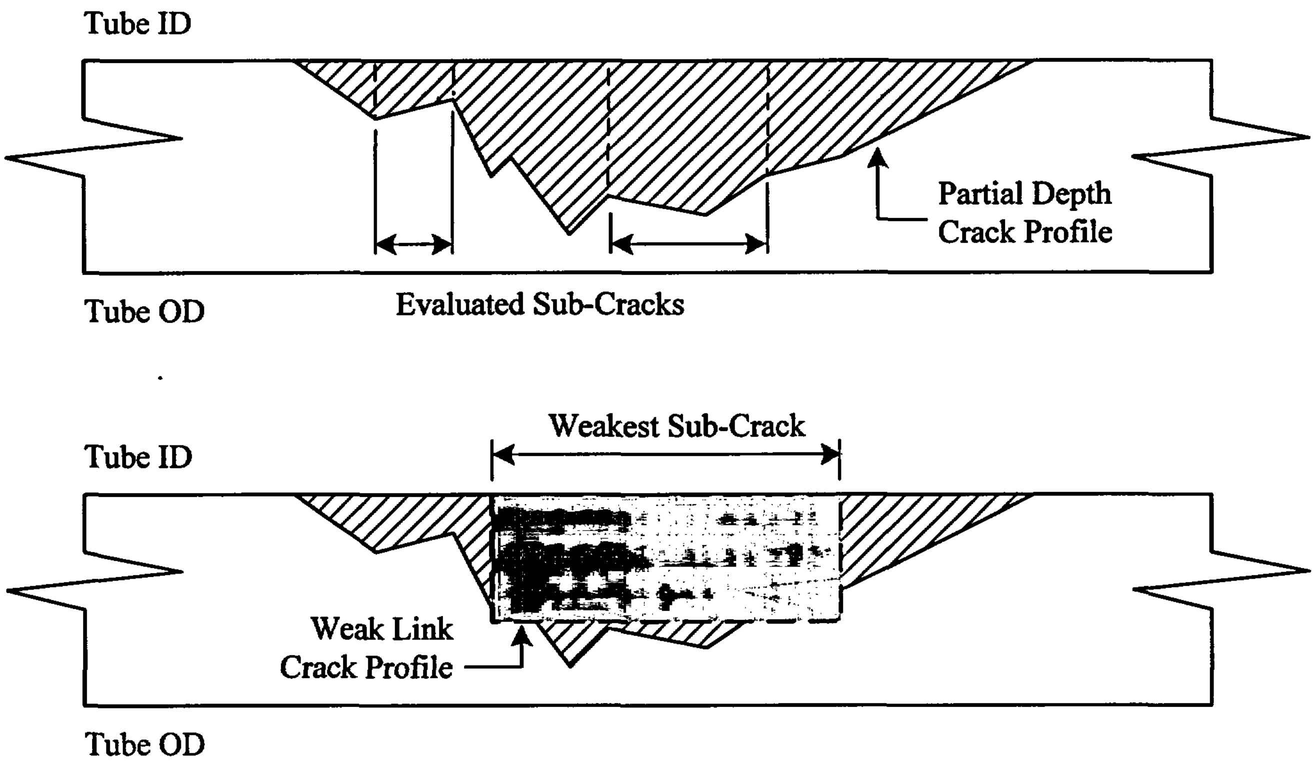


Figure 1: Representative part-throughwall axial crack profile with evaluated and weakest sub-crack profile shown.

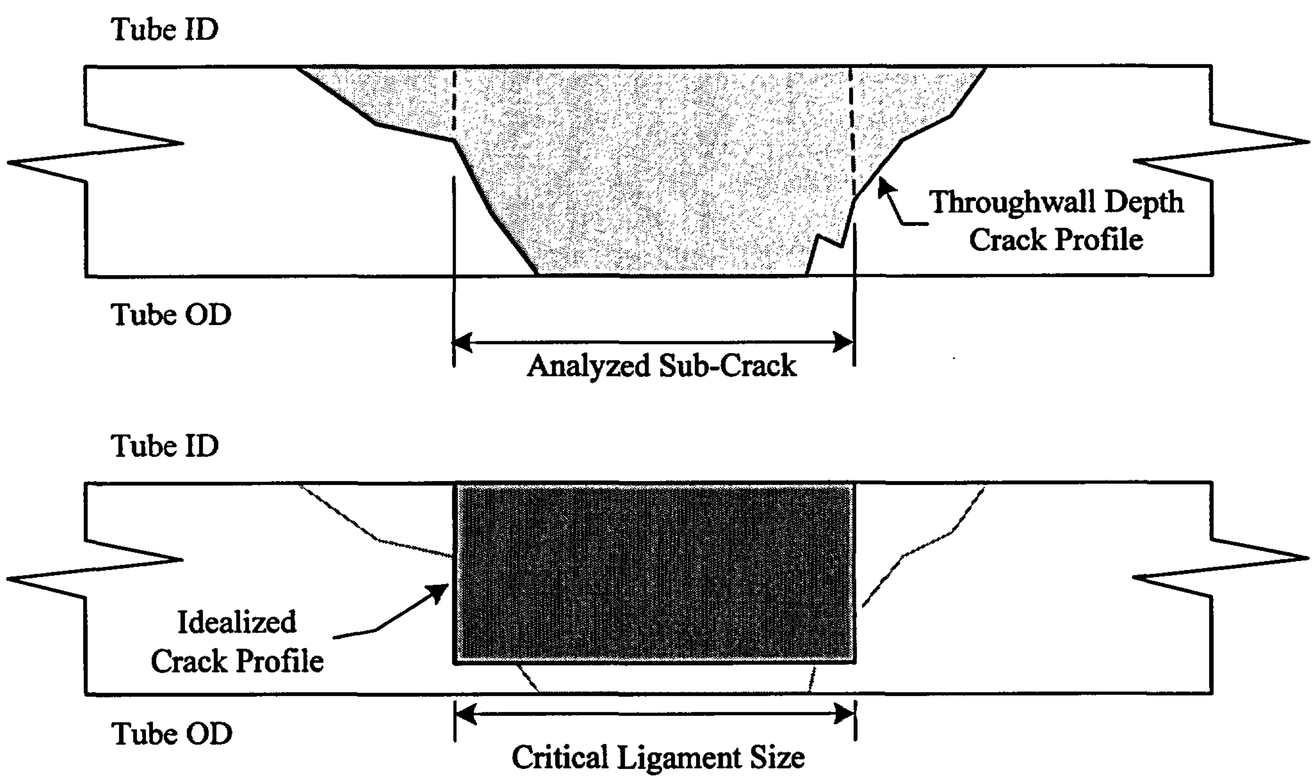


Figure 2: Representative throughwall axial crack profile with evaluated and critical idealized profile shown.

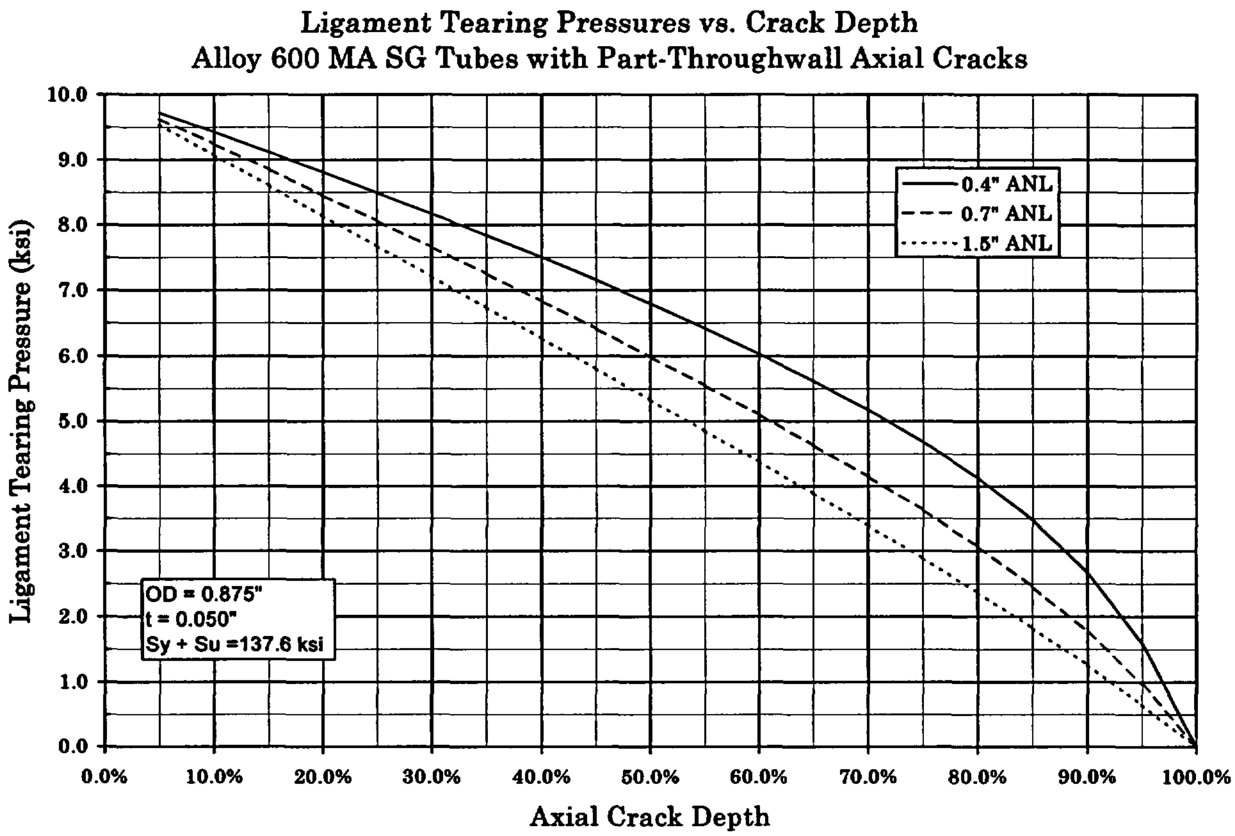


Figure 3: Ligament Tearing Pressure vs. Crack Length, Reference 2

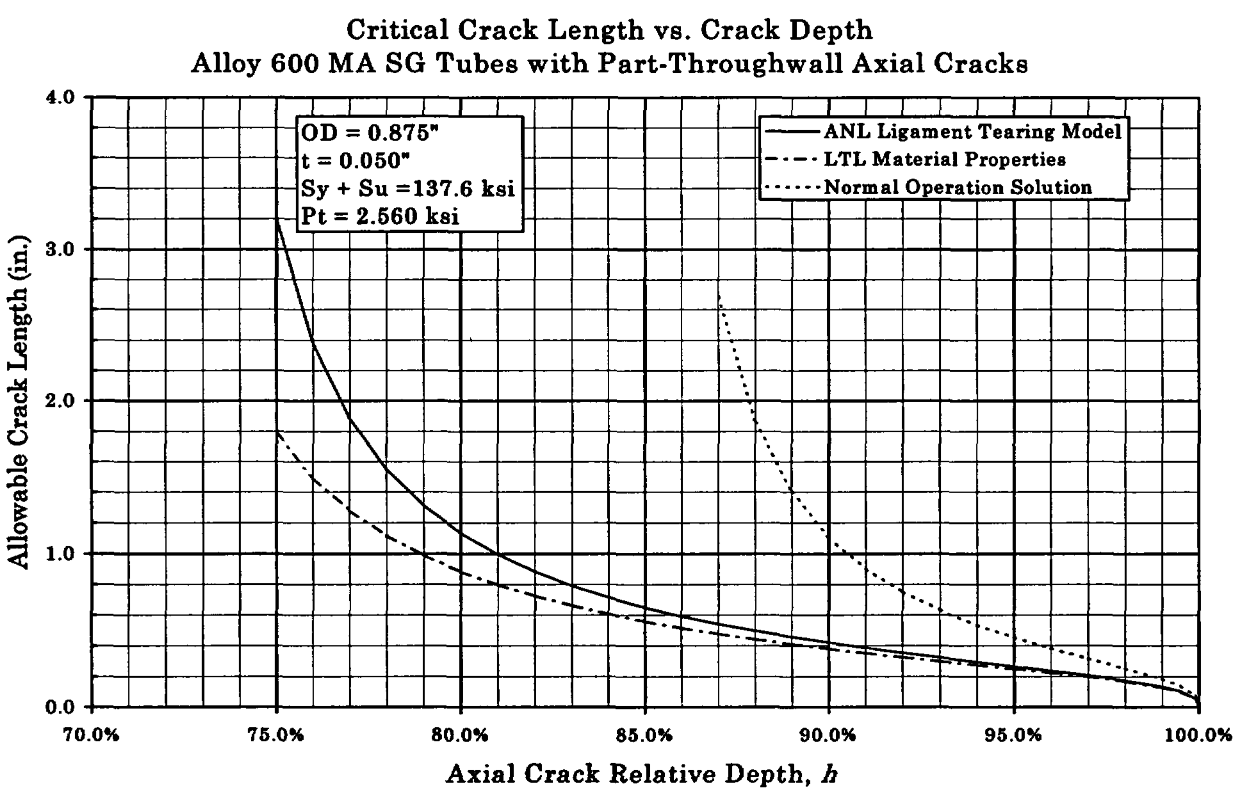


Figure 4: Critical Crack Length vs. Crack Depth, Reference 2

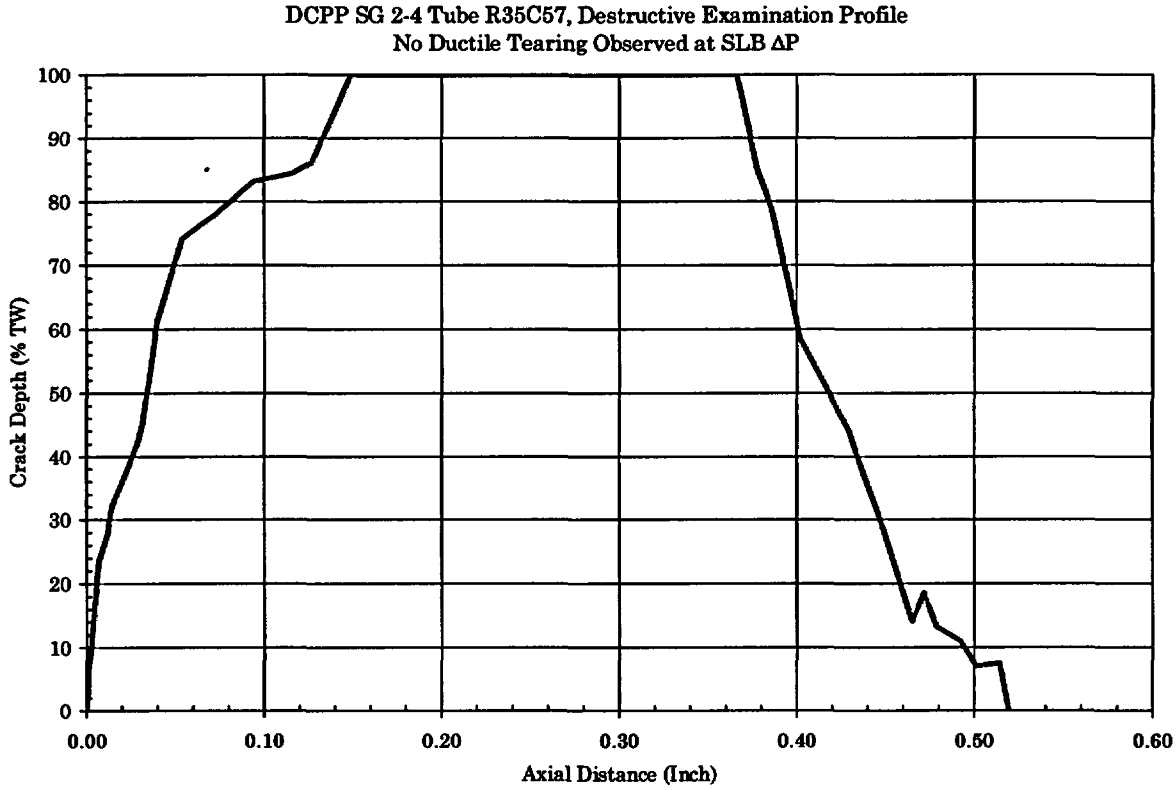


Figure 5: R35C57 Destructive Examination Depth Profile

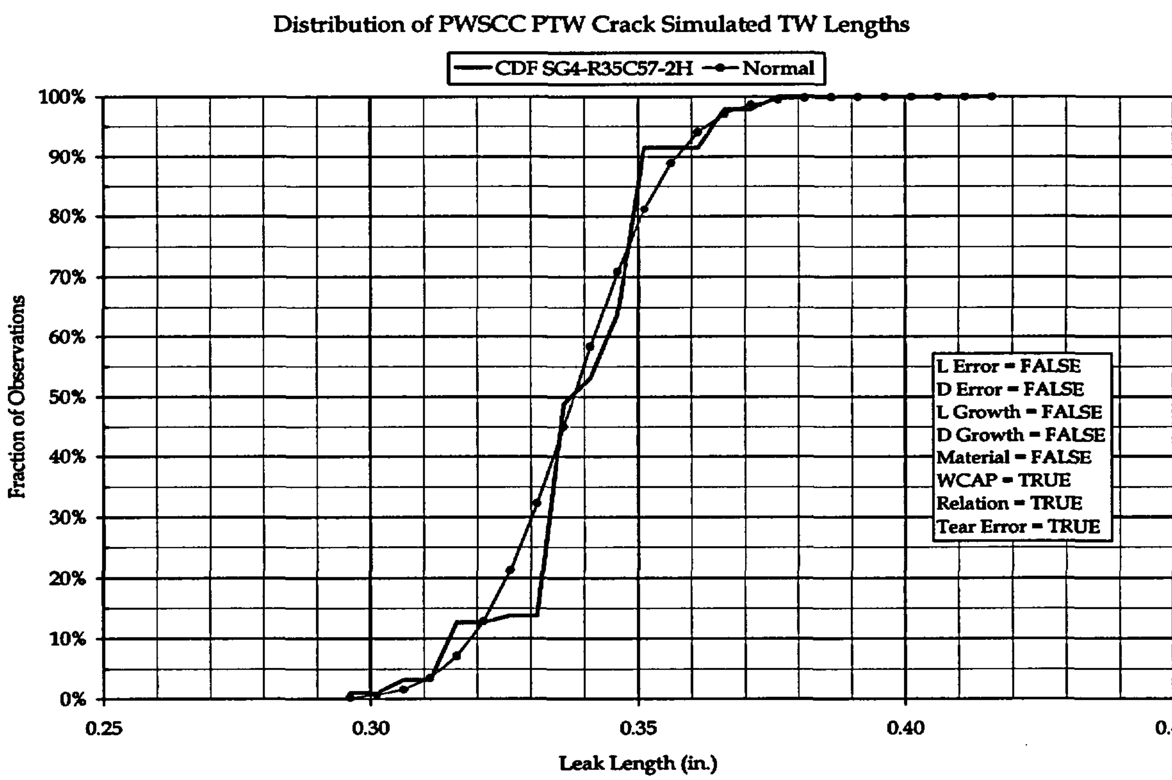


Figure 6: Distribution of R35C57 Torn Lengths

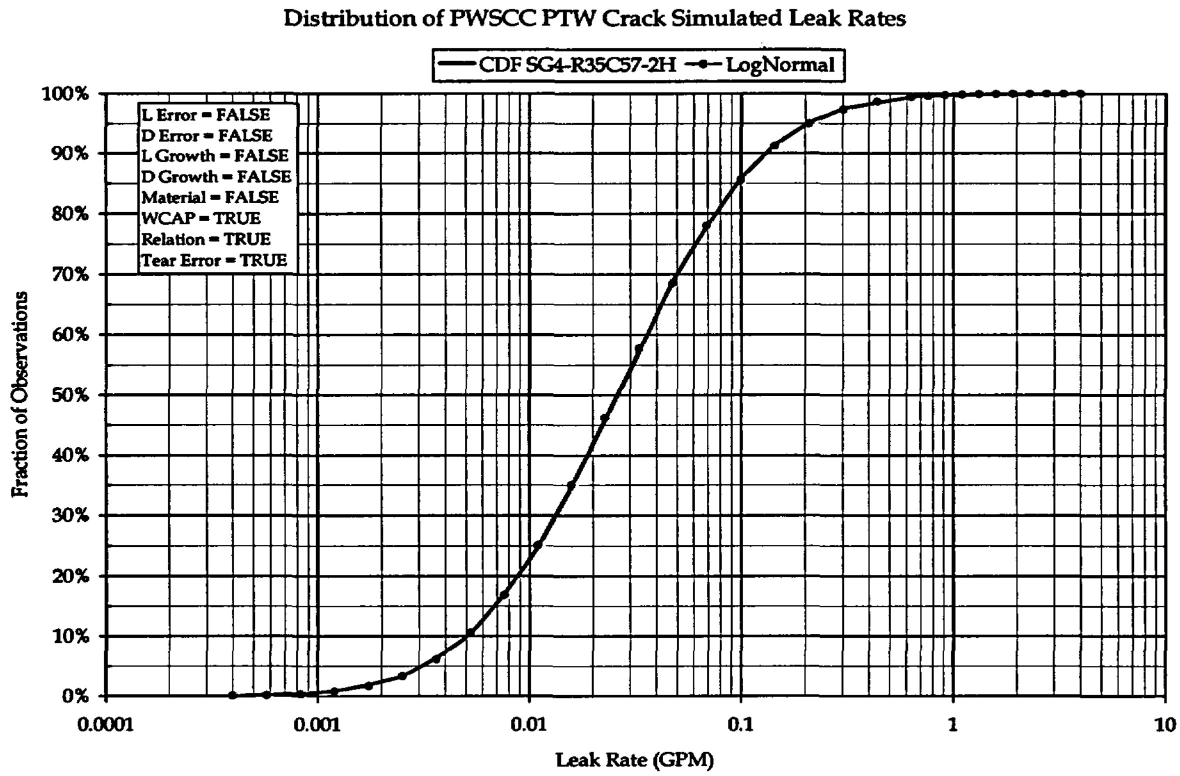


Figure 7: Distribution of R35C57 SLB Leak Rates

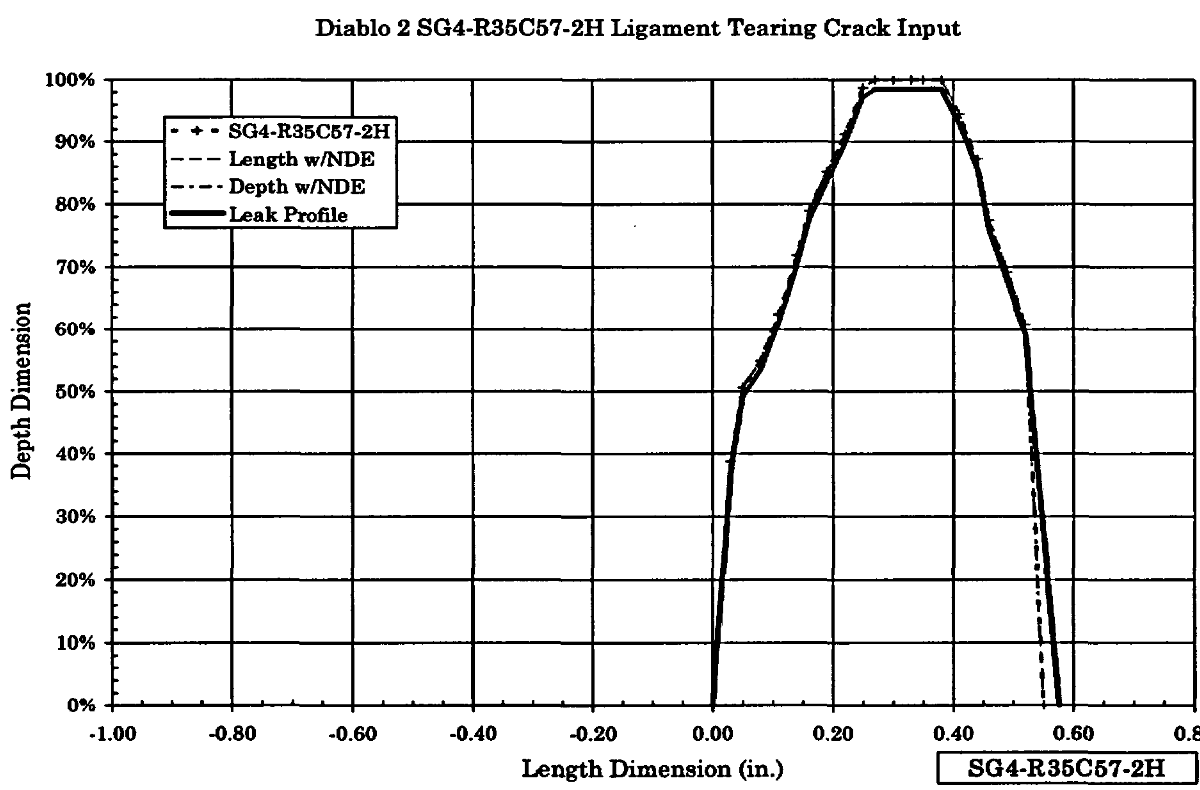


Figure 8: Sample Simulated R35C57 Profile

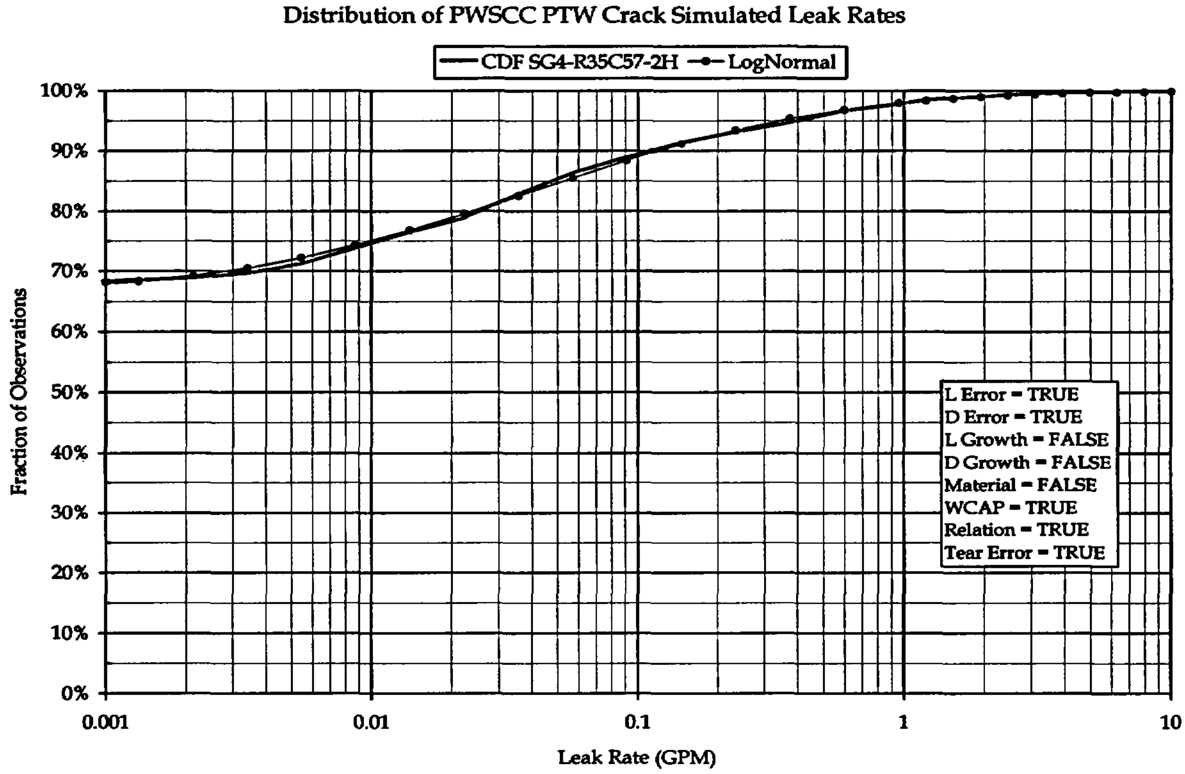


Figure 9: NDE Profile Distribution of R435C57 Torn Lengths

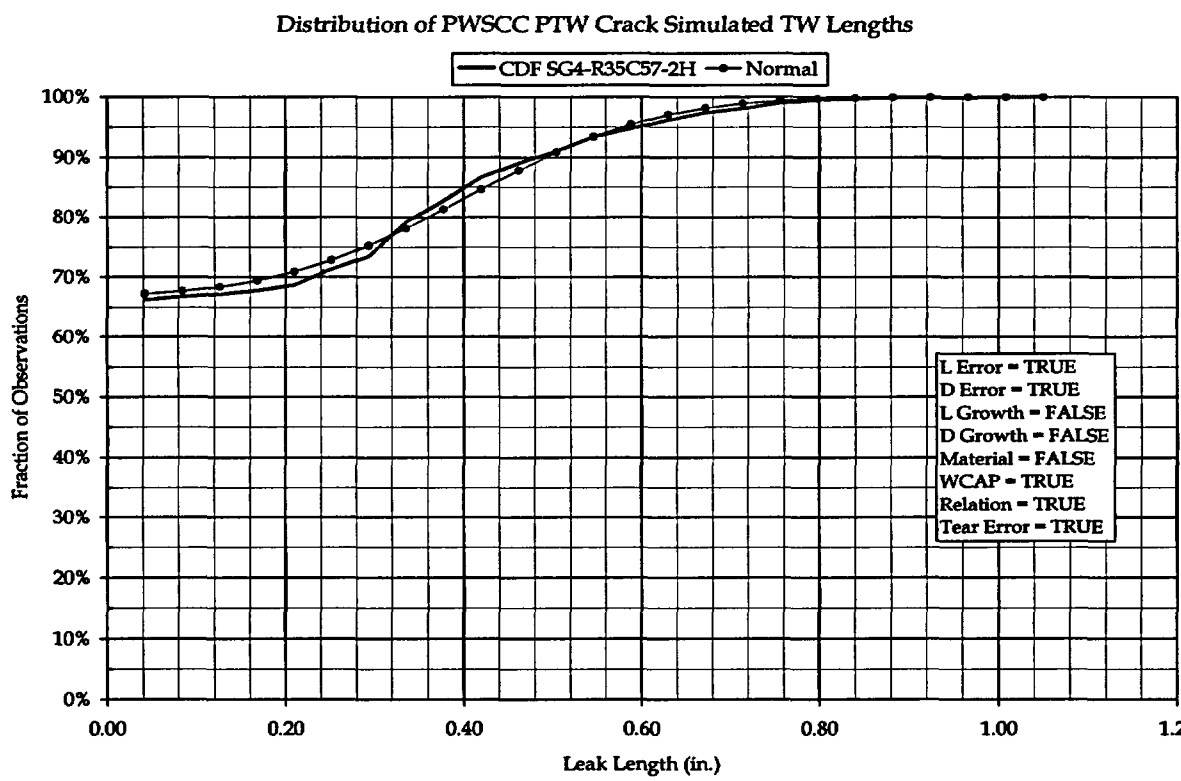


Figure 10: NDE Profile Distribution of R35C57 Leak Rates

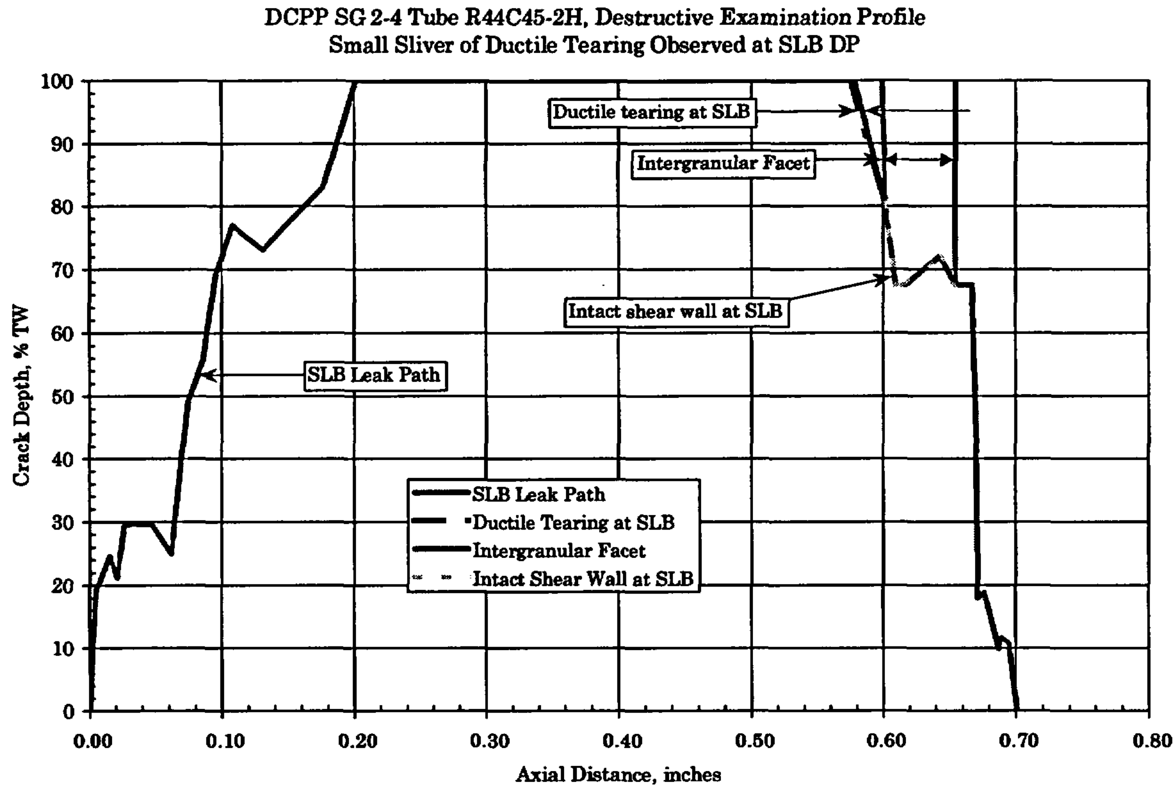


Figure 11: R44C45 Destructive Examination Depth Profile

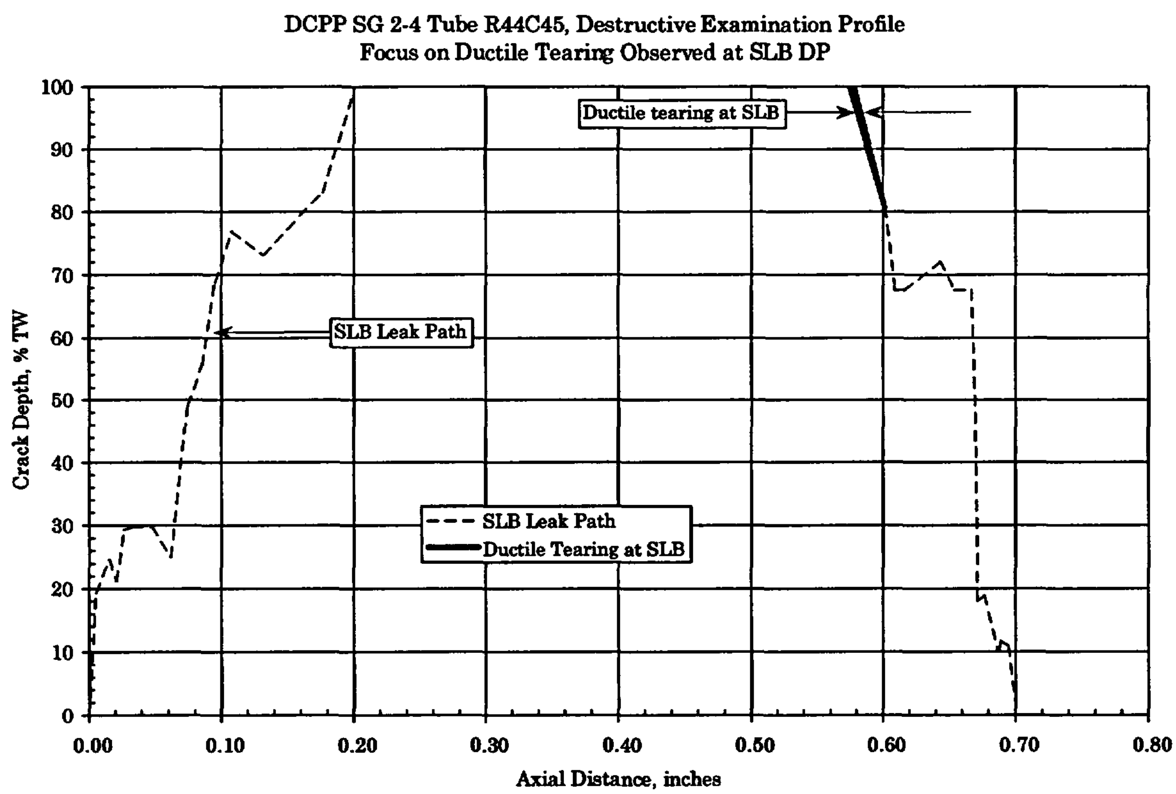


Figure 12: R44C45 Ductile Tearing

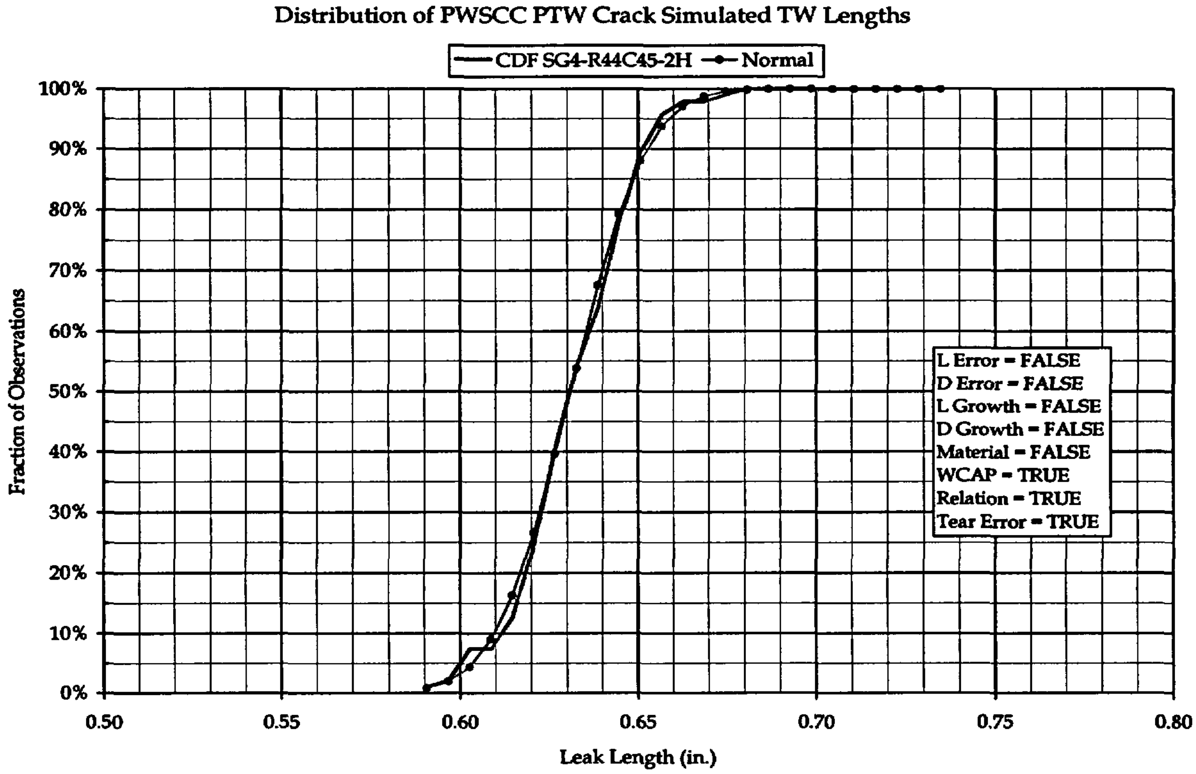


Figure 13: Distribution of R44C45 Torn Lengths

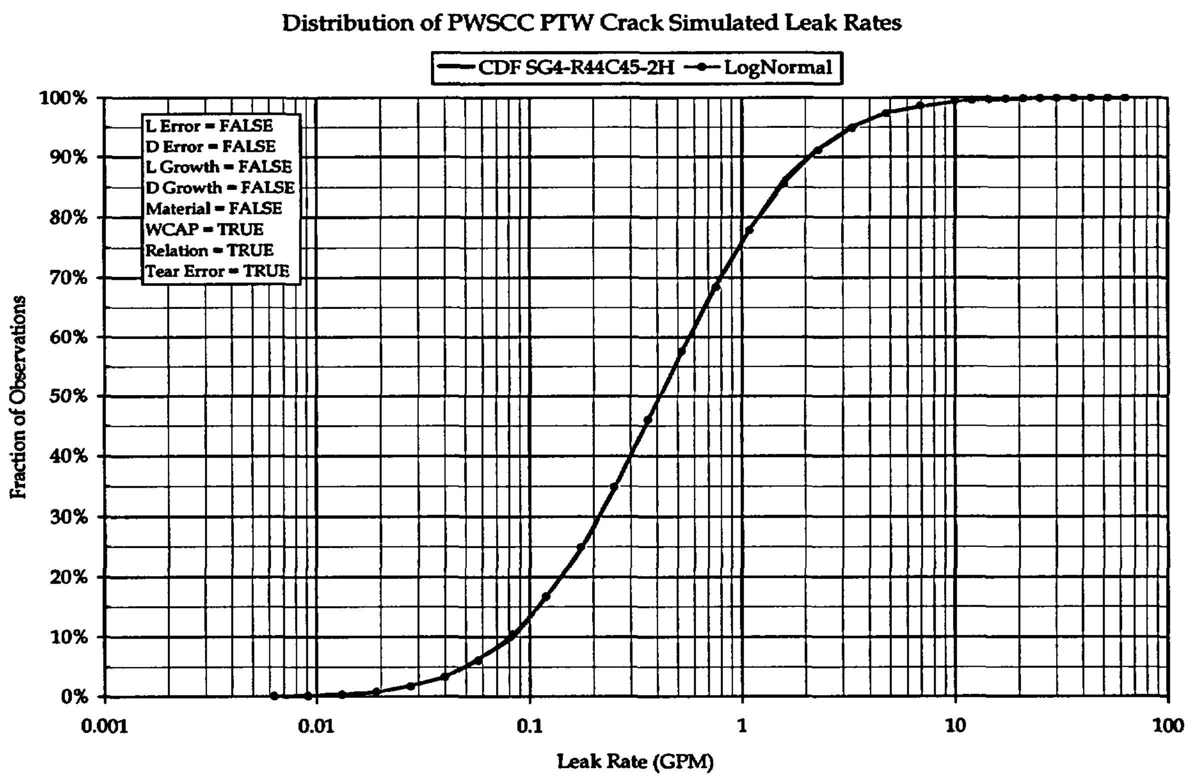


Figure 14: Distribution of R44C45 Leak Rates

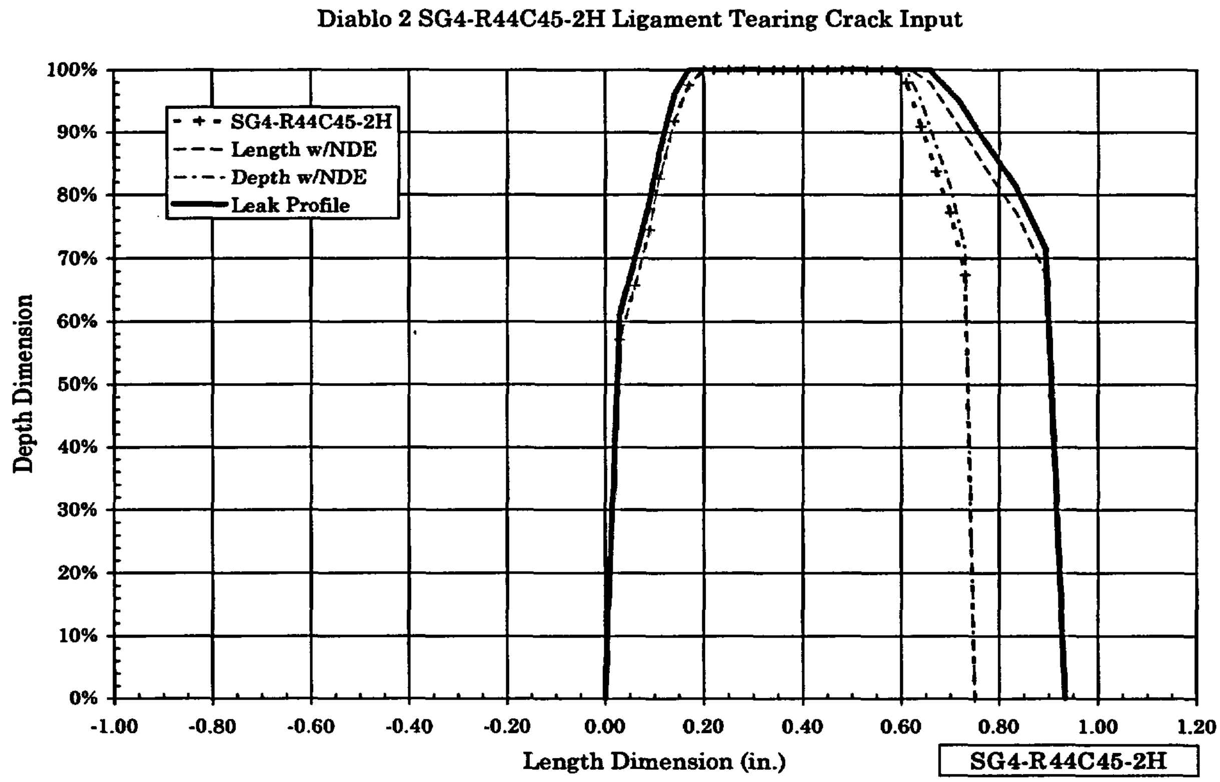


Figure 15: Sample Simulated R44C45 Profile

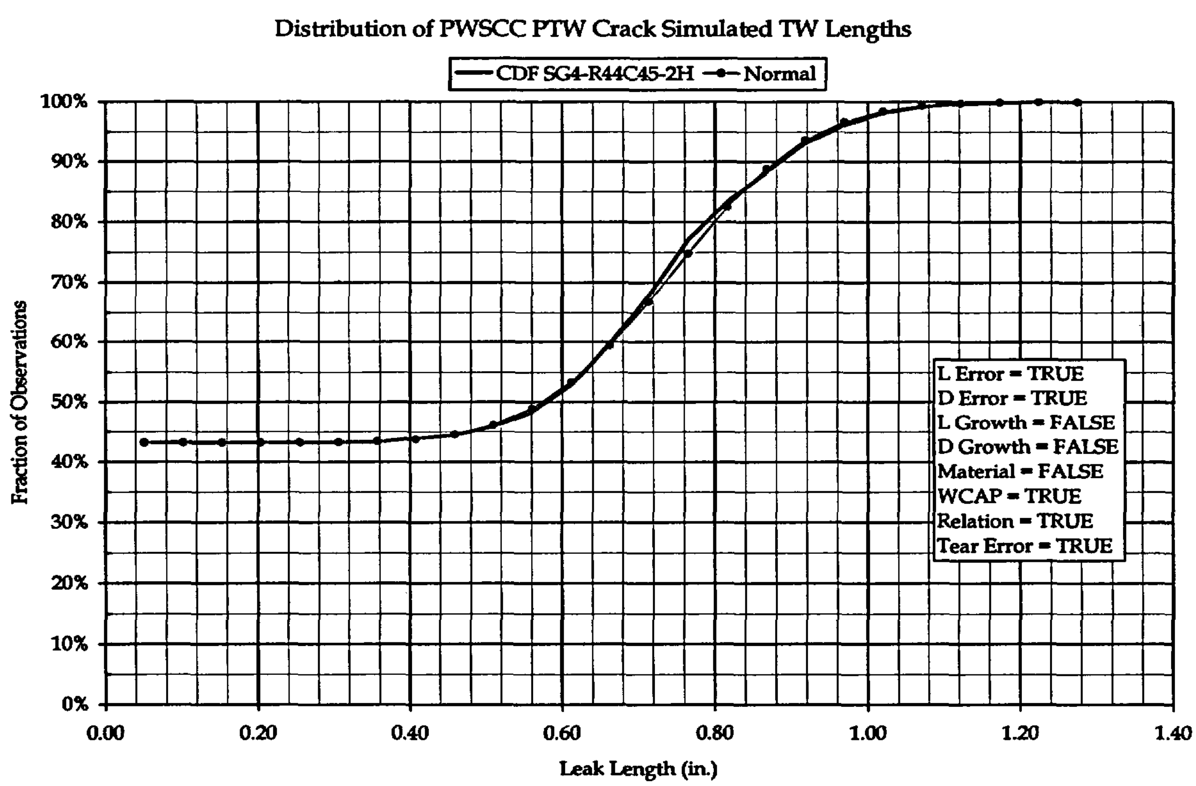


Figure 16: NDE Profile Distribution of R44C45 Torn Lengths

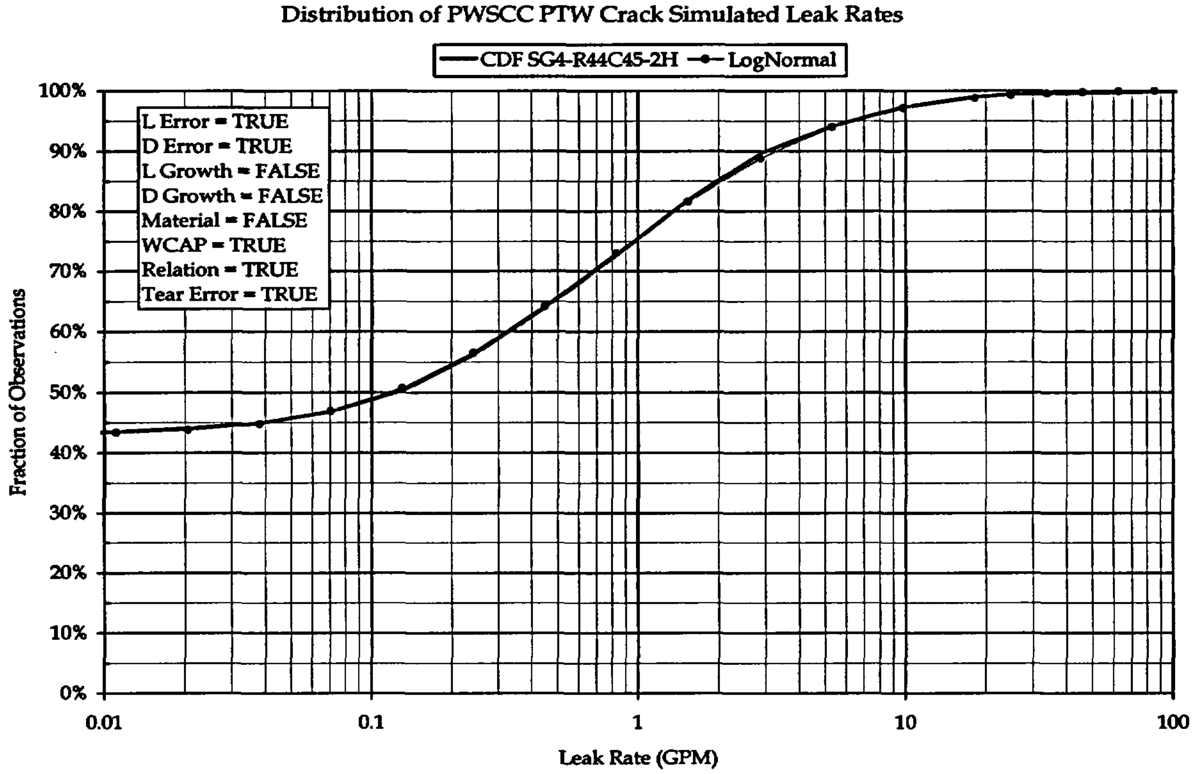


Figure 17: NDE Profile Distribution of R44C45 Leak Rates

SPECIAL REPORT 03-02

STEAM GENERATOR CONDITION MONITORING AND OPERATIONAL ASSESSMENT REPORT DIABLO CANYON POWER PLANT UNIT 2 ELEVENTH REFUELING OUTAGE

1.0 Summary

During the Unit 2 eleventh refueling outage (2R11), greater than 1 percent of inspected tubes in steam generator (SG) 2-4 were defective and required plugging. If greater than 1 percent of inspected tubes in any SG exceed the repair criteria, Nuclear Energy Institute (NEI) 97-06, Revision 1, requires that a Condition Monitoring (CM) report be submitted to the NRC within 120 days after returning the SG to service. This report provides a SG tube CM assessment for Unit 2 Cycle 11 based on 2R11 tube inspection results. For information, this report also provides an Operational Assessment (OA) for Unit 2 Cycle 12 based on the 2R11 tube inspection results.

For degradation subject to alternate repair criteria (ARC), PG&E follows the tube integrity assessment requirements of Diablo Canyon Power Plant (DCPP) technical specifications (TS) and NRC-approved licensing bases. The W* ARC report, PWSCC ARC report, and voltage-based ARC report are provided in separate enclosures in this letter. For all other degradation, PG&E follows the tube integrity assessment guidance provided in Electric Power Research Institute (EPRI) Report TR-107621, "Steam Generator Integrity Assessment Guidelines," Revision 1, dated March 2000.

Condition Monitoring

NEI 97-06, Revision 1, structural and leakage performance criteria for condition monitoring were satisfied at the end of Unit 2 Cycle 11 (EOC 11). This conclusion is based on assessing the 2R11 as-found conditions of the tubing on a degradation-specific basis. Unit 2 Cycle 11 had an actual duration of 1.64 effective full power years (EFPY). Probabilistic structural criteria applied in voltage-based repair criteria are defined in GL 95-05, not in NEI 97-06.

- Structural integrity performance criteria: $3\Delta P_{NO}$ and $1.4\Delta P_{SLB}$ are the burst margin requirements for free span degradation and degradation confined to the tube support plate (TSP) crevice, respectively. Structural integrity performance criteria were satisfied at EOC 11. Voltage-based repair criteria probability of burst (POB) for EOC 11 was less than the GL 95-05 1% reporting threshold, as described in a separate enclosure, and structural integrity for axial ODSCC at TSPs was satisfied at EOC 11.

- Accident-induced leakage performance criteria: Accident-induced leakage assessments are based on the steam line break (SLB) differential pressure.

- For degradation subject to ARC, the maximum allowable SLB induced leak rate limit is 10.5 gpm in a faulted SG, based on an analysis which uses current licensing basis assumptions and approved by the NRC. As described in Enclosure 1, the aggregate EOC 11 SLB leak rate from ARC degradation (PWSCC ARC, W* ARC, GL 95-05 voltage-based ARC) and non-ARC degradation in the limiting SG 2-4 is 3.614 gpm. This leak rate is less than the 10.5 gpm acceptance limit. Therefore, accident-induced leakage integrity performance criteria for ARC were satisfied at EOC 11.

- For degradation not subject to ARC, the maximum allowable SLB-induced leak rate is 1 gpm in a faulted SG per NEI 97-06. The DCPP-specific non-ARC SLB-induced leak rate limit is 0.72 gpm at room temperature. With the exception of SG 2-4, there is no EOC 11 SLB leakage attributed to any non-ARC degradation. For SG 2-4, in situ leak testing of U-bend circumferential PWSCC indications in R5C62 identified a ΔP_{SLB} (2405 psi) leak rate of 0.003 gpm at room temperature, which is much less than 0.72 gpm. Therefore, accident-induced leakage integrity performance criteria for non-ARC were satisfied at EOC 11.

- Operational leakage performance criterion: Primary-to-secondary leakage through any one SG must be limited to 150 gallons per day (gpd). This limit is reflected in DCPP TS. A small leak was detected in Unit 2 Cycle 11, peaking at about 8 gpd, which is well below the 150 gpd limit. Therefore, the operational leakage performance criterion was satisfied at EOC 11. The leak was initially detected very late in Unit 2 Cycle 9 and continued in cycles 10 and 11. The cycle 10 leak rate ranged from 1 to 2 gpd. The leak rate exceeded 5 gpd in cycle 11 in May 2002, resulting in increased monitoring in accordance with the EPRI primary to secondary leak guidelines. SG 2-4 was determined to be the highest contributor to leakage based on steam generator blowdown sampling. As discussed in this enclosure, this primary to secondary leakage is attributed to throughwall indications in SG tubes due to stress corrosion cracking. SG tube plugging performed in 2R11 has significantly reduced the primary to secondary leakage in Unit 2 Cycle 12, measured as 0.25 gpd.

Operational Assessment

NEI 97-06, Revision 1, structural and leakage performance criteria for condition monitoring are projected to be satisfied at the end of Unit 2 Cycle 12 (EOC 12). This conclusion is based on assessing the projected EOC 12 conditions of the tubing on a degradation-specific basis. Unit 2 Cycle 12 has a projected duration of 1.54 EFPY. Probabilistic structural criteria applied in voltage-based repair criteria are defined in GL 95-05, not in NEI 97-06.

- Structural integrity performance criteria: $3\Delta P_{NO}$ and $1.4\Delta P_{SLB}$ are the burst margin requirements for free span degradation and degradation confined to the TSP crevice, respectively. Structural integrity performance criteria were satisfied at EOC

12. Voltage-based repair criteria POB for EOC 12 is projected to be less than the 1% reporting threshold in GL 95-05, as described in a separate enclosure, when applying POPCD and voltage dependent growth methods. Application of POPCD is pending NRC approval.

- Accident-induced leakage performance criteria: Accident-induced leakage assessments are based on the steam line break (SLB) differential pressure.

    - For degradation subject to ARC, the maximum allowable SLB induced leak rate limit is 10.5 gpm in a faulted SG, based on an analysis which uses current licensing basis assumptions and approved by the NRC. As described in Enclosure 1, the aggregate EOC 12 SLB leak rate from ARC degradation (PWSCC ARC, W* ARC, GL 95-05 voltage-based ARC) and non-ARC degradation in the limiting SG 2-4 is 3.319 gpm (based on voltage-based ARC application of POPCD and voltage dependent growth), and 10.089 gpm (based on worst case SLB leakage from voltage based ARC (application of 1.0 POD for SG 2-4 R44C45 2H and 0.6 POD for other indications plus voltage dependent growth). These leak rates are less than the 10.5 gpm acceptance limit.

    - For degradation not subject to ARC, the maximum allowable SLB-induced leak rate is 1 gpm in a faulted SG per NEI 97-06. The DCPP-specific non-ARC SLB-induced leak rate limit is 0.72 gpm at room temperature. No non-ARC accident-induced leakage is postulated at EOC 12. Therefore, accident-induced leakage integrity performance criteria is satisfied at EOC 11.

2.0 Introduction

Steam Generator Background

DCPP Units 1 and 2 use Westinghouse Model 51 SGs with explosively expanded (WEXTEX) transitions. The SGs contain Alloy 600 Mill Annealed (MA) tubing. The nominal outside diameter of the tubing is 0.875 inch with a 0.050-inch nominal wall thickness. The DCPP Unit 1 and 2 SGs have historically operated with a nominal hot leg temperature (T_{hot}) of 603 degrees F. Starting with Cycle 11, Unit 1 has operated at a nominal T_{hot} of 604 degrees F due to an uprate. Unit 2 continues to operate with a nominal T_{hot} of 603 degrees F. The commercial operation dates for Units 1 and 2 are May 1985 and March 1986, respectively.

Starting with DCPP Unit 2 Cycle 8 and Unit 1 Cycle 9, the cycle lengths were extended to nominal 20-month operation. Prior to that time, the units operated on 18-month fuel cycles.

PG&E has implemented several initiatives to minimize primary water stress corrosion cracking (PWSCC) and outside diameter stress corrosion cracking (ODSCC). Primary side initiatives include U-bend heat treatment, WEXTEX tubesheet shotpeening, and

zinc injection. Secondary chemistry initiatives include: copper removal program; ethanol amine (ETA) to control pH; increased hydrazine levels; molar ratio control program to prevent excess alkalinity; boric acid addition program (including boric acid soaks at startup to mitigate denting and ODSCC at TSPs); tube sheet sludge lancing every outage; SG blowdown is maintained at 1 percent of the main steam flow rate; condensate polishers were installed and emergency (plant curtailment) procedures issued to protect against seawater condenser tube leaks.

Technical Specification Repair Criteria

DCPP TS require plugging of any tube that has degradation greater than or equal to 40 percent of the nominal tube wall thickness, unless ARC are implemented. Several ARC are implemented in DCPP Unit 2:

- In March 1998, the DCPP TS were revised to allow implementation of ARC for ODSCC at TSPs pursuant to NRC Generic Letter (GL) 95-05, "Voltage-Based Repair Criteria for Westinghouse Steam Generator Tubes Affected by Outside Diameter Stress Corrosion Cracking." The ODSCC ARC TS changes were granted by the NRC in LA 124/122 dated March 12, 1998, in response to license amendment request (LAR) 97-03. ODSCC ARC was implemented starting in 2R8 for Unit 2 and 1R9 for Unit 1.

- In February 1999, the DCPP TS were revised to allow implementation of W* ARC for axial PWSCC in the WEXTEX tubesheet region. The W* ARC TS for Cycles 10 and 11 were granted by the NRC in LA 129/127 dated February 19, 1999 (in response to LAR 97-04). The W* ARC TS for Cycles 12 and 13 were granted by the NRC in LA 151 dated April 29, 2002 (in response to LAR 01-03). W* ARC was implemented starting in 2R9 and 1R9.

- In May 2002, the DCPP TS were revised to allow implementation of ARC for axial PWSCC at dented TSPs. The PWSCC ARC TS changes were granted by the NRC in LA 152 dated May 1, 2002 (in response to LAR 00-06 Supplement 3). PWSCC ARC was implemented starting in 2R11 and 1R11. Validated depth sizing of axial PWSCC at dented TSP intersections was previously implemented in 2R9 and 2R10 for Unit 2, and 1R9 and 1R10 for Unit 1, such that axial PWSCC less than the TS limit of 40 percent maximum depth limit was allowed to remain in service.

Other than degradation subject to ARC, all crack-like indications are required to be plugged on detection by a rotating coil probe, regardless of depth measurements. Cold leg thinning and antivibration bar (AVB) wear are sized by bobbin and allowed to remain in service if less than 40 percent.

Degradation Assessment

NEI 97-06, Revision 1, requires completion of a degradation assessment (of both existing and potential degradation mechanisms) prior to each inspection. A degradation assessment, inspection/expansion plan, and tube repair plan were prepared and issued before 2R11. A summary of the inspection plan and actual expansion scope is provided in Table 1. The degradation assessment provides a summary of the EPRI nondestructive examination (NDE) techniques used in 2R11, including detection and sizing capabilities. The SG tube inspection contractor (Framatome ANP) performed a site specific technique qualification to demonstrate that the EPRI techniques are applicable for use at DCPP. The degradation assessment was revised during 2R11 to assess two new DCPP Unit 2 tube degradation mechanisms that were detected in 2R11.

Secondary Side Pressure Testing

As discussed earlier, the Unit 2 primary to secondary leak rate exceeded 5 gpd in cycle 11. SG 2-4 was determined to be the leaking SG. EPRI SG Integrity Assessment Guidelines Revision 1 (EPRI TR-107621-R1), Section 10.2, states that secondary side testing should be considered to identify leaking tubes if the primary to secondary leak rate exceeds 5 gpd. Therefore, 2R11 secondary pressure testing was initially conducted in SG 2-4 to implement this guidance. Eventually, based on the results of the SG 2-4 test, the scope of the secondary side pressure testing was expanded to include all four SGs. The secondary side and steam lines were filled with water to the gagged main steam isolation valves and overpressurized with nitrogen. The pressure was initially held at 200 psi, then increased and held at about 200 psi intervals, until a final pressure of 800 psi was reached. At each pressure, the tubesheet face was scanned and observed for evidence of tube or plug leakage.

Fifteen tubes in SG 2-4 were observed to have leakage (drips) or moisture. Based on this, the pressure testing was expanded to all four SGs. Three tubes and one hot leg plug in SG 2-1 were observed to have leakage or moisture. No leakage or moisture was identified in SG 2-2 or SG 2-3.

Table 5 and Table 6 summarize the results of the secondary side pressure testing in SG 2-4 and SG 2-1, respectively. For the 19 suspect tubes listed, the leak rates are in drips per minute (DPM). All leakage was confined to the hot leg, except for SG 2-4 R5C62, where drips were identified on both hot and cold legs.

For the 18 inservice tubes with suspected leakage, Tables 5 and 6 also provide the 2R11 and prior outage 2R10 eddy current (bobbin and Plus Point) results, and show that 14 of the tubes had large Plus Point voltage indications (greater than 1.6 volts).

One of the suspect tubes in SG 2-1 was plugged and not inservice, so there are no eddy current results. The leaking plug was attributed to cracking in the I-600 plug material. All of the 18 inservice tubes were in situ pressure tested, as described below.

In Situ Pressure Testing Program

EPRI in situ guidelines recommends that in situ pressure testing of certain degradation be conducted to support condition monitoring, as follows:

- Tubes that are determined to have primary to secondary leakage.
- Tubes with new degradation mechanisms not yet observed in the industry.
- Tubes with eddy current indications that exceed leakage and structural screening threshold values that are documented in the degradation assessment. The screening methodology is provided in EPRI Steam Generator In Situ Pressure Test Guidelines (EPRI Final Report TR-107620-R1 dated June 1999). Note: Updated in situ testing voltage threshold values are contained in EPRI draft report 1007904 dated May 6, 2003, Steam Generator In Situ Pressure Test Guidelines, and these voltages are applied in the condition monitoring and operational assessment.
- In situ test screening of PWSCC ARC axial PWSCC indications that extend outside the dented TSP crevice, and W* ARC axial PWSCC indications located in the WEXTEX region, are described in a separate enclosure. In situ test screening of axial ODSCC indications subject to voltage-based ARC is not required, as these indications are confined to the TSP crevice which limits the applicability of the in situ test to SLB conditions (at SLB, the TSPs are assumed to be displaced from the crack indications).

A total of 37 tubes were in situ pressure tested in 2R11. Table 7 identifies the tubes that were tested, degradation mechanism as detected by Plus Point, number of Plus Point indications, Plus point voltage, bobbin voltage, degradation location, the test pressures, and leak rate results.

The 18 inservice tubes that were identified as having potential leakage based on the results of the secondary side pressure tests were in situ pressure tested. 14 of the 18 tubes were confirmed to have leakage during in situ testing, as discussed below.

- SG 2-4 R5C62 with multiple free span circumferential PWSCC indications in the U-bend region was in situ pressure tested to NOP, ΔP_{SLB}, and $3\Delta P_{NO}$. SLB leakage of 0.004 gpm was measured at room temperature. At $3\Delta P_{NO}$, no burst occurred and a room temperature leak rate of 0.0456 gpm was measured.
- There were 13 tubes with large voltage TSP axial ODSCC indications (voltage-based ARC indications), 10 in SG 2-4 and 3 in SG 2-1. In situ testing was conducted at NOP and ΔP_{SLB}, with one exception: SG 2-4 R44C45 was only tested at NOP to prevent possible tearing of ligaments, as this tube was planned to be pulled for destructive examination. In situ leakage was measured in all 13 tubes. The maximum NOP leakage at room temperature was 0.004 gpm in R44C45. In

situ test results for axial ODSCC at TSPs are not applicable in voltage-based ARC, so these test results are for information only. The in situ leakage was limited due to the packed TSP crevice condition.

- SG 2-4 R2C29 axial PWSCC indication in the tubesheet (W* ARC indication) was in situ pressure tested to NOP, ΔP_{SLB}, and $3\Delta P_{NO}$. No leakage was detected.

- The two tubes with no detectable degradation by eddy current examination, plus a tube with a very shallow TSP axial ODSCC indication (SG 2-4 R3C29), were in situ pressure tested to $3\Delta P_{NO}$. No leakage was measured in these three tubes at NOP, ΔP_{SLB}, and $3\Delta P_{NO}$.

An additional 19 tubes were in situ pressure tested at NOP, ΔP_{SLB}, and $3\Delta P_{NO}$, because of free span degradation detected by Plus Point as described below. No in situ test leakage was measured in any of these 19 tubes:

- 11 tubes with circumferential PWSCC in Rows 3 through 10 U-bend region (new degradation mechanism). No leakage was measured.

- 1 tube with axial PWSCC in Row 1 U-bend region (known degradation mechanism). No leakage was measured.

- 2 tubes with circumferential PWSCC in Row 1 U-bend region (known degradation mechanism). No leakage was measured.

- 5 tubes with volumetric indications caused by sludge lance damage (new degradation mechanism). No leakage was measured.

In conclusion, one free span indication (SG 2-4 R5C62) had slight leakage at ΔP_{SLB} pressure. No other free span indications had in situ leakage. It is believed that the SG 2-4 operational leakage was mainly attributed to the R5C62 free span indication. It is also possible that leakage from the 13 tubes with TSP axial ODSCC could have contributed slightly to the Unit 2 Cycle 11 operational leakage, although the packed crevices would tend to prevent leakage at hot conditions.

Further degradation-specific condition monitoring and operational assessments are provided in later sections. All tubes that were in situ pressure tested were plugged.

Tube Pulls

In support of continued implementation of voltage-based ARC for axial ODSCC at TSPs, EPRI report NP-7480-L, Addendum 5 requires that a pulled tube specimen (minimum of two intersections) be obtained at the refueling outage following accumulation of three operating cycles from the previous tube pull. The previous

(initial) Unit 2 tube pull for axial ODSCC at TSPs was performed in 2R8. Therefore, a tube pull for axial ODSCC at TSPs was scheduled for 2R11. The primary emphasis for selecting an intersection for removal should be an indication that satisfies an open target indication voltage.

EPRI report NP-7480-L, Addendum 5, also recommends a tube pull for an indication with unanticipated voltage levels substantially higher than the bobbin voltage structural limit, if the destructive exam results are likely to determine whether or not condition monitoring or operational assessment results would satisfy acceptance limits.

In 2R11, several large ODSCC voltage indications were identified that could have filled an open target indication voltage. In addition, one indication (SG 2-4 R44C45 2H) had an unanticipated voltage level (21.5 bobbin volts) substantially higher than the approximately 9 volt structural limit. Therefore, two tubes were pulled with axial ODSCC indications at 2H intersection and NDD at 1H: SG 2-4 R44C45 2H (21.5 bobbin volts) and SG 2-4 R35C57 (5.09 bobbin volts). The destructive examination results are provided in a separate enclosure. Results of the laboratory leak and burst tests demonstrated burst margin greater than the deterministic 1.4 ΔP_{SLB} acceptance limit for both intersections, although this degradation is addressed in a probabilistic manner per GL 95-05.

Tube Repairs

Following eddy current inspections, 340 active tubes were plugged. Framatome alloy 690 roll plugs were used in both legs, with the exception of the two tubes that were pulled. The hot legs of the two tubes that were pulled were plugged with Framatome alloy 690 weld plugs. Table 2 provides the 2R11 plugging breakdown for each SG and reasons for plugging.

Framatome tubesheet stabilizers were installed in 5 tubes that contained circumferential defects at the top of tubesheet or at TSP 1H. These locations are described in Table 8.

The plug in plugs (PIPs) in six hot leg I-600 plugs were removed in 2R11. Framatome ally 690 weld plugs were installed in their place. This activity is discussed later.

2R11 Damage Mechanisms

Tables 2, 3, and 4 provide the number of SG tubes plugged in 2R11 and historical tubes plugged in Unit 2.

The following degradation mechanisms were detected in 2R11 and are assessed for SG tube integrity in this report. New degradation mechanisms are noted as "new".

- Axial PWSCC in hot leg WEXTEX tubesheet region (W* ARC).

- Axial PWSCC at hot leg dented TSP intersections (PWSCC ARC).
- Axial ODSCC at hot leg TSP intersections (Voltage-based ARC).
- Axial and Circumferential PWSCC in Row 1 U-bends.
- Circumferential PWSCC in Rows 3 through 10 U-bends (New).
- Circumferential PWSCC and ODSCC at hot leg dented TSP intersections.
- Combined axial ODSCC and axial PWSCC at hot leg TSP intersections (ID/OD).
- Circumferential ODSCC in hot leg WEXTEX top of tubesheet region (New).
- Volumetric indications in free span due to mechanical damage caused by sludge lancing equipment (new)
- Cold leg thinning at cold leg TSP intersections.
- AVB wear in U-bend region.
- TSP ligament thinning.
- Stress Corrosion Cracking in I-600 mechanical plugs.

This report also provides inspection results of the following potential degradation mechanisms that were not detected in 2R11.

- Potential stress corrosion cracking at free span dings.
- Potential tube damage due to loose parts and foreign objects.

14 tubes were plugged preventively in 2R11 for reasons discussed below, and CM OA is not required.

- 6 Row 1 tubes were preventively plugged due to excessive probe noise in the U-bend region.
- 3 Row 1 tubes and 1 Row 2 tube were plugged due to probe stalls in the U-bend region.
- 4 tubes were plugged due to permeability variability (PVN) concerns, 3 due to PVN in the U-bend region in high row tubes, and 1 due to PVN in the cold leg tubesheet region.

NRC Reporting and NRC Inspection

Technical Specification (TS) 5.5.9, "Steam Generator (SG) Tube Surveillance Program," Table 5.5.9-2, requires that the results of each SG tube inspection be classified as Category C-3 if more than one percent of the total tubes inspected are defective. Results of SG tube inspections that are classified as Category C-3, require NRC notification in accordance with 10 CFR 50.72(b)(2). SG 2-4 was determined to be in Category C-3 following completion of eddy current testing. TS 5.6.10.c requires the results of SG tube inspections, which fall into Category C-3, to be reported in a special report to the Commission within 30 days and prior to resumption of plant operation. "This report shall provide a description of investigations conducted to determine cause of the tube degradation and corrective measures taken to prevent recurrence."

TS 5.6.10.d requires that for implementation of ODSCC ARC, the NRC be notified prior to returning the SG to service if indications are identified that are circumferential, attributable to PWSCC, or the calculated conditional burst probability based on the projected end-of-cycle (or actual measured end-of-cycle) voltage distribution exceeds 0.01.

LER 2-2003-001 dated March 14, 2003, was submitted to the NRC via PG&E letter DCL-03-031 prior to the SGs return to service. The LER reported the above conditions to the NRC based on the 2R11 inspections. On March 4, 2003, PG&E presented to the NRC that the safety significance of exceeding the 0.01 burst probability was low.

An NRC special inspection team visited DCPP during 2R11 in February 2003 due to concerns about the structural and leakage integrity of the SG tubes based on results of the secondary side pressure tests and subsequent eddy current inspections. NRC special team inspection report number 50-323/03-09 provided the NRC inspection results and was transmitted to PG&E in NRC letter dated May 8, 2003. The NRC team identified no findings of significance during the examination.

3.0 Axial PWSCC in WEXTEX Region

Axial PWSCC in the WEXTEX tubesheet region is assessed under W* ARC. Enclosure 1 provides the CM OA for axial PWSCC in the WEXTEX region pursuant to W* ARC requirements.

4.0 Axial PWSCC at Dented TSP Intersections

Axial PWSCC at dented TSP intersections is assessed under PWSCC ARC. Enclosure 2 provides the CM OA for axial PWSCC at dented TSP intersections pursuant to PWSCC ARC requirements.

5.0 Axial ODSCC at TSP Intersections

Axial ODSCC at TSP intersections is assessed under ODSCC ARC. Enclosure 4 provides the CM OA for axial ODSCC at TSP intersections pursuant to GL 95-05 requirements. Enclosure 5 provides the destructive examination report for the two tubes that were pulled in 2R11 that contained TSP axial ODSCC in support of continued implementation of GL 95-05. The results of in situ testing of axial ODSCC at TSP intersections are discussed earlier.

6.0 Axial and Circumferential PWSCC in Row 1 and 2 U-Bends

SG tubes in Rows 1 and 2 U-bends were heat treated following one cycle of operation for Unit 2 and two cycles of operation for Unit 1 to relieve stresses and mitigate the potential for PWSCC in this location. One hundred percent of Rows 1 and 2 U-bends have been inspected each refueling outage. Bobbin probes were used in the first

refueling outage inspection. Since then, these inspections were conducted with a single coil rotating probe. Starting in 2R7 and 1R8, a Plus Point probe was used to inspect Rows 1 and 2 U-bends.

PWSCC has been detected in the U-bend region of Row 1 tubes in all Unit 1 and Unit 2 SGs. The majority of row 1 PWSCC has been axial, with a small number of circumferential. Axial PWSCC has also been detected in Row 2 in SG 1-4 (1R8) and SG 2-3 (2R8). Because of the row 2 indications, 20% Plus Point inspection of row 3 U-bends in SG 2-3 was performed in 2R8 and 2R9, and 20% Plus Point inspection of row 3 U-bends in SG 1-4 was performed 1R8 and 1R9. No PWSCC indications had ever been detected in row 3 or higher U-bends, based on these prior sampling plans.

The initial 2R11 Plus Point inspection scope of short radius U-bends was 100% of Rows 1 and 2 in all SGs, and 20% in Row 3 of SG 2-4.

Three PWSCC indications were detected in row 1 in 2R11: two axial PWSCC indications (SG 2-1 R1C24, SG 2-4 R1C93) and one circumferential PWSCC indication (SG 2-1 R1C43). Table 13 and Table 14 provides the Plus point data for these indications, respectively. These indications were located near the hot leg tangent points.

The maximum voltage of the axial PWSCC indications were 1.15 volts and 1.23 volts with estimated lengths of 0.38 inch and 0.24 inch (phase sizing). Plus Point depth sizing is not quantified for U-bend axial PWSCC; however, Plus Point estimated maximum depths are provided in Table 13. The maximum voltages were very close to the threshold voltage of 1.2 volts (exceeded by 1.23 volt indication in SG 2-4 R1C93) for in situ leak testing documented in EPRI draft report 1007904. As such, these indications were in situ leak and proof tested to ΔP_{SLB} and $3\Delta P_{NO}$ conditions, as described earlier. No leakage was observed from these in situ pressure tests. Therefore, leakage and structural integrity were satisfied at EOC 11 for axial PWSCC indications in Rows 1.

The maximum voltage of the circumferential PWSCC indication was 0.47 volts with estimated length of 15.7 degrees (phase sizing). Plus Point depth sizing is not quantified for U-bend circumferential PWSCC; however, the Plus Point estimated maximum depth is provided in Table 14. The maximum voltage is less than the threshold voltage of 0.5 volts for proof testing (independent of degradation morphology), and much less than the 1.83 volt threshold for in situ leak testing. These threshold values are documented in EPRI draft report 1007904. In addition, the measured length of 15.7 degrees is much less than the Row 1 through 10 100% throughwall structural limit length of 190 degrees which bounds $3\Delta P_{NO}$ conditions (WCAP-15147 draft Revision 2). Nonetheless, this indication was in situ leak and proof tested to ΔP_{SLB} and $3\Delta P_{NO}$ conditions, as described earlier. No leakage was observed from the in situ pressure test. Therefore, leakage and structural integrity were satisfied at EOC 11 for the circumferential PWSCC indication in Row 1.

No leakage was observed from these three in situ pressure tests. Therefore, leakage and structural integrity were satisfied at EOC 11 for these indications.

In light of lessons learned from the Indian Point (IP2) U-bend tube failure event, data quality requirements were implemented. If questionable data (e.g., excessive noise) were collected from the 0.680 mid-range (MR) probe, the U-bend was reinspected with a 0.680 high frequency (HF) Plus Point probe. If questionable data were subsequently collected with the 0.680 HF, then the tube was plugged for precautionary measures. This resulted in six Row 1 tubes being preventively plugged in 2R11. Additionally, three Row 1 tubes and one Row 2 tube were plugged due to probe stalls in the U-bend region.

Operational Assessment for PWSCC in Row 1 and Row 2 U-Bends

All three row 1 indications were detectable in the prior outage (2R10) Plus Point data based on a lookup review. The Plus Point lookup sizing is provided in Tables 12 and 13. A comparison of the 2R10 and 2R11 maximum Plus Point voltages show little change, indicating slow growth in depth. Plus Point depth sizing is not quantified for U-bend PWSCC, so differences in maximum depth are not assessed. Differences in flaw length are also negligible.

There is a large database of growth rates for axial PWSCC at dented TSPs, as discussed in Enclosure 2 for PWSCC ARC. For the data set used in the PWSCC ARC cycle 12 operational assessment, the 95 percentile growth rates are approximately 0.07 inch per EFPY for length, 10% per EFPY for maximum depth, and 9% per EFPY for average depth. There is a smaller growth rate database for circumferential PWSCC at dented TSPs. As discussed in Section 8 of this enclosure, the 95 percentile growth rates per EFPY for circumferential PWSCC at dented TSPs is 15 degree, 19% maximum depth, and 14% average depth.

Assuming that an axial PWSCC indication with a 100% throughwall length of 0.38 inch is the largest undetected Row 1 or Row 2 flaw and was left in service at BOC 12 (0.38 inch based on the length of the longest Row 1 axial PWSCC indication detected in 2R11), and adding a growth rate of 0.07 inch per EFPY, the resulting end of cycle 12 indication would be approximately 0.5 inches. This flaw length is less than the bounding Row 2 100% throughwall structural limit length of 0.64 inch for $3\Delta P_{NO}$ conditions, as defined in WCAP-15147 Revision 1, thereby demonstrating that structural integrity is satisfied at EOC conditions. Accounting for NDE uncertainty is not required since the indication is assumed to be throughwall and the length will be overestimated under the throughwall depth assumption due to coil lead-in and lead-out affects.

Assuming that a circumferential PWSCC indication with a 100% throughwall length of 15.7 degrees is the largest undetected Row 1 or Row 2 flaw and was left in service at

BOC 12 (15.7 degrees based on the length of the Row 1 circumferential PWSCC indication detected in 2R11), and adding a growth rate of 15 degree per EFPY, the resulting end of cycle 12 indication would be 39 degrees. This flaw length is much less than the Row 1 and 2 100% throughwall structural limit length of 190 degrees, thereby assuring structural integrity is satisfied at EOC conditions. The large margin between the projected EOC flaw length and the structural limit allows for large NDE uncertainties.

The Plus Point detection threshold for circumferential PWSCC maximum depth is about 35% as reported in section 8 of this enclosure. This detection threshold is assumed to be applicable for axial and circumferential PWSCC in Row 1 and 2 U-bends. Adding 19% per EFPY maximum depth growth over 1.54 EFPY results in an end of cycle maximum depth of 64% for axial and circumferential PWSCC in Row 1 U-bends. Therefore, no leakage should be postulated in a faulted SG following a SLB at EOC 12.

In conclusion, no axial or circumferential PWSCC indications in row 1 and 2 U-bends are expected that would challenge structural integrity performance criteria through EOC 12. In addition, no leakage should be postulated in a faulted SG following a SLB at EOC 12 due to the extremely low probability that indications would tear ligaments and pop through in one cycle.

7.0 Circumferential PWSCC in Row 3 to Row 10 U-Bends

As discussed earlier, the SG 2-4 secondary side pressure test identified a throughwall indication in the U-bend region of SG 2-4 R5C62. Both the hot leg and cold leg of the tube was observed to be leaking. Subsequent Plus Point inspection of the U-bend region of the tube identified 35 circumferential PWSCC indications throughout the bend region. As a result, the Plus Point inspection scope was expanded to the entire U-bend region of 100% of the tubes in all four SGs. This was the first time that the entire U-bend region of every tube had been 100% inspected with rotating coil probe technology. Eleven additional tubes with circumferential PWSCC indications were detected during this inspection, ranging from Row 3 to Row 10, specifically: rows 3, 4, 5, 6, 7, and 10. Each SG had at least one indication. No indications were identified beyond row 10. The bobbin coil was not able to reliably detect the U-bend circumferential indications, as this coil is not qualified for detection of circumferential indications in SG tubing.

Detection of circumferential PWSCC in U-bends beyond row 3 was a first of a kind occurrence in the industry. An operating experience report was issued to the industry. PG&E initiated a root cause assessment team to establish a root cause and develop a root cause report. An information letter was issued to EPRI SGMP to disseminate the circumstances of the event so that other utilities may make informed decisions about their SG programs. A complete eddy current evaluation of the 2R11 circumferential PWSCC indications is provided in Attachment 1 to this enclosure, Framatome ANP Report 51-5024976-00, Evaluation of U-bend Indications From Diablo Canyon Unit 2 Outage 2R11.

Additional probes were used to aid in the root cause investigation, including X-probe, rotating pancake probes, and high frequency Plus Point probe. In addition, video probes were employed in each tube with U-bend indications to try to establish a correlation of eddy current results with actual visual observations. The video probe inspection of the indications confirmed that the indications were circumferential, confined to the flanks, and relatively short. The video probe also confirmed that the deepest SG 2-4 R5C62 indication was 100% through-wall, based on moisture observed around the crack face.

All the indications originated from the ID of the tube, were circumferential but slightly inclined, and located near the flanks (sides) of the tubes. Table 11 identifies the tubes with circumferential PWSCC in rows 3 through 10 U-bends, and number of Plus Point indications in each location. Table 12 provides the Plus Point voltages, depths, and lengths of each indication. The Plus Point probe does not have quantified sizing capability in U-bends, so the depths and lengths are estimates. The R5C62 indications had much higher Plus Point voltages (maximum of 3.04 volt) compared to indications in the other 11 tubes. The Plus Point length of the deepest (3.04 volt) indication in R5C62 was measured as 127 degrees from null to null. The maximum length of the indications in the other 11 tubes was 39 degrees. The length of the deepest indications in R5C62 are considered to be overestimated due to lead-in and lead-out affect of the Plus Point coil for an apparent 100% through-wall indication. In addition, as noted above, the video probe inspection of the indications confirmed that they were relatively short. Conservatively assuming that the length of the longest circumferential PWSCC indication was 127 degrees, the length is less than the Rows 1 through 10 100% throughwall structural limit length of 190 degrees for the limiting structural loads which bound $3\Delta P_{NO}$ conditions (WCAP-15147 draft Revision 2). This difference allows for some margin for NDE uncertainty, even though NDE uncertainty margins on length do not appear to be needed in this case due to the expected Plus Point length overestimate for throughwall indications.

The root cause investigation determined that the circumferential PWSCC was caused by residual stresses in the U-bends. PWSCC of mill annealed alloy 600 tubing is a strong function of temperature and stress. Residual stress must be a significant contributor to the total stresses in a U-bend tube for PWSCC to develop. Residual stresses in the U-bends are created as a normal consequence of the cold forming operation (bending process). The magnitude of the residual stress is a function of the degree of plastic straining experienced in cold forming. The forming strains and residual stresses decrease as the U-bend radius increases, thus cracking would be expected first in low row tubes. U-bend residual stress measurements (performed in the late 1970s by Framatome, EdF, and Westinghouse) and finite element analyses confirm that the location of the highest residual tensile in U-bend tubes is on the flanks. The fact that the cracks were deep and of very limited circumferential extent are consistent with stress field predictions from large deformation finite element modeling of bent tubes.

All 12 tubes were in situ leak and proof tested to NOP, ΔP_{SLB} and $3\Delta P_{NO}$ differential pressures. Results of the in situ testing are shown in Table 7, and showed that only SG 2-4 R5C62 had leakage. At 2750 psi, the room temperature leak rate was 0.004 gpm. Conversion of this leak rate to the DCPP 2405 psi ΔP_{SLB} differential pressure results in a room temperature leak rate of 0.003 gpm, much less than 0.72 gpm allowable limit. At $3\Delta P_{NO}$, no burst occurred and a room temperature leak rate of 0.0456 gpm was measured. Therefore, structural and leakage margins were maintained at EOC 11 for the worst case circumferential PWSCC indications in R5C62 and circumferential PWSCC indications detected in rows 3 through 10 U-bends.

Operational Assessment

The $3\Delta P_{NO}$ structural limit for 100% throughwall circumferential cracking is about 264 degrees, or 73 percent degraded area (PDA), not accounting for NDE uncertainty, per WCAP-15147 Revision 1.

The growth rate of circumferential PWSCC in rows 3 through 10 cannot be quantified because there is no back-to-back Plus Point data for these indications. However, as described in Attachment 1, even though the bobbin coil cannot reliably detect circumferential indications, a historical bobbin data lookup review of prior inspections was performed for each of the 12 tubes with U-bend indications. The bobbin data lookup was conducted knowing the exact flaw locations based on 2R11 Plus Point inspections. With the exception of the largest Plus Point indication in SG 2-4 R5C62, the historical bobbin data review could not identify any of the indications in history. For R5C62, the bobbin review identified indications as far back as 1996. This indicates that the indications had slow growth. Moreover, the analytical and test information indicates that cracks should remain short, i.e., once away from the flanks of the tube, the residual stresses become compressive and crack growth in the hoop direction would be expected to stop.

There is a large database of growth rates for axial PWSCC at dented TSPs, as discussed in Enclosure 2 for PWSCC ARC. For the conservative data set used in the PWSCC ARC cycle 12 operational assessment, the 95 percentile growth rates per EFPY are bounded by 0.09 inch for length, 18% for maximum depth, and 15% per EFPY for average depth. There is a smaller growth rate database for circumferential PWSCC at dented TSPs. As discussed in Section 8 of this enclosure, the 95 percentile growth rates per EFPY for circumferential PWSCC at dented TSPs are 15 degree, 19% maximum depth, and 14% average depth. These numbers are essentially the same as axial PWSCC at dents, and are therefore used in the operational assessment for circumferential PWSCC in U-bends. Considering that bobbin indications in R5C62 could be traced to 1996, and that Unit 2 has accumulated 6 EFPY since 1996, a circumferential PWSCC indication at 2R11 would have to be at least 90 degrees after applying a growth rate of 15 degree per EFPY. This length is longer than visually observed in 2R11, and thus the growth rate represents a conservative upper bound

prediction, even though growth in the hoop direction would be expected to stop as discussed above.

The assumed detection threshold for circumferential PWSCC in Rows 3 and higher is 39 degrees (the maximum length of the 2R11 indications, excluding R5C62). Adding 23 degrees growth (corresponding to a cycle length of 1.54 EFPY) to the detection threshold results in a projected EOC 12 circumferential PWSCC indication of 62 degrees. This length is much less than the 190 degree structural limit, thus allowing large margins for NDE length measurement uncertainty. In addition, the axial stress field in the flanks of the U-bends is very limited in circumferential extent, which is consistent with the short flaw lengths found for previously uninspected tubes. Consequently, the potential circumferential extent is much less than the structural limit. Therefore, structural margins would be maintained at EOC 12.

The possibility of circumferential PWSCC in Rows 11 and higher U-bends at EOC 12 is unlikely, given the 100% Plus Point inspection performed in 2R11 with no detected indications, and the decreasing residual stresses in higher rows. The structural limit for circumferential PWSCC in Rows 11 and higher U-bends would be less than that for Row 1 through 10 U-bends. Nonetheless, based on the low probability of indications in higher rows, the limited circumferential involvement expected based on U-bend stress considerations and the large margins identified for indications in lower rows, there would be large structural margins for postulated EOC 12 indications in Rows 11 and higher.

Because Plus Point inspections were performed in 100% of the U-bends and secondary side pressure testing was performed in all SGs to assist in identification of throughwall indications, it is reasonable to assume that all 100% throughwall U-bend indications were detected and plugged. The Plus Point detection threshold for circumferential PWSCC maximum depth is about 35% as reported in section 8 of this enclosure. Adding 19% per EFPY maximum depth growth over 1.54 EFPY results in an end of cycle maximum depth of 64%. Therefore, leakage integrity would be maintained for cycle 12.

In conclusion, no circumferential PWSCC indications in U-bends are expected that would challenge structural integrity performance criteria through EOC 12. In addition, no leakage should be postulated in a faulted SG following a SLB at EOC 12 due to the extremely low probability that indications would tear ligaments and pop through in one cycle. This conclusion is validated based on the results of in situ pressure testing results of the worst case throughwall indication in R5C62, which demonstrated structural integrity at $3\Delta P_{NO}$ conditions and significant SLB leakage margin compared to the performance criteria limit.

8.0 Circumferential PWSCC and ODSCC at Dented TSP Intersections

Six circumferential PWSCC indications and one circumferential ODSCC indication were detected by Plus Point at > 2 volt dented hot leg TSP intersections, as listed in Table 8. All the circumferential indications (SCI) were plugged. The smallest dent voltage at which circumferential cracking was detected in 2R11 was 6.7 volts.

The SCI were sized using the technique described in Appendix B of WCAP-15573, Revision 1. The depth profiles were then processed for corrections in accordance with the depth adjustment rules in Section 4.10.4 of WCAP-15573, Revision 1. The adjusted NDE results were corrected for 95 percentile NDE uncertainty using the NDE uncertainty regression parameters in Tables 4-19 to 4-21 in WCAP-15573, Revision 1. The adjusted NDE and adjusted NDE with uncertainty results are listed in Table 7.

The $3\Delta P_{NO}$ structural limit for a SCI is about 264 degrees, assuming a 100% throughwall defect. The longest NDE lengths were 52.5 degrees for PWSCC and 35.6 degrees for ODSCC, and are adjusted to 106.9 degrees and 175.2 degrees after applying large 95 percentile NDE uncertainties. These lengths are less than the 264 degree structural limit. Therefore, structural integrity was satisfied at EOC 11.

The Plus Point voltage of the 2R11 TSP circumferential ODSCC indication was 0.15 volts, much less than the 1.31 volt threshold for leak testing of circumferential ODSCC indications at explosive expansions (approximately equivalent to a dented TSP) documented in EPRI draft report 1007904. The largest Plus Point voltage of the 2R11 TSP circumferential PWSCC indications was 0.54 volts, much less than the 1.25 volt threshold for leak testing of circumferential PWSCC indications in explosive transitions (approximately equivalent to a dented TSP) documented in EPRI draft report 1007904. In addition, the largest NDE maximum depths were 68.7 percent for ODSCC and 78 percent for PWSCC, including 95 percent NDE uncertainty. Based on these NDE measurements, the circumferential indications were shallow and no SLB leakage should be postulated for these indications at EOC 11.

Per WCAP-15573, Revision 1, Section 4.13, the largest projected EOC average depths are 54 percent for PWSCC and 64 percent for ODSCC. The largest average depths detected in 2R11 were 34.7 percent for PWSCC and 34.4 percent for ODSCC with no NDE uncertainty added, and 49.4 percent and 53 percent with 95 percent NDE uncertainty. Thus, the projected EOC indications bound the largest indications found in 2R11.

Operational Assessment

The six TSP intersections containing circumferential PWSCC and the one TSP intersections containing circumferential ODSCC were also inspected by Plus Point in 2R10 and were detectable in 2R10 data based on a lookup. The growth rates were very small. Adding these data points to the existing data points from WCAP-15573 Revision 1 and from 1R11 results in the following growth rates:

Post-2R11 95% Probability Growth Rates per EFPY for TSP Circumferential Cracking
Kunin Minima Distribution

	PWSCC	ODSCC
Average Depth	14%	9%
Maximum Depth	19%	17%
Length	15 deg	27 deg
Number of DCPP data points	24	9

The limited data would indicate that PWSCC depth growth rates are larger than ODSCC. However, due to the small population of ODSCC growth data points, the ODSCC growth is conservatively assumed to be the same as PWSCC.

The AD growth data at 95% cumulative probability can be combined with the estimated detection thresholds derived from destructive examination (no NDE uncertainty is necessary) to obtain a deterministic projection of expected EOC 12 average depths. Based on the 2R10 lookup, the average depth of the TSP ODSCC circumferential indication was 25%, which is less than the 35% AD detection threshold estimated for ODSCC. Based on the 2R10 lookup, the mean average depth for TSP PWSCC circumferential indications not detected at 2R10 was 31%, which is slightly larger than the 25% AD detection threshold estimated for PWSCC. Therefore, the AD detection threshold for PWSCC is assumed to be 31%.

The projected EOC 12 average depths are given in the following table, and are greater than or equal to the largest indications found to date.

Average Depth Comparison of EOC Projected TSP Circumferential Indications with Largest Measured Indications

	PWSCC	ODSCC
Detection threshold for Average Depth	31%	35%
+95% AD growth over 1.54 EFPY cycle	22%	22%
Projected EOC 12 Average Depth	53%	57%
Largest Average Depth found to date	49%	57%

From the above table, the deepest projected EOC 12 circumferential indication at a dented TSP is 57% average depth. Assuming that this flaw is 57% average depth over 360 degrees results in a very conservative EOC 12 projection of 57 percent degraded area (PDA). This conservative projection is less than the circumferential indication structural limit of 73 PDA, provided in WCAP-15147 Revision 1, "Regulatory Guide 1.121 Analysis for Diablo Canyon Units 1 and 2 to Define Structural Limits for Various Modes of Degradation." Since the largest circumferential crack angle found at 2R11 was 175 degrees including adjustment for angle uncertainty at 95% probability, the assumption that the projected EOC 12 indication is 360 degrees is extremely conservative.

Similar to above, the maximum depth (MD) growth data at 95% cumulative probability can be combined with the estimated detection thresholds derived from destructive examination (no NDE uncertainty is necessary) to obtain a deterministic projection of expected EOC 12 maximum depths. Based on the 2R10 lookup, the maximum depth of the TSP ODSCC circumferential indication was 40%, which is less than the 45% MD detection threshold estimated for ODSCC. Based on the 2R10 lookup, the mean maximum depth for TSP PWSCC circumferential indications not detected at 2R10 was 45%, which is slightly larger than the 35% MD detection threshold estimated for PWSCC. Therefore, the AD detection threshold for PWSCC is assumed to be 45%.

The projected EOC 12 maximum depths are given in the following table, and bound the largest indications found to date.

Maximum Depth Comparison of EOC Projected TSP Circumferential Indications with Largest Measured Indications

	PWSCC	ODSCC
Detection threshold for Maximum Depth	45%	45%
+95% MD growth over 1.54 EFPY cycle	29%	29%
Projected EOC 12 Maximum Depth	74%	74%
Largest Maximum Depth found to date	68%	72%

The projected EOC 12 maximum depth of 74% presents no challenge to SLB leakage integrity.

Based on the comprehensive inspection of dented TSP intersections during 2R11, the slow rate of circumferential degradation growth, acceptably low detection threshold, the limited maximum angular extent associated with circumferential cracks, and large structural margin associated with circumferential indications, no TSP circumferential indications are expected that would challenge structural performance criteria at EOC 12. Since the largest projected maximum depth is not near throughwall, it is also unlikely that TSP circumferential indications will tear ligaments and pop through over the next cycle. Therefore, no leakage is postulated in a faulted SG following a SLB at EOC 12.

9.0 Combined Axial PWSCC and Axial ODSCC at Dented TSP Intersections

Seven tubes contained axial PWSCC and axial ODSCC (ID/OD) indications located at the same dented TSP intersection. These tubes were plugged because this type of flaw combination is excluded from both PWSCC ARC and ODSCC ARC application. Six of these intersections had either ID or OD indications that were left inservice in the prior inspection (2R10): four axial ODSCC indications under ODSCC ARC, and two axial PWSCC indications because they were less than 40 percent maximum depth. The remaining one intersection had no indications of either ID or OD degradation in 2R10 based on 2R10 Plus Point inspection.

PG&E letter to the NRC dated August 22, 2002 (letter DCL-02-098) derived a bounding conservative hoop direction ligament thickness of 0.1 inch (2 times the tube wall thickness of 0.050 inch), such that if this separation distance is met or exceeded, there is no interaction relative to either burst pressure or leak rate.

Based on review of the eddy current data and terrain maps for all 7 ID/OD intersections, the axial PWSCC and axial ODSCC components are separated by hoop direction ligament gaps. The shortest gap is 53 degrees (0.40 inch). This separation distance exceeds the required hoop direction ligament thickness of 0.1 inch. Therefore, the flaws are treated independently for CM, under their respective ARC, for structural and leakage integrity.

Operational Assessment

Extent of Inspection at Dented TSP Intersections

All ID and OD bobbin indications in any size dent were Plus Point inspected. In addition, as discussed in the PWSCC ARC enclosure, Plus Point inspections were performed on 100% of all intersections with greater than or equal to 5 volt dents, and 100% of intersections with greater than 2 volt and less than 5 volt dents up to the highest hot leg TSP with any PWSCC indication and 20% of greater than 2 and less than 5 volt dents at the next highest TSP.

Based on the extent of the inspection and repair of all detected combined ID/OD indications, any potential combined PWSCC and ODSCC indications left in service at dented TSP intersections would have one of the indications below the detection threshold of the +Point coil or both of the ID/OD indications would be new indications. The +Point detection threshold would be expected to be less than 30% and 20% maximum depth for ODSCC and PWSCC indications, respectively. As a consequence of the low detection thresholds and modest crack depth and length growth rates for both axial PWSCC and ODSCC (see PWSCC ARC report and ODSCC ARC report in separate enclosures), deep new indications would not be expected at EOC 12.

Number of Occurrences of Combined Axial PWSCC and ODSCC Indications

As discussed above, a total of 7 tubes were reported in the 2R11 inspection with combined axial PWSCC and axial ODSCC (ID/OD) indications located at the same dented TSP intersection. These tubes were plugged because this type of flaw combination is excluded from both PWSCC ARC and ODSCC ARC application.

All data on combined ID/OD indication through 2R11 are given in Table 10. A total of 82 TSP intersections have been identified with combined ID/OD indications, 9 for Unit 2 and 73 for Unit 1. Of the 82 total intersections, only 32 were found in previously active tubes, while the remainder were detected in tubes that were deplugged and then replugged.

Dependence of Combined Axial PWSCC and ODSCC Indications on Dent Voltage

The vast majority (80 out of 82) of the ID/OD intersections have small dents, less than 5 volts. The two intersections with greater than 5 volt dents were associated with deplugged tubes.

The dominance of axial ODSCC at non-dented TSP intersections or intersections with small dents is expected based upon experience in eddy current examination of > 5 volt dents as part of ODSCC ARC applications. Few indications have been reported in > 5 volt dents under ARC applications for many plants. For DCPP Units 1 and 2, axial ODSCC has been detected in only 12 intersections with >5 volt dents, with the first occurrence in 1R9 and 2R9, and none in 2R11. This number is small when compared to the number of Plus Point inspections of greater than 5 volt dents (e.g., over 400 and 1200 >5 volt dent inspections in 2R11 and 1R11, respectively). The number is also small when compared to the number of ODSCC signals detected in active tubes in 1R11 (1022) and 2R11 (1873). When the intersection is highly dented, corrodents can be expected to have increased difficulty in concentrating within the crevice, and axial ODSCC is very infrequent in large dents. Consequently, the potential occurrence of combined ID/OD indication can be expected to be dominantly limited to dents < 5 volts as supported by DCPP Units 1 and 2 inspection results. This limits the potential population of TSP intersections with significant potential for combined ID/OD indications, and also increases the likelihood of bobbin detection in less than 5 volt dents.

Crack Sizes for Combined Axial PWSCC and ODSCC Indications

The Plus Point sizing of all PWSCC indications at TSP intersections with ODSCC indications are given in Table 10. Table 10 also provides the Plus Point and bobbin voltages for the ODSCC indications. The largest maximum and average depths for the PWSCC indications in previously active tubes at these intersections are shallow, only 45% and 31%, respectively. New PWSCC indications are also small as discussed below. The largest voltages for the ODSCC indications at intersections with PWSCC in active tubes are 4.58 bobbin volts and 2.66 Plus Point volts (2R11 SG 2-2 R22C67). The 4.58 bobbin voltage is well below the ODSCC ARC structural limit of 9.45 volts and would have less than a 50% probability of leaking as a free span indication, per the updated ODSCC ARC correlations in Attachment 1 of Enclosure 4. The other ID/OD indications in Table 10 are small, and it can be expected that all indications found to date at TSP intersections with combined ID/OD cracks have large structural margins and no leakage.

New Indication Crack Sizes and Growth Rates

Since either the PWSCC or ODSCC indication or both indications must be a new indication, new indication crack sizes are of interest for assessing potential interaction

between the ID and OD indications. Both the ID and OD new indications are small. The largest 1R11 and 2R11 maximum and average depths for all new PWSCC indications are 55% and 35%, respectively. The largest of all new ODSCC indications at any TSP intersection has a bobbin coil voltage of 2.3 volt in 2R11 and 1.6 volt in 1R11. The average voltage for new indications is 0.51 volts in 1R11 and 0.45 volts in 2R11. The largest new ODSCC indication at a TSP with ID/OD indications in Table 10 had a bobbin voltage of 1.29 volts and a largest Plus Point voltage of 0.38 volts. The largest new PWSCC indication at a TSP with ID/OD indications in Table 10 had a maximum depth of 45%. Since both the new PWSCC and ODSCC indications are small, the structural influence of a new ID or OD indication interacting with an indication left in service would be small even under the very low likelihood of closely spaced indications.

The PWSCC maximum depth, average depth, and length growth rate distributions from the five prior cycles are provided in a separate enclosure. The 2R11 growth rates are small and bounded by the pre-2R11 cumulative growth distributions used in the PWSCC ARC operational assessment. The 1R11 and 2R11 ODSCC bobbin voltage growth distributions for new indications and prior indications indicate that new indication growth is considerably smaller than growth for prior indications. The upper 95% growth/EFPY for new ODSCC indications is 0.248 volts and 0.237 volts for 1R11 and 2R11, respectively. Based on the modest growth rates for new PWSCC and ODSCC indications, any new indications occurring to obtain combined ID and OD flaws at the same intersection would continue to be small indications.

Separation Distances Between Axial PWSCC and ODSCC Indications

Based on review of the eddy current data and terrain maps for DCPP Units 1 and 2 intersections with combined ID/OD indications, the axial PWSCC and axial ODSCC components are separated by hoop direction ligament gaps in excess of 30° (0.23"). The angles separating the PWSCC and ODSCC indications are given in Table 10. The lowest separation angle found in DCPP Units 1 and 2 is 34° (0.26"), found at 1R11. The separation angles between axial PWSCC and ODSCC indication are predominantly in the 40° to 90° range. This range of separation angles can be expected based upon the separation distances between the locations of maximum hoop stress on the tube ID and OD at dented TSP intersections as discussed below.

Figure 1 shows the UT circumferential dent profile for DCPP Unit 1 1R7 pulled tube R12C32-1H, which had a dent voltage of 1.1 volts. The UT profile indicates a maximum dent indentation of about 7.3 mils, which is large for a 1.1 volt dent. The maximum OD hoop stress resulting from the local dent deformation would occur at the point of maximum OD curvature. From Figure 1, this occurs at about 45° to 50° (absolute angle of about 265° in Figure 1) from the centerline of the PWSCC crack. Other UT profiles from Diablo Canyon pulled tubes show similar dent shapes and angles between the PWSCC crack and maximum OD curvature ranging from about 40° to 90° where the larger value occurred for pulled tube R10C22-2H (Figure 2). For

R10C22, the major diameter (5.9 mil diameter increase) of the strongly ovalized tube had the greatest OD curvature. For R21C43 as shown in Figure 3, the location of maximum OD curvature is about 70° left of vertical (between absolute angles of 150° and 180°) from the upper axial crack near 90°. The DCPP Units 1 and 2 PWSCC to ODSCC crack separation angles are consistent with the expected range of crack separation based on the Diablo Canyon dent profiles. The DCPP crack separation distances and the expected distances based on the dent profiles exceed the required hoop direction ligament thickness of 0.1 inch. Therefore, the DCPP ID/OD flaws can be evaluated independently for burst and structural integrity under their respective ARCs. Further development of this conclusion is provided in the following sections.

Contributing Causes for Axial PWSCC at Dented PWSCC Indications

Axial PWSCC is found at one or two locations at dented TSP intersections. When two cracks occur, the cracks are separated by about 180° (Figure 3) and occur at the minor axis of the ovalized tube such as for the dent shapes of Figures 1 to 3. At the minor axis, the ID hoop stresses are the largest and the crack locations are consistent with the maximum ID hoop stress locations as also shown in the figures. The typical dent has a local deformation superimposed on the ovalized tube as seen in the figures. The PWSCC indications are dominantly within the TSP although a few occurrences of cracks outside the TSP are found in the inspections and can be reasonably expected when significant ovalization extends to the axial length outside the TSP.

Contributing Causes for Axial ODSCC at Dented PWSCC Indications

Axial ODSCC cracks can occur at dented TSP intersections as a result of increased OD hoop stresses from the dent or from corrodents within the crevice with or without a dent. The latter is the source of OD corrosion at non-dented TSP intersections. When the intersection is highly dented, corrodents can be expected to have increased difficulty in concentrating within the crevice, and axial ODSCC is very infrequent in large dents. The latter conclusion is supported by ODSCC ARC testing in > 5 volt dents where few indications are found, and by the lack of significant ODSCC cracking within the TSP crevices in highly dented SGs, such as the replaced North Anna and Indian Point SGs.

Axial ODSCC caused by dent deformation would be circumferentially separated from the axial PWSCC cracks due to the differences in locations of the maximum ID hoop stress at the minor axis of ovalized dent shapes and the maximum OD hoop stress at the point of maximum OD curvature of the local deformation or ovalization (maximum curvature corresponds to the smallest radius of curvature). The axial PWSCC and ODSCC cracks caused by the dent stresses would not be closely spaced and clearly not superimposed upon each other in axial alignment. As discussed below, the point of maximum ID stress in a dent that causes the PWSCC crack has a high OD compressive stress such that OD cracking would not be expected at the minor tube axis. As noted in the earlier discussion of separation distances, the ID and OD cracks at dented TSP intersections have separation angles dominantly between 40° and 90°

(minimum of 34°), which exceed crack separation distances required to prevent interaction between axial cracks. The UT profiles of Figures 1 to 3 show expected crack separation distances of 45° and 90° based on locations of maximum OD curvature. Consequently, axial PWSCC and ODSCC indications resulting from dent stresses have a negligible potential for reductions in burst pressure or increased leakage above that of the individual indications evaluated as isolated cracks.

Axial ODSCC resulting principally from corrodents in the crevice can be widely distributed around the tube at non-dented intersections. Microcracks that are shallow dominate the numbers of cracks around the circumference and may result from residual surface stresses in the tube. Macrocracks form at one or more locations when the microcracks grow and coalesce by corrosion of the ligaments between the microcracks to form significant axial lengths. It would be expected that the microcracks form where the OD hoop stresses are the largest. The largest OD hoop stresses in a dented tube lead to crack separation from the ID cracks as discussed in the above paragraph. Consequently, even when the ODSCC would be principally from corrodents in non-dented tubes, the axial ODSCC macrocracks for dented tubes can be expected to be separated from the PWSCC axial cracks. The potential for some shallow ODSCC microcracks near axial PWSCC in dented tubes is also small due to the high OD compressive stresses near the points of the minor axis of the ovalized tube unless the microcracks formed before denting (i.e., in the first cycle of Diablo Canyon SG operation). Although the potential for ODSCC microcracks cannot be excluded, these cracks would be too shallow to significantly influence the axial PWSCC burst pressure or leakage. If present, these microcracks have not grown to detectable levels since no ODSCC Plus Point indications have been found at less than 30° from the nearest axial PWSCC crack.

Stress Results from Finite Element Model of a Dented Tube

A stress analysis of the dent in DCPP Unit 1 pulled tube R12C32-1H was previously performed. Three cases were analyzed varying the axial denting force centered at the TSP centerline at 40%, 60% and 100% of the 0.75 inch TSP thickness. The results show that the maximum ID hoop stress occurs, as expected, along the vertical centerline of the local deformation and the maximum hoop stress exceeds yield while not strongly dependent on the length of the applied dent forces. The OD hoop stress along the dent centerline is highly compressive. Even the mid-wall hoop stresses are compressive over all or most of the length of the applied denting force. The high OD compressive hoop stresses at the minor axis of the ovalized dent shape and local deformation can be expected to prevent initiation of ODSCC closely spaced (about <30°) with the axial PWSCC indications. Since the mid-wall stresses are predicted to also be compressive near the location of maximum dent deformation, the PWSCC cracks would be expected to be shallow with low growth rates as found for DCPP Units 1 and 2. This expectation is consistent with DCPP Units 1 and 2 inspection results for which the maximum reported depths for a PWSCC crack in an active tube at 1R11 and 2R11 were 55% maximum depth and 35% average depth.

Conclusions Relative to Closely Spaced Axial PWSCC and ODSCC Indications at Dented TSP Intersections

Based on the above assessments, the potential for closely spaced axial PWSCC and ODSCC macrocracks at the same dented TSP intersection is negligible due to the high compressive OD hoop stresses near the minor axis of dent ovalization where the PWSCC occurs. Even the potential for shallow ODSCC microcracks is negligible unless formed prior to the denting which occurred in the first cycle of operation for the Diablo Canyon SGs. Consequently, combined PWSCC and ODSCC indications at the same dented TSP intersection would have no impact on the operational assessment, and separate operational assessments for the individual indications are appropriate.

The circumferential locations of axial PWSCC and ODSCC cracks should be different based on stress state considerations as discussed above. Even in an aggressive environment there must be a stress to drive the crack. In the hoop direction, the initiation of a crack should relieve the tendency for the adjacent formation of a macrocrack. Microcracks can still form because of residual surface stress although the high compressive stresses at the locations of maximum dent deformation are expected to exceed any residual or applied hoop tensile stresses. If a residual surface stress is the initiator, then the crack should be no more than a microcrack and interaction would not be expected to be meaningful. Once the first crack has formed there should be little impetus for another closely spaced significant crack to form because the stress intensity factor for the already formed crack would tend to make it continue to grow. If microcracks do form ahead of existing cracks, the stress field is very intense in the immediate vicinity (the plastic zone), and their tendency is to grow to the tip of the existing crack thereby providing one mechanism for extension of the macrocrack. This coalescing of cracks is the mechanism for growth in length of the macrocrack.

The inspection results for the separation distances between PWSCC and ODSCC cracks show separation distances of > 30°, which is consistent with expectations based on dent shapes from Diablo Canyon pulled tubes measured by field UT examinations. A separation distance of > 30° is adequate to permit the indications to behave structurally as independent cracks with no significant interaction affects on burst pressure or leakage. A conservative requirement on the separation distance for no interaction is about 13° (separation distance of 0.10 inch). Burst test results for throughwall EDM notches with separation angles as small as 18° (tests with 20 TW notches around tube circumference) in expansion transitions show no reductions in burst pressure compared to single notches of the same throughwall length.

If an ID or OD indication is left in service under the applicable ARC at a dented TSP intersection, any additional OD or ID crack to form combined ID/OD cracks at the same TSP intersection must be below the Plus Point coil detection threshold since all tubes with combined ID/OD cracks are repaired. The sizes and growth rates for new PWSCC and ODSCC indications at Diablo Canyon are small as shown by the 1R11 and 2R11

inspection results. The small sizes for the new indications reduce the potential for burst pressure or leakage effects from combined ID/OD cracks even under the very unlikely assumption that the indications are more closely spaced than found to date (minimum of 34°).

10.0 Circumferential ODSCC in WEXTEX Region

One circumferential ODSCC indication (SCI) in the hot leg top of tubesheet WEXTEX transition region was detected by Plus Point in 2R11. The Plus point data is listed in Table 8.

The SCI was sized using the technique described in Appendix B of WCAP-15573, Revision 1. The depth profiles were then processed for corrections in accordance with the depth adjustment rules in Section 4.10.4 of WCAP-15573, Revision 1. The adjusted NDE results were corrected for 95 percent NDE uncertainty using the NDE uncertainty regression parameters in Tables 4-19 to 4-21 in WCAP-15573, Revision 1. The adjusted NDE and adjusted NDE with uncertainty results are listed in Table 8.

As noted in Table 8, the location of the SCI was 0.07 inch above the top of tubesheet. The SCI was located in WEXTEX Zone 4 (center region) of the top of tubesheet. Zone 4 is noted to have the most tube scale buildup.

The $3\Delta P_{NO}$ structural limit for an SCI is about 264 degrees, assuming a 100 percent throughwall defect. The measured length was 77.7 degrees, and adjusted to 192.5 degrees after applying large 95 percent NDE uncertainties. This length is less than the 264 degree structural limit. Therefore, structural integrity was satisfied at EOC 11.

The measured Plus Point voltage was 0.15 volts, much less than the 1.31 volt threshold for leak testing of circumferential ODSCC in transitions as documented in EPRI draft report 1007904. Based on this voltage, the SCI was shallow and no SLB leakage should be postulated for this indication at EOC 11. The SCI has a high NDE adjusted maximum depth of 85.5 percent. However, the deep depth at this low voltage is not realistic and is most likely due to difficulties in sizing indications below about 0.5 volts.

Operational Assessment

The 2R11 WEXTEX transition circumferential ODSCC indication could be detected and sized in the prior 2R10 data based on a lookup analysis. The lookup sizing used the same WCAP-15573 Revision 1 sizing techniques. The following maximum growth rates per EFPY were observed: 6.9 degree, 8% AD, and 10.5% MD. This growth data point, along with 4 growth data points from the 1R11 inspection, represent the only WEXTEX transition circumferential ODSCC growth rate data points using the WCAP-15573 Revision 1 sizing techniques. Since the 2R11 indication has a very low Plus Point voltage (0.15 volts), similar to the small voltages of the 1R11 top of tubesheet

circumferential ODSCC indications, sizing of the indications for growth rates may not be reliable.

Because of this limited growth data, the growth rates are assumed to be the same as TSP circumferential PWSCC. Conservatively assuming the same detection threshold as for TSP circumferential ODSCC, the projected EOC 12 average depth and maximum depth would be 57% and 74%, respectively. Circumferential indications of this size present no challenge to structural and leakage integrity, as described in the previous section regarding TSP circumferential indications. The 2R11 WEXTEX transition circumferential ODSCC indication has a maximum voltage of only 0.15 volts, rendering depth sizing unreliable for comparison with projected EOC depths.

Based on the 100% Plus Point inspection of the hot leg WEXTEX region, observations of small numbers of circumferential indications, very small growth rates, and large structural margin, there is a low probability that ODSCC circumferential indications located in the WEXTEX transition zone will challenge the $3\Delta P_{NO}$ structural integrity performance criteria through EOC 12. There is a low probability that circumferential ODSCC indications in the WEXTEX transition zone would grow through-wall in a cycle, and no leakage should be postulated in a faulted SG following a SLB at EOC 12.

11.0 Volumetric Indications

Ten OD volumetric indications (SVI) in 5 row 1 tubes were detected by bobbin and confirmed by Plus Point in 2R11, as listed in Table 9. The locations are located about 22 inches above the top of hot leg tubesheet (TSH) and top of cold leg tubesheet (TSC). Phase sizing of these indications was performed using 300 kHz +Point data, and the results are shown in Table 9. The Plus Point voltage of the largest flaw was about 1.6 volt, with an estimated length of 1.1 inch, maximum depth of 50% through-wall, and width of 0.50 inch.

These indications were believed to be damage caused by the "new" sludge lancing equipment used in the prior 2R10 outage since all the defects are in row 1 tubes, located about 22 inches above the top of the tubesheet, and were not present in 2R10 eddy current data, as sludge lancing in 2R10 was conducted after the eddy current inspection.

These defects were made in 2R10 when the enhanced Westinghouse sludge lance tooling was used, which utilized a monorail system. The enhanced equipment allowed 10 row coverage per index, which was quicker than the four row coverage per index method used by the old equipment in prior outages. The enhanced system used nozzles on only one side of the lance, which resulted in a flexing of the joints of the monorail, allowing the lance to occasionally contact the tubes, producing wear at those locations. The old method has never resulted in generation of tube defects, as it is designed with opposing nozzles that keep the lance centered in the tube lane.

Prior to 2R11, Westinghouse had determined that the enhanced equipment could cause tube defects. As a result, Westinghouse transmitted letter LTR-SRC-01-042, dated November 20, 2001, which identified DCPP 1 & 2, Beaver Valley 1, Seabrook, Surry 1 and Vogtle 1 & 2 as potentially affected plants that have used the enhanced equipment.

The enhanced equipment was only used in 1R10 and 2R10. There were no similar eddy current indications in 1R11.

In situ pressure testing of all 5 tubes was performed up to $3\Delta P_{NO}$ pressure. No leakage was detected. Thus, condition monitoring was satisfied. All five tubes were plugged in 2R11, so there is no need for an operational assessment.

After 2R11, PG&E notified the industry of this event via OE15901, Steam Generator Sludge Lance Damage to U-Tubes.

12.0 Cold Leg Thinning (CLT)

CLT indications at cold leg TSP intersections are detected by bobbin probes as part of the 100 percent full-length bobbin inspection. CLT indications are sized by bobbin (phase based depth sizing) using EPRI ETSS 96001.1. CLT indications are plugged if bobbin indicates a depth greater than or equal to 40 percent through-wall.

Bobbin indications at cold leg TSPs with prior outage Plus Point were sized by bobbin as CLT indications. Bobbin indications at cold leg TSPs in the CLT zone with no prior outage Plus Point were inspected by Plus Point in 2R11. Volumetric indications confirmed by Plus Point in the CLT region were sized by bobbin. If Plus Point did not confirm the indication, the indication was left in service as a distorted OD signal (DOS).

In 2R11, 152 CLT indications were detected and sized by bobbin, of which 9 were greater than or equal to 40 percent and plugged. 26 new CLT indications were detected. The majority of CLT indications were located at either 1C or 2C, with a few indications at either 3C or 4C.

Based on development of a CLT structural model assuming elliptical wastage for the flaws, the $1.4\Delta P_{SLB}$ structural limit for a tube with CLT confined to the TSP is about 84 percent as provided in WCAP-15147 Revision 1. The CLT repair limit is 40 percent, thereby allowing for NDE uncertainty and flaw growth progression.

Westinghouse report SG-SGDA-02-41, Cold Leg Thinning Database for Tube Integrity Assessments and NDE Depth Sizing, October 31, 2002, reports that phase based depth sizing of CLT indications is not reliable below about 1.9 volts because of low signal to noise ratios.

There were several 2R11 CLT indications in which phase-based sizing yielded large percent through-wall results at small bobbin voltage amplitudes. For example, of the 9 CLT indications that were greater than or equal to 40%, the 3 largest indications had very small bobbin voltages and resulted in overestimated sizes (86% at 0.35 volts, 72% at 0.46 volts, and 49% at 0.63 volts). Of the 26 new indications, the largest voltage was 0.98 volts (measured as 5% through-wall), and the largest measured throughwall was 86% (0.35 volts). Based on the SG-SGDA-02-41 results that show a 1.9 volt indication corresponds to about a 40% maximum depth, CLT indications less than 1.9 volts can be excluded from current tube integrity assessments that rely only on phase sizing.

The deepest indication identified in 2R11 with a bobbin voltage greater than 1.9 volts was 42 percent through-wall. In accordance with EPRI ETSS 96001.1, sizing of CLT with bobbin coil has an NDE standard regression error of 16.4% at 90/50 confidence. Standard error for analyst uncertainty at 90/50 confidence is 0.89% times 1.28, or 1.14% (reference "Appendix G Generic NDE Information from CM/OA," extracted from "Capabilities of Eddy Current Analysts to Detect and Characterize Defects in SG Tubes," Doug Harris, presented at November 1996 EPRI NDE workshop). The combined NDE system uncertainty (SRSS) of the analyst and technique uncertainties is 16.4%. Adding total NDE uncertainty to the 42% bounding indication results in a CLT flaw of 58.4%, which is less than the CLT structural limit of 84%. Therefore, the structural integrity performance criteria were satisfied for this bounding indication at EOC 11. Because greater than 1.9 volt CLT indications were too shallow to consider ligament tearing (pop through), no leakage is postulated in a faulted SG following a SLB at EOC 11. The 42% bounding indication in 2R11 was less than the bounding flaw size projected in the prior cycle OA.

Operational Assessment

There were 26 new CLT indications in 2R11, and all were detectable in the prior outage based on a lookup of 2R10 bobbin data. The 95 percentile growth rate of all indications is 9.4% per EFPY. For CLT indications that were greater than or equal to 1.9 bobbin volts in 2R11 (16 growth data points), the maximum growth rate was 4.9% per EFPY.

The sum of the largest CLT indication remaining in service following an inspection (39%), plus 9.4% per EFPY growth, plus 16.4% NDE uncertainty, results in a projected EOC 12 flaw size of 70% through-wall. This value is less than the CLT structural limit of 84%. The projected EOC 12 depth bounds the largest CLT indication detected in 2R11 that was greater than 1.9 volt.

In conclusion, no CLT indications are expected to challenge structural integrity performance criteria through EOC 12. In addition, no leakage should be postulated in a faulted SG following a SLB at EOC 12 due to the extremely low probability that CLT indications would tear ligaments and pop through in one cycle.

13.0 Antivibration Bar (AVB) Wear

AVB wear indications are detected by bobbin probes during the 100 percent full-length bobbin inspection. AVB wear indications are sized by bobbin using EPRI ETSS 96004.1. AVB wear indications are plugged if bobbin indicates a depth greater than or equal to 40 percent through-wall.

In 2R11, bobbin identified 287 AVB wear indications, of which 3 were greater than or equal to 40 percent and plugged. 28 new indications were detected.

The $3\Delta P_{NO}$ structural limit for the worst case tube with AVB wear is about 65 percent as provided in WCAP-15147 draft Revision 2. The AVB wear repair limit is 40 percent, thereby allowing for NDE uncertainty and flaw growth progression.

The deepest indication identified in 2R11 was 41 %. In accordance with EPRI ETSS 96004.1, sizing of AVB wear with bobbin coil has an NDE standard regression error of 5.74% at 90/50 confidence. Standard error for analyst uncertainty at 90/50 confidence is 0.86% times 1.28, or 1.1 % (reference "Appendix G Generic NDE Information from CM/OA," extracted from "Capabilities of Eddy Current Analysts to Detect and Characterize Defects in SG Tubes," Doug Harris, presented at November 1996 EPRI NDE workshop). The combined NDE system uncertainty is SRSS of the analyst and technique uncertainties, 5.8%. Adding total NDE uncertainty to the bounding indication results in a AVB wear flaw of 46.8%, which is less than the AVB wear structural limit of 65%. Therefore, the structural integrity performance criteria were satisfied for this bounding indication at EOC 11. Because AVB wear was too shallow to consider ligament tearing (pop through), no leakage is postulated in a faulted SG following a SLB at EOC 11. The largest 2R11 flaw size was less than the bounding flaw size projected in the prior cycle OA.

Operational Assessment

A growth rate assessment was performed on AVB wear indications for which bobbin calls were made in 2R11 and 2R10. Also included in the growth assessment were 2R10 lookup calls of new 2R11 indications. All new indications were detectable in 2R10 based on lookups. As a result, 287 indications are in the growth distribution, and the 95% growth rate per EFPY is 3.0%.

The sum of the largest detected AVB wear indication remaining in service following 2R11 (39%), plus 3% per EFPY growth, plus 5.8% NDE uncertainty, results in a projected EOC 12 flaw size of 49.7% through-wall. This value is less than the AVB wear structural limit of 65%. The projected EOC 12 depth bounds the largest indication detected in 2R11.

In conclusion, no AVB wear indications are expected to challenge structural integrity performance criteria through EOC 12. In addition, no leakage should be postulated in a

faulted SG following a SLB at EOC 12 due to the extremely low probability that AVB wear indications would tear ligaments and pop through in one cycle.

14.0 Tube Support Plate (TSP) Ligament Thinning

Starting in 1R8 and 2R8, PG&E implemented an inspection program to detect degradation of steam generator TSPs. A summary of this program was reported to the NRC in response to GL 97-06 (PG&E Letter DCL-98-046 dated March 27, 1998). Visual inspections performed in 1R8 confirmed several missing TSP ligaments. Westinghouse has concluded that the missing TSP ligaments are related to TSP drilled hole manufacturing anomalies. The TSP manufacturing practices employed at the time that the DCPP steam generators were produced used a stacked drilling procedure. Several TSPs were clamped together and drilled simultaneously. A review of the suspect ligament crack (SLC) locations indicates distinct location patterns, indicative of manufacturing anomalies of the automatic drilling equipment.

The eddy current inspection program consists of several steps: bobbin inspection to detect SLC using computerized data screening; Plus Point sample inspection of existing Plus Point confirmed "baseline" indications; and Plus Point inspection of newly detected bobbin SLC indications. Plus Point confirmed indications are called either ligament crack indication (LIC) or ligament gap indication (LIG). The following provides a summary of the 2R11 inspection results.

Baseline Inspection and Results

To satisfy 20 percent inspection recommendations in the EPRI guidelines and to ensure that the current TSP condition is not changing, Plus Point inspection of 100 percent of the baseline indications in all Unit 2 SGs was performed in 2R11. There were 51 baseline indications before 2R11.

In 2R11, Plus Point confirmed all 51 baseline indications (50 LIC and 1 LIG). For the one repeat LIG indication, a gap measurement of 86 degrees was reported. This is the same gap size reported in 2R10, thus indicating no change in the material condition of the TSPs.

Inspection for New Indications

Plus Point confirmed 19 new indications (18 LIC and 1 LIG). Eleven of the LIC indications were located in SG 2-3 at the 7th TSP. These indications were not called by bobbin, and were detected by Plus Point as part of the first of a kind 100% U-bend region inspection. As such, there were no prior rotating probe inspections at these locations. Since TSP ligament indications are normally detectable by both Plus Point and bobbin coil, the 2R11 bobbin data was re-analyzed at these locations. Very weak or nonexistent SLC signals were present at nine locations, and two indications were

detectable and then traced to the preservice inspection baseline data, indicating that they did not initiate during plant operation.

Eight of the new indications (seven LIC and one LIG) were located in SG 2-2 at 4C and 5C TSPs, called by bobbin, and subsequently inspected and confirmed by Plus Point. For the LIG indication, a gap measurement of 20 degrees was reported, and a bobbin indication was traceable to the preservice inspection baseline data, indicating that it did not initiate during plant operation. For the 7 LIC indications, prior outage bobbin data was reviewed. All 7 were detectable in 2R10, the signals were very weak or nonexistent in 2R7, and were not detectable in preservice inspection baseline data. This review indicates that the signals were getting stronger with increased service time.

All new indications will continue to be monitored as required by plant procedures. Based on the 2R11 inspections, there are now of a total of 70 Plus Point TSP ligament indications in Unit 2.

Assessment of Plugging Criteria

The largest measured LIG gap was 86 degrees, less than the 146 degree threshold gap for preventive tube repair. As such, tube plugging was not required.

15.0 Stress Corrosion Cracking of I-600 Mechanical Plugs

There are several types of plugs installed in DCPP Unit 2: I-690 Framatome roll plugs, I-690 Framatome weld plugs, I-690 Westinghouse rib plugs, and I-600 Westinghouse rib plugs. Prior to 2R11, there were 16 I-600 plugs in service, and all had been previously repaired with a plug in plug (PIP) or plug a plug (PAP) method in response to I-600 plug stress corrosion cracking concerns identified in NRC Generic Letter 89-01. There has been no occurrence of stress corrosion cracking in I-690 plugs in the industry.

During the secondary side pressure test, a visual inspection of all plugs was performed to verify their integrity. One plug (SG 2-1 R1C73 hot leg I-600 Westinghouse rib plug with PIP) was observed to have moisture. No moisture or abnormalities were detected in any other plugs, including none of the other I-600 repaired (PIP or PAP) plugs.

PG&E investigated this issue and determined that the I-600 plug must be cracked. The tube was originally plugged in 2R2 because of a throughwall crack like indication located in the U-bend. Therefore, when the secondary side was pressurized, water leaked past the U-bend throughwall indication, past the plug, and then past the unseated PIP. It is presumed that the PIP was unseated by the secondary to primary differential pressure. It is unlikely that the PIP allowed primary to secondary leakage during normal operation.

PG&E decided to remove the SG 2-1 R1C73 hot leg PIP, and all hot leg PIPs in SGs 2-1, 2-2, and 2-4. Framatome alloy 690 weld plugs were installed in their place. The following six I-600 hot leg PIPs were removed and replaced with I-690 weld plugs: SG 2-1 R1C73, SG 2-1 R1C41, SG 2-2 R1C4, SG 2-2 R1C53, SG 2-2 R1C68, SG 2-4 R1C21.

Following the 2R11 plug removal and replacement activities, there are an additional 10 I-600 Westinghouse rib plugs still in service. These are listed in Table 15.

16.0 Potential Stress Corrosion Cracking at Free Span Dings

No occurrences of stress corrosion cracking at free span dings has been observed at DCPP Units 1 and 2, based on Plus Point sampling of free span dings every outage starting in 2R7 and 1R8.

In 2R11, Plus Point inspection was performed on 100 percent of greater than 5 volt free span dings in both the hot and cold legs to verify that no PWSCC or ODSCC is occurring in free span dings. A total of 108 greater than 5 volt free span dings in 92 tubes were Plus Point inspected. 52 of these dings were located in the U-bend, and 2R11 was the first outage in which Plus Point inspection of U-bend dings was performed, in response to concerns at Comanche Peak. The entire length of free span between the support structures was Plus Point inspected, and no indications at free span dings were detected.

Bobbin coil was credited for detection of potential stress corrosion cracking in less than 5 volt free span dings. Three DNI (ding with possible indication) calls were made in 2R11 based on the bobbin coil inspection. Subsequent Plus Point inspection of thee three locations did not confirm any degradation.

17.0 Potential Tube Damage from Loose Parts and Foreign Objects

The bobbin and Plus Point data were reviewed for possible loose part (PLP) indications. In addition, a foreign object search and removal (FOSAR) visual examination of the tube sheet annulus and blowdown lane regions was performed to identify loose parts.

The bobbin and Plus Point examinations did not detect any PLP signals. No tube wear was located that could be attributed to a loose part.

FOSAR activities were conducted after sludge lancing was completed. Two small loose parts were identified and documented in action requests, one in SG 2-1 (described as a magnetic cylindrical pin) and one in SG 2-2 (described as magnetic debris). The evaluation did not identify the exact secondary side source of the loose parts. Condition monitoring was satisfied for loose parts concerns on the basis that their small mass precluded the possibility of potential tube damage in cycle 11.

Table 1
2R11 SG Tube Inspection and Expanded Inspections

	Area	Probe	Initial Inspection	Expanded Inspection
1	Full Length	Bobbin	100%	N/A
2	Repeat TSP PWSCC	+Point	100%	N/A
3	Repeat W* indications	+Point	100%	N/A
4	Hot Leg TTS Region	+Point	• 100% • Extent is +2" to –8.5"	N/A
5	Cold Leg TTS Region	+Point	• 100% in SG 2-4 • 20% in SG 2-1, 2-2, 2-3, biased to Zone 4 • Extent is +2" to –8.5" • 100% of cold leg anomalies	N/A
6	Rows 1 and 2 U-Bends	+Point	100%	NA
7	Row 3 and higher U-Bends	+Point	100% Row 3 in SG 2-4 20% Row 3 in SG 2-1, 2-2, 2-3	100% of U-bend region in all SGs (Row 3 to Row 46)
8a	>2 Volt Dented TSP	+Point	• 100% of ≥5 volt dents, both hot leg and cold leg • SG 2-1: 20% of >2 and <5 volt dents at 1H • SG 2-2: 100% of >2 and <5 volt dents from 1H to 5H (critical area), 20% at 6H • SG 2-3, 2-4: 100% of >2 and <5 volt dents from 1H to 3H (critical area), 20% at 4H • All 20% samples shall contain a minimum of 50 dents. If the population of >2 and <5 volt dents at the TSP elevation is less than 50, then inspect 100% of >2 and <5 volt dents at the TSP.	NA
8b	< 2 Volt Dented TSP	+Point	N/A (credit bobbin for detection of axial PWSCC. Plus Point inspect all bobbin DIS indications, see below)	NA
9	Distorted ID support plate bobbin signals (DIS) at dented TSP	+Point	100% of DIS calls by bobbin	NA
10	Distorted OD support plate bobbin signals (DOS) to support voltage-based ARC	+Point	• DOS at < 5 volt dented intersections (no lower voltage cutoff) • ≥ 2 volt DOS • DOS with suspected TSP ligament cracking • DOS in the wedge region exclusion zone • DOS at 7th TSP exclusion zone • DOS that extend outside the TSP crevice	> 1 volt DOS in SG 2-2, 2-3, 2-4 100% hot leg DOS in SG 2-1
11	Suspected TSP Ligament Cracking	+Point	100% of existing baseline indications.	NA
12	Free Span Dings	+Point	100% of >5 volt dings (including hot leg, cold leg, and U-bend) Credit bobbin for detection of SCC in <5 volt dings	NA
13	Hot leg and cold leg special interest as identified by bobbin program	+Point	• New CLT indications • CLT indications in the wedge zone • New SLC • Free span bobbin indications that are new or exhibit growth or change (MBI, FSI, DNI) • Possible loose part (PLP) indications • Mix residuals: all HL intersections > 2.3 SPR volts, and minimum of 5 largest HL SPR per SG. • Previously unreported dents (PUD) at TSPs in scope of dent program • Copper deposit signals	

Table 2
Tubes Plugged in 2R11

LOCATION	MECHANISM	ORIENT	2-1	2-2	2-3	2-4	Total
WEXTEX TTS	PWSCC	Axial	1	1	1	1	4
	ODSCC	Circ	1	0	0	0	1
Hot Leg TSP	PWSCC	Axial	0	4	0	0	4
	PWSCC	Circ	0	6	0	0	6
	PWSCC/ODSCC	Axial	0	4	1	1	6
	ODSCC	Circ	0	1	0	0	1
	ODSCC	Axial	33	22	30	184	269
Cold Leg TSP	Thinning		4	1	3	1	9
Rows 1 and 2 U-bend	PWSCC	Axial	1	0	0	1	2
	PWSCC	Circ	1	0	0	0	1
	Preventive (probe stall or noise)		2	4	3	1	10
Row 3 to Row 10 U-bend	PWSCC	Circ	1	2	3	6	12
U-bend	AVB Wear		1	0	1	1	3
Free Span above TTS	Sludge Lance mechanical damage		2	0	1	2	5
Various	Preventive (permeability variation, PVN)		0	2	1	1	4
Various	In situ to 3dPNO of tubes that had no degradation detectable					3	3
Pluggable Tubes 2R11			47	47	44	202	340
% Plugged to date			3.2%	6.7%	3.5%	9.3%	5.7%

Note: Some tubes may be plugged for multiple degradation mechanisms. In these cases, the tube is listed in only one degradation mechanism category.

Table 3
DCPP Unit 2 Historical Tube Plugged by Mechanism and SG

LOCATION	MECHANISM	ORIENT	2-1	2-2	2-3	2-4	Total
WEXTEX TTS	PWSCC	Axial	25	7	18	16	66
	PWSCC	Circ	0	4	3	5	12
	ODSCC	Circ	1	0	0	0	1
	Volumetric		1	2	1	0	4
Hot Leg TSP	PWSCC	Axial	0	79	5	24	108
	PWSCC	Circ	0	37	0	0	37
	PWSCC MMode	Axial/Circ	0	5	0	0	5
	PWSCC/ODSCC	Axial	0	4	1	3	8
	ODSCC	Circ	0	8	0	0	8
	ODSCC	Axial	39	29	41	229	338
	OD Volumetric		0	1	0	0	1
Cold Leg TSP	Thinning		17	21	9	5	52
	Volumetric		1	0	1	0	2
Rows 1 and 2 U-bend	PWSCC	Axial	13	11	18	14	56
	PWSCC	Circ	3	1	1	0	5
	Possible Ind		1	3	1	1	6
	Preventive (stall, noise)		2	4	4	1	11
Row 3 to Row 10 U-bend	PWSCC	Circ	1	2	3	6	12
U-bend	AVB Wear		2	2	4	3	11
	Restriction		1	0	0	1	2
Various	Preventive (PVN)		0	2	1	1	4
Free Span above TTS	Mechanical damage		2	3	3	2	10
Various	3dPNO in situ of NDD tubes		0	0	0	3	3
Preventive Plugging	NRCB 88-02		0	1	5	1	7
Pluggable Tubes			109	226	119	315	769
% Plugged			3.2%	6.7%	3.5%	9.3%	5.7%

Note: Some tubes may be plugged for multiple degradation mechanisms. In these cases, the tube is listed in only one degradation mechanism category.

Table 4 - DCPP Unit 2 Tubes Plugged by Mechanism and Outage

LOCATION	MECHANISM	ORIENT	2R1	2R2	2R3	2R4	2R5	2R6	2R7	2R8	2R9	2R10	2R11	Unplug	Total
Cycle EFPY			1.02	1.02	1.11	1.27	1.31	1.34	1.33	1.62	1.46	1.44	1.64		
Cumulative EFPYs			1.02	2.05	3.16	4.43	5.74	7.08	8.41	10.03	11.49	12.93	14.53		
WEXTEX Tubesheet	PWSCC	Axial					24	11	34	27	5	1	4	43	63
	PWSCC	Circ					1	1	8	3	1	1			15
	ODSCC	Circ											1		1
	Volumetric						1	0	0	3	0				4
Hot Leg TSP	PWSCC	Axial					17	3	53	26	18	15	4	28	108
	PWSCC	Circ							16	6	5	4	6		37
	PWSCC MMode	Ax/Circ							3	0	1	1			5
	PWSCC/ODSCC	Axial							1	1	0	0	6		8
	ODSCC	Circ									5	2	1		8
	ODSCC	Axial					3	8	68	7	22	28	269	67	338
	OD - Volumetric								1						1
Cold Leg TSP	Thinning						5	10	10	3	7	8	9		52
	Volumetric										2				2
Rows 1 and 2 U-bend	PWSCC	Axial					10	2	32	9	0	1	2		56
	PWSCC	Circ							3	0	1		1		5
	Possible Ind			6											6
	Preventive (stall, noise)											1	10		11
Rows 3 through 10 U-bend	PWSCC	Circ											12		12
U-bend	AVB Wear						1	3	2	0	0	2	3		11
Free Span above TTS	Mech damage		2	0	0	0	0	0	0	3	0		5		10
U-bend	Probe restriction			1	0	1	0	0	0	1	0			1	2
Various	Preventive (PVN)												4		4
Various	NDD-3dPNO in situ												3		3
Preventive Plugging	NRCB 88-02			5	0	0	0	0	0	2	0				7
Precautionary Plugging	NRCB 88-02			19	0	0	0	0	0	0	0			19	0
Tubes Plugged			2	31	0	1	62	38	231	91	67	64	340		769
Tubes Unplugged			0	0	19	0	1	0	0	0	138	0	0	158	158
Cum. Tubes Plugged			2	33	14	15	76	114	345	436	365	429	769		769
Cum. Tubes Plugged (%)			0.01%	0.24%	0.10%	0.11%	0.56%	0.84%	2.55%	3.22%	2.69%	3.17%	5.67%		5.67%

Note: Some tubes may be plugged for multiple degradation mechanisms. In these cases, the tube is listed in only one degradation mechanism category.

Table 5
SG 2-4 Secondary Side Pressure Test Results and Eddy Current Results

Tube (SG 2-4)	Leak Rate HL drip/minute				2R11 Bobbin			2R11 +point			2R10 Bobbin			2R10 +point		
	200 psi	400 psi	600 psi	800 psi	Voltage	Ind	Loc	Voltage	Ind	Loc	Voltage	Ind	Loc	Voltage	Ind	Loc
R6C4		Moist			NDD			NDD (Ubend exam)			NDD					
R2C29		Moist	Moist		3.32	DTS	TEH +17.33	5.21	SAI	TSH -4.13	1.54	DTS	TEH +17.18	4.29	SAI	TSH -4.37
								1.22	SAI	TSH -2.18	1.16	DTS	TEH +17.42	0.87	SAI	TSH -2.26
R3C29		Moist			0.22	DOS	2H	0.4	SAI	2H	NDD					
R12C38		0.12	Moist		6.20	DOS	1H	3.37	SAI	1H	1.90	DOS	1H			
R6C39		Moist	Moist		3.35	DOS	1H	0.21	SAI	1H	1.24	DOS	1H			
					0.59	DIS	2H	0.18	SAI	1H						
								0.27	SAI	1H						
								0.29	SAI	1H						
								1.96	SAI	1H						
R31C39		0.05	0.05	Moist	4.82	DOS	1H	2.49	SAI	1H	0.94	DOS	1H			
					0.46	DOS	2H									
R44C45		0.16	0.1	0.05	21.50	DOS	2H	0.29	SAI	2H	2.00	DOS	2H	2.49	SAI	2H
								12.12	SAI	2H				0.13	SAI	2H
R7C48		Moist	Moist	Moist	1.63	DOS	1H	0.18	SAI	1H	0.96	DOS	1H			
								0.79	SAI	1H						
								0.24	SAI	1H						
					4.55	DOS	2H	3.63	SAI	2H	1.39	DOS	2H			
R29C48		Moist			5.04	DOS	2H	0.25	SAI	2H	1.29	DOS	2H			
								3.50	SAI	2H						
R42C55		Moist			NDD			NDD (Ubend exam)			NDD					
R5C62	1 HL	2 HL	3 HL	2 HL	0.48	DIS	4H	DNF			NDD					
		3 CL	2 CL	2 CL	0.23	FSI	7H +13.75	35 SCI in Ubend region								
					0.28	FSI	7H +19.48									
R15C80	0.25	0.25	0.25	0.3	4.93	DOS	2H	0.15	SAI	2H	1.37	DOS	2H			
								0.24	SAI	2H						
								0.42	SAI	2H						
								2.83	SAI	2H						
R44C48			Moist		2.3	DOS	2H	0.14	SAI	2H	NDD					
								2.08	SAI	2H						
R28C54			Moist	Moist	3.58	DOS	1H	3.02	SAI	1H	1.10	DOS	1H			
					0.62	DOS	2H				0.37	DOS	2H			
R18C76			Moist	Moist	6.64	DOS	2H	5.65	SAI	2H	1.73	DOS	2H			
								2.17	SAI	2H						

Table 6
SG 2-1 Secondary Side Pressure Test Results and Eddy Current Results

Tube (SG 2-1)	Leak Rate HL drip/minute				2R11 Bobbin			2R11 +point			2R10 Bobbin			2R10 +point		
	200 psi	400 psi	600 psi	800 psi	Voltage	Ind	Loc	Voltage	Ind	Loc	Voltage	Ind	Loc	Voltage	Ind	Loc
R1C73 HL plug	0.1		Moist													
R30C41				Moist	5.1	DOS	1H	4.44	SAI	1H	1.4	DOS	1H			
R34C31			Moist	Moist	2.73	DOS	1H	2.76	SAI	1H	0.66	DOS	1H			
R27C33				Moist	2.83	DOS	1H	1.64	SAI	1H	1.36	DOS	1H			

Table 7
2R11 In Situ Pressure Test Summary

SG	Row	Col	Degradation by Eddy Current Inspection	Number of Plus Point indications	Maximum Plus Point voltage	Bobbin voltage	Degradation Location	Leakage/Moisture Observed during Secondary Side Pressure test?	1750 psi NO dP (gpm)	2750 psi SLB dP (gpm)	4950 psi 3NO dP (gpm)
21	27	33	axial ODSCC	1	1.64	2.83	1H	Yes	0	0.001	NA
21	30	41	axial ODSCC	1	4.44	5.1	1H	Yes	0	0.0232	NA
21	34	31	axial ODSCC	1	2.76	2.73	1H	Yes	0	0.0053	NA
24	3	29	axial ODSCC	1	0.4	0.22	2H	Yes	0	0	0
24	6	39	axial ODSCC	5	1.96	3.35	1H	Yes	0	0.0028	NA
24	7	48	axial ODSCC	4	3.63	4.55	2H	Yes	0.0012	0.0063	NA
24	12	38	axial ODSCC	1	3.37	6.2	1H	Yes	0	0.0037	NA
24	15	80	axial ODSCC	4	2.83	4.93	2H	Yes	0.0011	0.0041	NA
24	18	76	axial ODSCC	2	5.65	6.64	2H	Yes	0	0.0134	NA
24	28	54	axial ODSCC	1	3.02	3.58	1H	Yes	0.0011	0.0061	NA
24	29	48	axial ODSCC	2	3.5	5.04	2H	Yes	0.0016	0.0035	NA
24	31	39	axial ODSCC	1	2.49	4.82	1H	Yes	0	0.0037	NA
24	44	45	axial ODSCC	2	12.12	21.5	2H	Yes	0.004	NA	NA
24	44	48	axial ODSCC	2	2.08	2.3	2H	Yes	0	0.0062	NA
24	6	4	no degradation detected	0	NDD	NDD		Yes	0	0	0
24	42	55	no degradation detected	0	NDD	NDD		Yes	0	0	0
24	2	29	axial PWSCC (W*)	2	5.21	3.32	4 inch below HL TTS	Yes	0	0	NA
21	1	24	Axial PWSCC	1	1.15		U-bend		0	0	0
21	1	43	Circumferential PWSCC	1	0.47		U-bend		0	0	0
21	5	54	Circumferential PWSCC	7	0.73		U-bend		0	0	0
22	4	51	Circumferential PWSCC	21	0.57		U-bend		0	0	0
22	10	19	Circumferential PWSCC	2	0.37		U-bend		0	0	0
23	3	86	Circumferential PWSCC	2	0.56		U-bend		0	0	0
23	3	93	Circumferential PWSCC	1	0.5		U-bend		0	0	0
23	4	52	Circumferential PWSCC	1	1.15		U-bend		0	0	0
24	1	93	Circumferential PWSCC	1	1.23		U-bend		0	0	0
24	5	60	Circumferential PWSCC	3	1.1		U-bend		0	0	0
24	5	62	Circumferential PWSCC	35	3.04	NDD	U-bend	Yes	0	0.004	0.0456
24	5	68	Circumferential PWSCC	5	0.69		U-bend		0	0	0
24	6	23	Circumferential PWSCC	5	0.64		U-bend		0	0	0
24	6	53	Circumferential PWSCC	1	0.85		U-bend		0	0	0
24	7	52	Circumferential PWSCC	9	0.35		U-bend		0	0	0
21	1	9	sludge lance damage SVI	2	0.41	1	22 inch above HL and CL TTS		0	0	0
21	1	28	sludge lance damage SVI	2	1.22	4.75	22 inch above HL and CL TTS		0	0	0
23	1	86	sludge lance damage SVI	2	0.66	1.54	22 inch above HL and CL TTS		0	0	0
24	1	67	sludge lance damage SVI	2	1.65	4.49	22 inch above HL and CL TTS		0	0	0
24	1	86	sludge lance damage SVI	2	1.52	3.4	22 inch above HL and CL TTS		0	0	0

Notes:

- NA means the tube was not pressurized to the specified differential pressure.
- *R44C45 was not tested higher than NOP because the tube was pulled for further destructive exam.*
- The leak rates correspond to the test pressures and are in gpm at room temperature condition.
- Actual NOP, SLB, and 3NOP differential pressures are 1473 psi, 2405 psi, and 4419 psi. The actual test values account for thermal and gage corrections.

Table 8
2R11 Circumferential Indications at Dented Tube Support Plates and Top of Tubesheet

											Unadjusted NDE			Adjusted NDE			Adjusted for Upper 95% NDE Uncertainty			Growth Rate per EFPY		
SG	Row	Col	Crack	Support	Location inch	Circ Type	Dent volt	Mixed Mode ?	Stabilize ?	Flaw Volt	Angle deg	Max Depth %	Avg Depth %	Angle deg	Max Depth %	Avg Depth %	Angle deg	Max Depth %	Avg Depth %	Angle deg	Max Depth %	Avg Depth %
21	20	45	1	TSH	0.07	ODSCC	NA	No	Yes	0.15	77.7	100.0	83.9	77.7	85.5	73.1	192.5	97.6	77.0	6.9	10.5	8.0
22	3	30	1	1H	-0.29	ODSCC	43.7	No	Yes	0.15	35.6	96.0	56.8	35.6	46.0	34.4	175.2	68.7	53.0	14.6	3.7	5.5
22	8	20	1	1H	0.13	PWSCC	38.4	No	Yes	0.35	50.2	90.0	61.0	50.2	54.0	34.5	104.6	74.4	49.3	13.1	-3.4	-7.4
22	9	3	1	1H	0.14	PWSCC	26.7	No	Yes	0.54	35.7	88.0	41.9	35.7	40.0	21.2	89.8	64.2	40.3	5.7	0.0	-1.0
22	14	30	1	4H	-0.11	PWSCC	11.9	No	No	0.37	29.3	96.0	62.7	29.3	59.0	34.7	83.2	78.0	49.4	3.8	11.6	2.4
22	15	36	1	1H	0.16	PWSCC	6.7	No	Yes	0.52	23.5	38.0	21.1	23.5	40.0	25.0	77.3	64.2	42.9	2.1	0.0	-0.9
22	18	6	1	1H	0.24	PWSCC	25.8	No	Yes	0.46	32.0	33.0	25.2	32.0	40.0	23.2	86.0	64.2	41.6	4.5	0.0	-3.1
22	19	30	1	4H	0.10	PWSCC	16.6	No	No	0.53	52.5	54.0	39.8	52.5	43.0	22.5	106.9	66.4	41.2	14.9	-3.7	-4.9

Note 1: SG 21 R20C45 indication is located in WEXTEX Zone 4, the center of the bundle.
Note 2: Growth rate based on adjusted NDE, not the NDE uncertainty adjusted NDE.
Note 3: All locations were previously Plus Point inspected in 2R10 and detectable in 2R10 based on a lookup evaluation.
Note 4: Location (inch) is relative to the centerline of the tube support plate (e.g., 1H), for TSP indications, and relative to the top of tubesheet (TSH), for tubesheet indications.

Table 9
2R11 Plus Point Volumetric Indications
Tube damage done by sludge lancing tool in 2R10 and detected in 2R11

SG	Row	Column	Location	Bobbin Volts	+Point Volts	MD %	Length inch	Width inch
21	1	9	TSH + 23.08	0.75	0.34	<1	0.78	0.41
21	1	9	TSC + 22.31	1.00	0.41	14	0.62	0.35
21	1	28	TSH + 22.14	4.75	1.21	<1	1.16	0.45
21	1	28	TSC + 22.56	2.83	1.22	27	1.19	0.47
23	1	86	TSH + 22.99	0.85	0.35	<1	0.65	0.43
23	1	86	TSC + 23.13	1.54	0.66	23	0.79	0.58
24	1	67	TSH + 22.57	3.85	1.36	28	1.01	0.50
24	1	67	TSC + 22.56	4.49	1.65	48	1.13	0.50
24	1	86	TSH + 22.94	3.40	1.52	32	0.67	0.41
24	1	86	TSC + 22.73	2.03	0.81	28	0.82	0.37

Note 1: All indications were in situ leak and proof tested to $3\Delta P_{NO}$. No leakage was identified.

Table 10 - DCPP Units 1 and 2 Axial ODSCC and Axial PWSCC at Same TSP Intersection (ID/OD Flaws)

Insp.	SG	Row	Col.	TSP	Dent Volts	ID/OD Separation Angle (Deg.)	Deplug	PWSCC New?	ODSCC New?	PWSCC NDE Data					ODSCC NDE Data		
										Crack No.	Length (in.)	MD (%)	AD (%)	Max Volt	No. OD Cracks	Largest Bobbin Volts	Largest +Point Volts
2R11	22	12	71	1H	4.63	61		New		1	0.11	37	24.6	0.39	1	NDD	0.16
2R11	22	22	67	2H	0.63	53		New		1	0.23	38	24.8	0.91	2	4.58	2.66
2R11	22	24	58	2H	2.02	147		New	New	1	0.07	20	12.8	0.29	1	NDD	0.22
2R11	22	28	38	1H	1.56	55			New	1	0.16	33	17.6	0.44	2	0.86	0.15
2R11	23	8	66	1H	1.42	78		New		1	0.11	20	14.5	0.43	1	0.62	0.24
2R11	24	16	11	3H	1.27	83			New	1	0.26	30	17.2	0.72	1	0.63	0.18
2R11	24	34	43	3H	4.63	63		New		1	0.39	36	22.8	0.65	3	1.73	0.72
1R11	11	14	87	2H	0.51	71		New		1	0.09	30	20.8	0.29	1	0.62	0.63
1R11	11	15	81	2H	1.2	82		New		1	0.19	21.5	12.4	0.5	1	0.75	0.36
1R11	11	16	45	2H	1.32	71		New	New	1	0.14	34	22.1	0.84	2	1.29	0.16
1R11	11	22	71	2H	0.83	81			New	1	0.11	40	28.6	0.67	1	0.48	0.16
1R11	11	24	20	2H	1.43	49			New	1	0.07	43	22.7	0.71	1	0.81	0.22
1R11	11	33	40	2H	0.86	59		New	New	1	0.26	45	28.7	1.13	2	1.26	0.25
1R11	11	36	30	2H	0.56	46			New	1	0.17	43	30.5	1.34	2	0.54	0.22
1R11	12	5	59	1H	1.02	49	1R11			1	0.34	43	32.4	1.3	2	0.54	0.22
1R11	12	6	70	2H	1.54	71	1R11			1	0.11	36	25.8	0.79	2	0.57	0.25
1R11	12	7	28	2H	2.33	64	1R11			1	0.07	20	12.4	0.31	1	0.49	0.17
1R11	12	7	56	1H	1.13	90	1R11			1	0.26	43	34.3	2.2	1	0.52	0.2
1R11	12	7	84	1H	2.19	53	1R11			1	0.34	45	35.6	3.06	1	0.6	0.28
1R11	12	8	67	1H	1.2	64			New	1	0.2	29	16.9	0.88	1	0.46	0.14
1R11	12	8	51	1H	1.48	76	1R11			1	0.18	32	19.2	0.69	1	0.51	0.19
1R11	12	9	28	1H	2.53	71	1R11			1	0.16	47	30.3	1.47	2	0.59	0.27
1R11	12	9	77	1H	2.45	95	1R11			1	0.23	39	23.4	1.34	1	0.62	0.29
1R11	12	10	35	1H	1.34	80	1R11			1	0.11	51	33.4	1.65	1	0.51	0.19
1R11	12	10	83	1H	6.72	60	1R11			1	0.27	64	37.5	1.15	2	0.57	0.25
1R11	12	11	27	1H	2.13	49	1R11			1	0.5	29	18.7	0.86	1	0.53	0.21
1R11	12	11	47	2H	2.32	73	1R11			1	0.21	36	26.7	1.06	1	0.52	0.2
1R11	12	12	66	2H	2.21	80	1R11			1	0.13	45	30.9	1.51	1	0.59	0.27
1R11	12	12	80	1H	1.04	49	1R11			1	0.07	20	12.9	0.6	1	0.45	0.24
1R11	12	12	84	2H	0.73	64	1R11			1	0.29	42	31.1	1.5	1	0.55	0.35
1R11	12	13	81	1H	3.18	49	1R11			1	0.13	23	16.5	0.88	1	0.43	0.33
1R11	12	13	89	1H	2.33	57	1R11			1	0.4	53	41.3	2.97	1	0.56	0.44

Table 10 - DCPP Units 1 and 2 Axial ODSCC and Axial PWSCC at Same TSP Intersection (ID/OD Flaws)

Insp.	SG	Row	Col.	TSP	Dent Volts	ID/OD Separation Angle (Deg.)	Deplug	PWSCC New?	ODSCC New?	PWSCC NDE Data					ODSCC NDE Data		
										Crack No.	Length (in.)	MD (%)	AD (%)	Max Volt	No. OD Cracks	Largest Bobbin Volts	Largest +Point Volts
1R11	12	16	73	1H	18.03	47	1R10		New	1	0.12	21	15.2	0.64	1	0.51	0.19
1R11	12	16	76	2H	0.52	64	1R10		New	1	0.18	20	9.7	0.39	1	0.05	0.2
1R11	12	17	8	6H	2.95	75	1R11			1	0.23	24	15.6	0.81	1	0.57	0.25
1R11	12	19	14	2H	1.34	84	1R11			1	0.18	44	35	1.73	1	0.54	0.22
1R11	12	19	51	1H	1.21	76	1R11			1	0.57	54	44	3.24	1	0.64	0.32
1R11	12	20	52	2H	2.55	83	1R11			1	0.23	43	28.3	0.91	1	0.52	0.2
1R11	12	20	58	1H	0.65	55	1R11			1	0.54	57	40.3	2.09	1	0.51	0.19
1R11	12	21	37	4H	2.25	80	1R11			1	0.25	34.5	24.2	0.88	1	0.48	0.16
1R11	12	21	50	1H	2.38	56	1R11			1	0.76	57	47.1	2.04	1	0.95	0.64
1R11	12	21	53	6H	2.52	56	1R11			1	0.62	64	50.7	1.97	1	0.53	0.21
1R11	12	22	32	2H	1.44	51	1R11			1	0.27	54	42.1	2.28	2	0.55	0.23
1R11	12	22	34	2H	0.69	51	1R11			1	0.18	42	31.3	1.03	3	0.55	0.23
1R11	12	22	38	1H	4.7	65	1R11			1	0.08	30	22	0.58	2	0.54	0.22
1R11	12	25	72	1H	2.06	77		New	New	1	0.09	24	17.3	0.48	1	0.47	0.15
1R11	12	26	71	2H	1.4	75	1R11			1	0.42	42	30.5	1.68	1	0.5	0.18
1R11	12	26	77	2H	0.71	68	1R11			1	0.44	50	38.9	1.87	1	0.81	0.36
1R11	12	26	78	1H	1.29	68	1R11			1	0.32	50	38.6	2.43	1	0.65	0.33
1R11	12	27	50	1H	1.95	34			New	1	0.11	27	17.4	0.88	1	0.51	0.19
1R11	12	27	36	2H	0.54	58	1R11			1	0.09	20	12.5	0.77	1	0.44	0.12
1R11	12	28	56	2H	0.75	79	1R11			1	0.25	40	29.2	1.12	1	0.44	0.11
1R11	12	28	58	1H	1.67	72	1R11			1	0.6	60	44.9	3.05	1	0.54	0.22
1R11	12	28	68	6H	1.26	57	1R11			1	0.08	21	10.9	0.56	1	0.32	0.11
1R11	12	29	43	2H	1.34	69	1R11			1	0.24	39	31.1	1.86	2	0.62	0.42
1R11	12	29	56	2H	1.34	106	1R11			1	0.25	34	24.6	1.82	1	0.54	0.22
1R11	12	29	67	2H	3.02	83	1R11			1	0.36	48	36.9	2.11	1	0.57	0.25
1R11	12	30	16	1H	0.9	48			New	1	0.15	41	28	0.7	1	0.64	0.32
1R11	12	31	32	3H	1.67	69	1R11			1	0.11	20	9.7	0.32	1	0.42	0.09
1R11	12	35	45	2H	1.82	95	1R11			1	0.29	48	35.7	1.41	1	0.43	0.27
1R11	12	35	65	2H	2.36	46	1R11			1	0.31	48	37.4	1.88	3	0.55	0.23
1R11	12	37	72	1H	1.65	76	1R11			1	0.17	34	24.5	0.93	1	0.57	0.25
1R11	12	38	70	1H	2.42	61	1R11			1	0.09	20	15.6	0.52	1	0.63	0.31
1R11	12	40	63	1H	0.87	83	1R11			1	0.11	21	9.9	0.46	1	0.68	0.36
1R11	12	42	28	2H	1.41	69			New	1	0.11	32	20.1	0.88	1	0.6	0.28

Table 10 - DCPP Units 1 and 2 Axial ODSCC and Axial PWSCC at Same TSP Intersection (ID/OD Flaws)

Insp.	SG	Row	Col.	TSP	Dent Volts	ID/OD Separation Angle (Deg.)	Deplug	PWSCC New?	ODSCC New?	PWSCC NDE Data					ODSCC NDE Data		
										Crack No.	Length (in.)	MD (%)	AD (%)	Max Volt	No. OD Cracks	Largest Bobbin Volts	Largest +Point Volts
1R10	11	28	50	1H	0.35	47	1R10			1	0.09	29	19.1	0.64	2	0.96	0.81
1R10	12	9	34	2H	2.02	44		New		1	0.09	21	13.3	0.41	2	0.76	0.26
1R10	12	14	72	2H	2.92	58	1R10			1	0.42	38	16.3	1.04	1	0.53	0.21
1R10	12	14	82	1H	1.55	61	1R10			1	0.05	20	10	0.39	1	0.55	0.23
1R10	12	15	10	1H	1.76	90			New	1	0.21	24	14	0.48	1	0.44	0.27
1R10	12	17	60	2H	2.92	51	1R10			1	0.17	22	7.2	0.56	1	0.56	0.24
1R10	12	24	72	1H	1.24	82	1R10			1	0.26	22	15.5	0.4	1	0.27	0.14
1R10	12	26	43	2H	2.12	70	1R10			1	0.26	30	15.4	0.81	1	0.58	0.26
1R10	12	27	71	1H	1.86	74			New	1	0.23	39	25.4	1.12	2	0.62	0.3
1R10	12	33	37	1H	2.01	79		New	New	1	0.11	20	12	0.38	1	0.52	0.2
1R10	12	38	63	1H	2.35	79		New	New	1	0.14	22	13.9	0.78	1	0.69	0.37
1R10	12	41	62	1H	0.82	109		New	New	1	0.21	27	17	0.54	1	0.56	0.24
1R9	11	9	6	1H	0.95	79		New	New	1	0.13	37	27.2	0.38	1	0.35	0.27
1R9	12	6	47	1H	0.77	44		New	New	1	0.12	26	16.7	0.35	1	0.34	0.11
1R9	12	13	75	2H	2.23	53		New	New	1	0.11	20	11	0.42	1	0.37	0.14
2R7	24	9	12	3H	1.84	89		New	New	1	0.32	23	17.8	1.64	1	1.25	0.38
2R8	24	34	34	3H	2.96	57		New	New	1	0.16	35.5	26.4	0.38	1	0.64	0.32
1R11	12	7	28	2H			1R11			2	0.1	24	14.9	0.55			
1R11	12	16	73	1H			1R10		New	2	0.15	20	12.3	0.5			
1R11	12	20	58	1H			1R11			2	0.19	54	44.4	2.23			
1R11	12	21	50	1H			1R11			2	0.56	64	39	1.65			
1R11	12	22	38	1H			1R11			2	0.61	48	38.7	2.19			
1R11	12	31	32	3H			1R11			2	0.34	48	40.6	1.67			
1R10	12	14	72	2H			1R10			2	0.07	20	12	0.58			

Table 11
Circumferential PWSCC in Rows 3 through 10 U-bend Region

SG	Row	Col	Number of Indications
21	5	54	7
22	4	51	21
22	10	19	2
23	3	86	2
23	3	93	1
23	4	52	1
24	5	60	3
24	5	62	35
24	5	68	5
24	6	23	5
24	6	53	1
24	7	52	9

Table 12 - Plus Point Data for Circumferential PWSCC in Rows 3 through 10 U-Bend Region									
SG	Row	Col	TSP	Inch	Crack	Max Volt	Max Depth %	Average Depth %	Length degree
21	5	54	7H	21.03	1	0.23	81.0	47.7	18.4
21	5	54	7H	21.65	2	0.26	84.0	42.0	18.4
21	5	54	7H	22.40	3	0.52	88.0	57.5	34.2
21	5	54	7H	22.60	4	0.63	99.0	60.0	29
21	5	54	7H	23.87	5	0.41	94.0	40.1	18.4
21	5	54	7H	25.50	6	0.46	90.0	49.8	28.9
21	5	54	7H	25.95	7	0.73	84.0	55.3	36.8
22	4	51	7H	3.97	1	0.57	99.0	66.0	33.2
22	4	51	7H	4.19	2	0.35	99.0	60.0	24.9
22	4	51	7H	4.49	3	0.52	90.0	76.5	27.7
22	4	51	7H	4.60	4	0.34	84.0	65.3	27.7
22	4	51	7H	4.28	5	0.33	99.0	65.6	22.2
22	4	51	7H	7.72	6	0.33	87.0	52.5	22.2
22	4	51	7H	8.16	7	0.15	82.0	44.9	19.4
22	4	51	7H	8.36	8	0.22	68.0	50.4	19.4
22	4	51	7H	8.81	9	0.46	84.0	60.5	22.2
22	4	51	7H	9.28	10	0.16	79.0	52.5	19.4
22	4	51	7H	9.73	11	0.41	98.0	62.1	22.2
22	4	51	7H	10.17	12	0.43	74.0	57.2	24.9
22	4	51	7H	10.98	13	0.38	95.0	61.2	24.9
22	4	51	7H	11.18	14	0.33	92.0	57.3	24.9
22	4	51	7H	11.42	15	0.37	97.0	66.0	25
22	4	51	7H	11.73	16	0.22	79.0	46.3	22.1
22	4	51	7H	12.34	17	0.38	84.0	55.3	19.4
22	4	51	7H	12.80	18	0.29	95.0	51.6	25
22	4	51	7H	21.59	19	0.43	100.0	40.9	22.1
22	4	51	7H	21.43	20	0.18	84.0	66.3	24.9

Table 12 - Plus Point Data for Circumferential PWSCC in Rows 3 through 10 U-Bend Region									
SG	Row	Col	TSP	Inch	Crack	Max Volt	Max Depth %	Average Depth %	Length degree
22	4	51	7H	21.63	21	0.40	92.0	54.8	22.2
22	10	19	7H	14.90	1	0.37	92.0	55.7	32.9
22	10	19	7H	16.28	2	0.21	74.0	48.4	19.2
23	3	86	7H	18.30	1	0.56	75.0	45.4	22.4
23	3	86	7H	18.42	2	0.29	89.0	47.0	21.4
23	3	93	7H	18.35	1	0.50	72.0	56.0	22.6
23	4	52	7H	22.02	1	1.15	71.0	55.0	36.6
24	5	60	7H	4.30	1	1.10	88.0	67.9	36
24	5	60	7H	14.51	2	0.70	80.0	49.7	24.9
24	5	60	7H	14.95	3	0.90	73.0	53.2	38.7
24	5	62	7H	4.31	1	0.52	97.0	58.8	28.4
24	5	62	7H	4.67	2	2.48	100.0	89.8	78.9
24	5	62	7H	4.97	3	0.28	63.0	41.0	25.2
24	5	62	7H	5.45	4	0.23	49.0	34.9	15.8
24	5	62	7H	9.27	5	1.21	71.0	45.8	28.4
24	5	62	7H	9.52	6	0.86	67.0	47.3	41
24	5	62	7H	10.89	7	0.12	56.0	38.7	19
24	5	62	7H	11.30	8	1.54	100.0	83.4	85.2
24	5	62	7H	11.57	9	0.35	79.0	43.8	22.1
24	5	62	7H	12.58	10	1.77	100.0	77.9	82.2
24	5	62	7H	12.95	11	1.37	100.0	78.4	69.5
24	5	62	7H	13.30	12	1.52	100.0	24.2	78.9
24	5	62	7H	14.13	13	0.33	88.0	49.1	25.2
24	5	62	7H	14.50	14	2.23	100.0	89.9	91.6
24	5	62	7H	14.77	15	1.31	100.0	86.6	88.4
24	5	62	7H	15.71	16	0.27	92.0	54.2	15.8
24	5	62	7H	16.04	17	2.01	100.0	83.7	91.6
24	5	62	7H	16.40	18	1.42	100.0	82.9	75.8
24	5	62	7H	17.25	19	0.15	83.0	50.6	12.6
24	5	62	7H	17.71	20	1.25	99.0	70.6	101.1
24	5	62	7H	17.88	21	0.55	88.0	63.9	44.2
24	5	62	7H	19.04	22	0.25	92.0	47.7	28.4
24	5	62	7H	19.59	23	3.04	100.0	89.8	126.4
24	5	62	7H	21.06	24	0.54	100.0	72.1	34.7
24	5	62	7H	21.30	25	0.59	99.0	65.6	47.4
24	5	62	7H	22.46	26	0.58	100.0	67.0	41.1
24	5	62	7H	22.68	27	0.55	100.0	60.1	37.9
24	5	62	7H	23.08	28	0.68	99.0	72.9	66.4
24	5	62	7H	23.29	29	0.52	92.0	67.9	37.9
24	5	62	7H	23.89	30	1.23	100.0	18.5	75.7
24	5	62	7H	24.15	31	0.25	79.0	45.0	34.7
24	5	62	7H	24.80	32	1.18	100.0	73.6	91.5
24	5	62	7H	25.52	33	0.49	98.0	53.8	41.1
24	5	62	7H	25.76	34	1.90	100.0	89.1	104.2
24	5	62	7H	26.07	35	0.33	100.0	47.5	34.7
24	5	68	7H	25.61	1	0.31	97.0	51.1	38.5
24	5	68	7H	18.30	2	0.36	99.0	52.2	27.5
24	5	68	7H	17.56	3	0.30	68.0	48.4	30.2

Table 12 - Plus Point Data for Circumferential PWSCC in Rows 3 through 10 U-Bend Region									
SG	Row	Col	TSP	Inch	Crack	Max Volt	Max Depth %	Average Depth %	Length degree
24	5	68	7H	16.43	4	0.69	65.0	48.2	33
24	5	68	7H	12.89	5	0.21	89.0	42.1	22
24	6	23	7H	30.20	1	0.42	74.0	50.3	25.5
24	6	23	7H	29.31	2	0.40	98.0	60.8	22.7
24	6	23	7H	28.38	3	0.64	71.0	53.8	28.4
24	6	23	7H	27.46	4	0.17	65.0	38.8	17
24	6	23	7H	15.82	5	0.48	77.0	48.1	22.6
24	6	53	7H	27.55	1	0.85	97.0	52.2	36
24	7	52	7H	4.32	1	0.24	84.0	51.7	30.7
24	7	52	7H	11.97	2	0.21	96.0	55.9	25.1
24	7	52	7H	13.30	3	0.11	99.0	44.8	22.4
24	7	52	7H	13.81	4	0.16	95.0	54.7	22.4
24	7	52	7H	15.77	5	0.14	66.0	36.0	19.9
24	7	52	7H	16.49	6	0.30	73.0	45.5	19.9
24	7	52	7H	16.79	7	0.25	69.0	46.7	22.7
24	7	52	7H	18.53	8	0.35	98.0	62.9	25.5
24	7	52	7H	19.18	9	0.25	99.0	60.0	28.3

Table 13
Plus Point Data for Axial PWSCC in Row 1 U-Bends

				2R11 Data				2R10 Lookup				Growth Rate/EFPY	
SG	Row	Col	U-bend Location	2R11 Cal	Max Volt	MD %	Length inch	2R10 Cal	Max Volt	MD %	Length inch	MD %	Length inch
21	1	24	Hot Leg Tangent	Cold 39	1.15	68	0.38	cold 37	1.11	66	0.41	1.22	1.22
24	1	93	Hot Leg Tangent	Cold 30	1.23	99	0.24	cold 29	1.15	56	0.11	26.22	6.71

Table 14
Plus Point Data for Circumferential PWSCC in Row 1 U-Bends

				2R11 Data				2R10 Lookup				Growth Rate/EFPY	
SG	Row	Col	U-bend Location	2R11 Cal	Max Volt	MD %	Length degree	2R10 Cal	Max Volt	MD %	Length degree	MD %	Length degree
21	1	43	Hot Leg Tangent	cold 55	0.47	61	15.7	cold 29	0.77	86	20.6	-15.24	-2.99

Table 15
Inservice Alloy 600 Plugs In DCPP Unit 2

SG	Row	Col	I-600 Plug Installed	I-600 Hot Leg Plugs				I-600 Cold Leg Plugs				Notes
				Heat	Type	Repair	Repair Date	Heat	Type	Repair	Repair Date	
21	1	41	2R2					4523	Rib	PAP	2R7	
21	1	73	2R2					4523	Rib	PAP	2R7	
22	1	4	2R2					4523	Rib	PAP	2R7	
22	1	53	2R2					4523	Rib	PAP	2R7	
22	1	68	2R2					4523	Rib	PAP	2R7	
23	10	37	2R2	5222	Rib	PIP	2R4					1
23	10	43	2R2	5222	Rib	PIP	2R4					1
23	11	43	2R2	5222	Rib	PIP	2R4					1
23	12	43	2R2	5222	Rib	PIP	2R4					1
24	1	21	2R2					4523	Rib	PAP	2R7	

Note 1: Westinghouse U-bend damper installed in this tube and extends from tube end hot to over the U-bend.

Figure 1
Field UT Circumferential Dent Profile for Pulled Tube R12C32

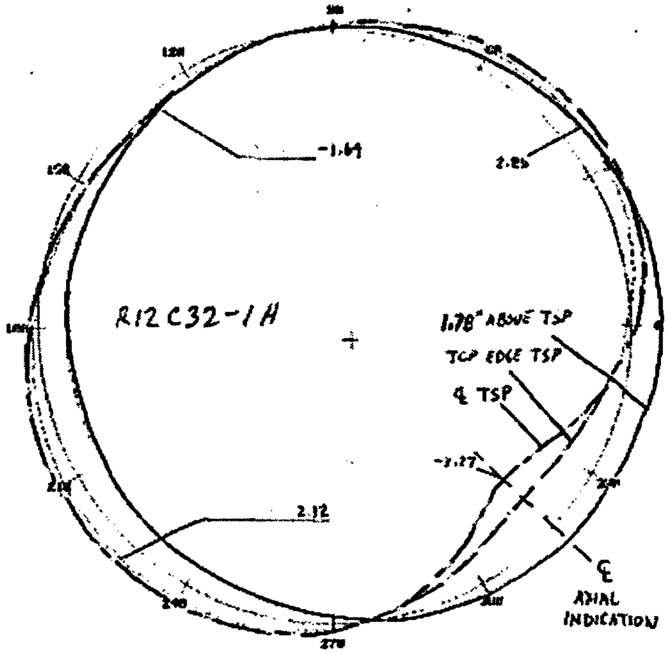


Figure 2
Field UT Circumferential Dent Profile for Pulled Tube R10C22

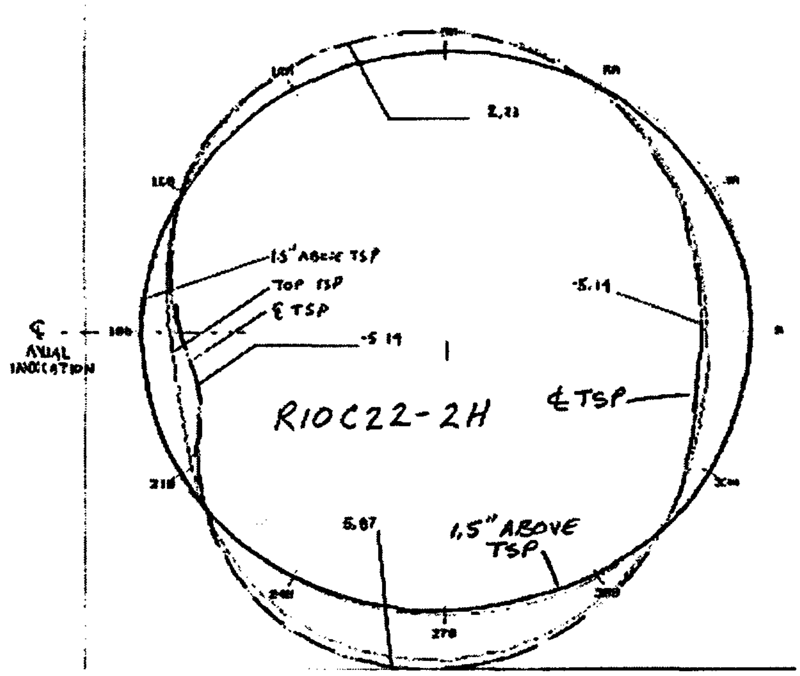
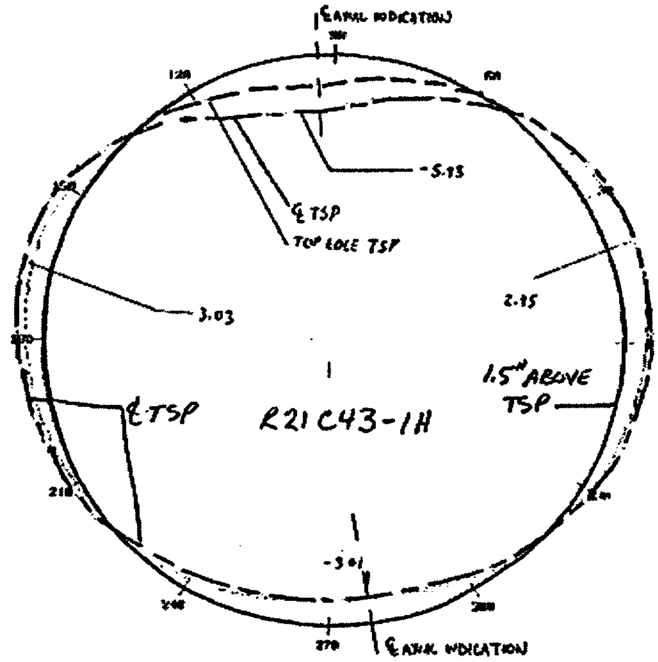


Figure 3
Field UT Circumferential Dent Profile for Pulled Tube R21C43



SPECIAL REPORT 03-02

ATTACHMENT 1 TO ENCLOSURE 3

FRAMATOME ANP REPORT 51-5024976-00
"EVALUATION OF U-BEND INDICATIONS FROM DIABLO CANYON UNIT 2 OUTAGE 2R11"

FRAMATOME ANP

ENGINEERING INFORMATION RECORD

Document Identifier 51 - 5024976-00

Title Evaluation of U-bend Indications From Diablo Canyon Unit 2 Outage 2R11

PREPARED BY:		REVIEWED BY:	
Name	WM Boudreaux	Name	ML Harris
Signature	WMBoudreaux	Signature	DEBrooks-Crocker for MLHarris
Date	3-18-03	Date	3-18-03

Technical Manager Statement: Initials TAR Tori A. Richards

Reviewer is Independent.

Remarks:

During the Diablo Canyon 2R11 outage eddy current inspection a number of tubes were identified with circumferential indications in the U-bend region. This report documents an evaluation of those indications.

Introduction

The Diablo Canyon Nuclear Power Plant (DCPP) Unit 2 entered its 11th refueling outage in February 2003. During a hydro test a number of tubes were noted to be leaking, one in particular from both tube ends. Tube R5-C62 in steam generator 24 was this tube. A +Point™ examination of the U-bend region revealed multiple indications of cracking. Similar inspections of other tubes revealed additional indications in all 4 steam generators. Because these indications are new to Diablo Canyon a comprehensive evaluation was necessary.

Objectives

The main objectives of the evaluation include the following:

- Determine the tube wall origin of the indications (Inside Diameter or Outside Diameter)
- Determine the major axis direction of the indications (Circumferential or Axial)
- Characterize the morphology of the indications and describe the similarities and differences between individual indications and tubes
- Determine the axial position of the indications along the tube's length
- Estimate the length and depth of the indications
- Measure the signal amplitude of the indications
- Determine the angular position of the indications relative to the intrados of the tube
- Perform a review of any historical examination data to determine flaw evolution
- Identify possible indicators of susceptible tubes through a comparison of flawed and non-flawed tubes
- Define the source of the "ridges" in the eddy current plots in which the indications are located
- Determine if DCPP Unit 2 steam generators are the only ones with these "ridge" signals
- Compare these indications to historical Row 1 indications reported at DCPP

A number of other objectives were established which are addressed in separate reports including:

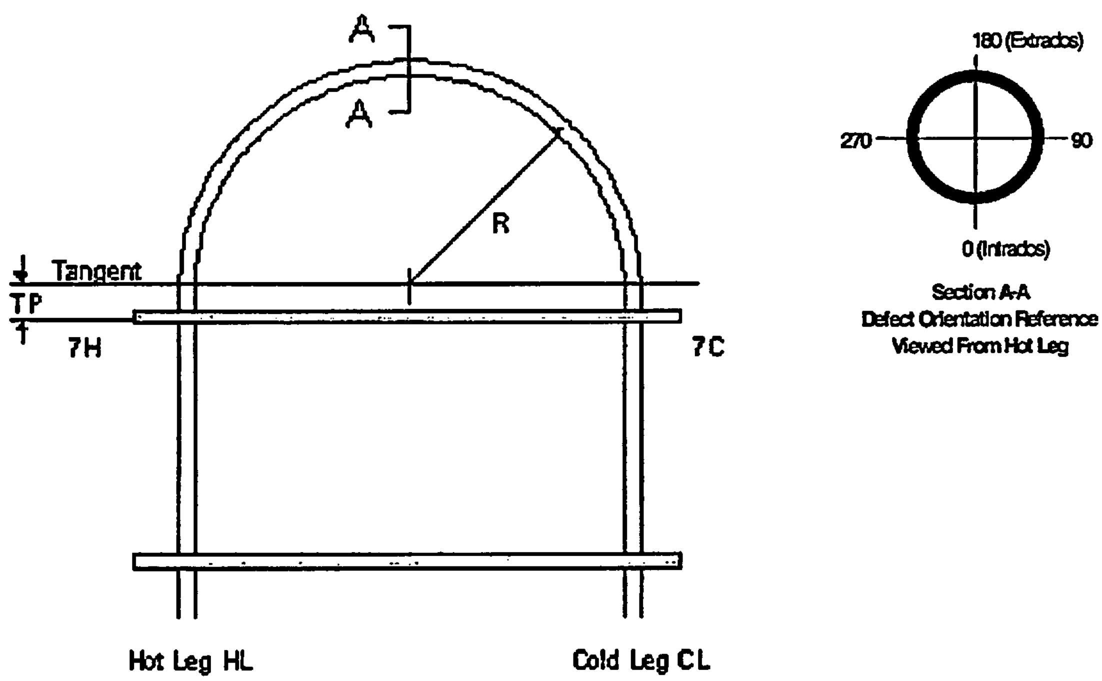
- Evaluation of the indications with the X-Probe
- Profilometry of tubes to evaluate ovality
- Visual inspection of the indications
- In-Situ pressure testing of the indications
- Evaluation of the bending process used during fabrication
- Stress Analysis of the U-bend

Inspection Plan

The eddy current inspection plan followed during 2R11 was a rotating +Point probe examination of the complete U-bend region of all in-service tubes in all four steam generators. The +Point probe examination used three basic coil types to include the standard mid-range PP14A, the high frequency PP9A and a magnetically biased PP14A coil. The standard mid-range PP14A coil was the primary use coil for the examination and the other two coil types were used for special applications. Additional eddy current examinations, using other probe types, were performed on specific tubes to help answer the established objectives. In addition to the +Point probe examinations all of the tubes with U-bend indications were examined with the X-Probe and tube SG 24 R5-C62 was also examined with a rotating pancake probe. Numerous other inspections were performed, aside from eddy current examination, and the results of these are documented in separate reports.

U-bend Sketch

The figure below shows the U-bend region of a tube with support structures, basic references, tube lengths and a circumferential orientation reference viewed from the hot leg side of the tube. The primary reference points discussed in this report include the hot leg tube support plate (7H) from which all indications are referenced, the tangent (bend start and stop points), the apex (center of the bend, identified by the Section A-A symbol), the intrados (bottom and shortest radius of the bend), the extrados (top and longest radius of the bend) and the flanks (sides, shown at the angular positions 90° and 270°) of the tube. The table at the bottom of the figure presents dimensional data for the first 10 rows of tubes.



Row	R	Arc Length	Tangent Pt	Length
1	2.19	6.88	3.70	14.28
2	3.47	10.90	3.70	18.31
3	4.75	14.92	3.70	22.33
4	6.03	18.94	3.70	26.36
5	7.31	22.97	3.70	30.38
6	8.59	26.99	3.70	34.41
7	9.87	31.01	3.70	38.43
8	11.16	35.06	3.70	42.46
9	12.44	39.08	3.70	46.48
10	13.72	43.10	3.70	50.51

(Example: 7H+4.98 is 1.28" above tangent)

FIGURE 1 – DIAGRAM OF U-BEND REGION WITH REFERENCES

Tubes With Indications

There were 15 tubes with indications in the U-bend region. Three of these tubes were in Row 1 and the other 12 were in Rows 3 thru 10. Diablo Canyon has a history of circumferential and axial indications in the Row 1 and 2 U-bends of both Units. These indications are not considered a new phenomenon, as are those discovered this outage in Rows 3 thru 10, and are therefore not discussed in the same context in this report. The table below presents a summary of the distribution of the indications by steam generator and row.

TABLE 1 – DISTRIBUTION OF TUBES WITH INDICATIONS

Row	1	3	4	5	6	7	10	Total
Total	3	2	2	4	2	1	1	15
SG 21	2			1				3
SG 22			1				1	2
SG 23		2	1					3
SG 24	1			3	2	1		7

The tubesheet map in the following figure shows the coordinates of the tubes with U-bend indications. The affected tubes are distinguished by label (refer to the legend for an explanation) for each steam generator to promote a visual reference for the condition in a particular steam generator as well as all four combined. It can be noted that a number of the tubes with indications have similar tube coordinates (neighboring tubes) and are grouped in a few basic areas in the steam generator.

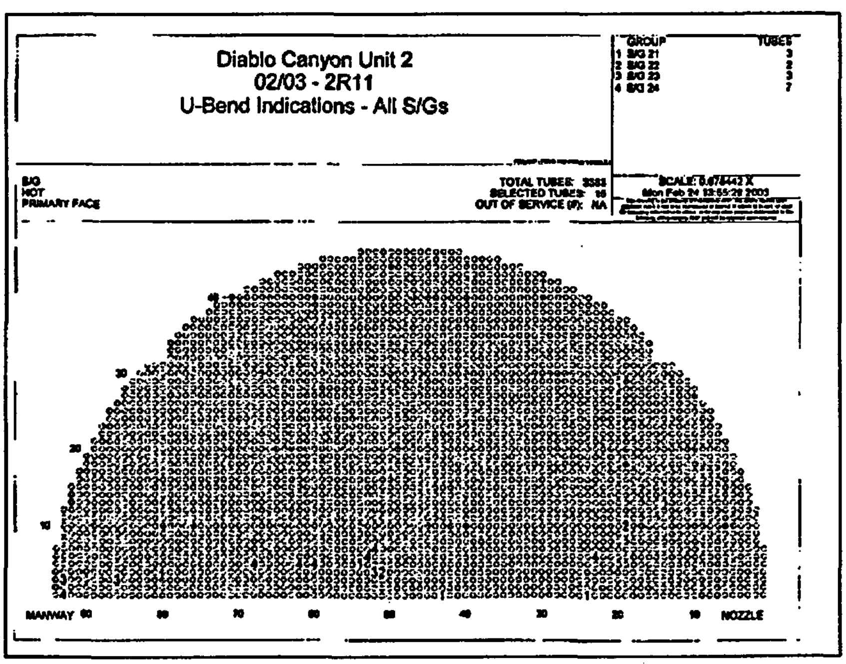


FIGURE 2 – MAP OF U-BEND INDICATIONS IN ALL STEAM GENERATORS

Indication Morphology

All of the indications originate from the tube wall's inner surface and propagate towards the outer tube wall. This was confirmed by all of the eddy current probes used including the +Point probe, pancake probe, X-Probe and bobbin probe. The signal parameters used to determine this were the phase angle, phase relationship (rotation between the frequencies) and the voltage drop across those frequencies.

All of the indications are circumferentially oriented as confirmed by the +Point probe and the X-Probe. Additionally, the pancake probe was used in tube SG 24 R5-C62 and it showed these circumferential indications to be slightly off-axis (inclined) by approximately 15 degrees. The off-axis angle was consistent for all of the large indications in this tube.

The morphology of the indications in Rows 3 thru 10 is very similar among the affected tubes, though SG 24 R5-C62 has many more indications of larger amplitude. The indications are all located within the "ridge" signals seen by the +Point probe, with one exception. The exception is one indication in SG 23 R4-C52 where the indication is outside, but immediately adjacent to the ridge. These "ridge" signals are attributed to ovalization of the tube as confirmed by the pancake probe and the X-Probe. It is also understood that some degree of tube wall thickness variation exists in this area as well. These "ridge" signals are coincident with the sides or flanks of the tube. The arc lengths of the indications are short and, for the most part, contained within the "ridge" signal.

Eleven of the 12 tubes (Rows 3-10) have at least one indication in the tangent area, and of the 13 individual tangent area indications, nine of them are at the cold leg tangent. Four of the 12 tubes have a single indication in the U-bend and the remaining 8 tubes have multiple indications. Nine tubes have indications on only one side of the tube and 3 tubes have indications on both sides of the tube. Two of the tubes with indications on both sides of the tube have only a single indication on the opposite side and the third, SG 24 R5-C62, has two indications on the side of the tube opposite the majority of the indications. The voltage amplitude of the indications in tube SG 24 R5-C62 is considerably larger than those in the other 11 tubes. The angular position of the indications is discussed in a later paragraph.

TABLE 2 – SUMMARY OF +POINT INDICATIONS

SG	Row	Col	Orientation	Axial Position	Number of Indications	Observations
21	1	24	Axial	HL tangent	1	Intrados
21	1	43	Circ	HL tangent	1	Intrados
21	5	54	Circ	Throughout bend	7	
22	4	51	Circ	Throughout bend	21	Indications on both sides
22	10	19	Circ	Throughout bend	2	No tangent area indication
23	3	86	Circ	CL tangent	2	Indications on both sides
23	3	93	Circ	CL tangent	1	
23	4	52	Circ	CL tangent	1	Indication not in ridge but close
24	1	93	Axial	HL tangent	1	Intrados
24	5	60	Circ	Throughout bend	3	
24	5	62	Circ	Throughout bend	35	Indications on both sides
24	5	68	Circ	Throughout bend	5	
24	6	23	Circ	Throughout bend	5	
24	6	53	Circ	CL tangent	1	
24	7	52	Circ	Throughout bend	9	

Note: The number of indications is based on the +Point Sizing Database

Axial Position, Amplitude, Depth and Length

The following table lists detailed information about each indication to include the axial position (inches) or elevation along the tube length referenced from tube support plate 7H, the signal's +Point probe maximum amplitude (volts) from the sizing database, the maximum and average depth estimate (%TW) calculated from the incremental (line-by-line) sizing results, and the indication length (degrees) also calculated from the incremental sizing results. The depth and length estimates presented here are uncorrected NDE values directly from analysis of the data.

TABLE 3 – INDICATION LISTING WITH +POINT RESULTS

SG	ROW	COL	LOC	ELEV	IND #	MAX VOLTS	MAX DEPTH	AVG DEPTH	LENGTH
21	5	54	7H	21.03	1	0.23	81.0	47.7	18.4
21	5	54	7H	21.65	2	0.26	84.0	42.0	18.4
21	5	54	7H	22.40	3	0.52	88.0	57.5	34.2
21	5	54	7H	22.60	4	0.63	99.0	60.0	29
21	5	54	7H	23.87	5	0.41	94.0	40.1	18.4
21	5	54	7H	25.50	6	0.46	90.0	49.8	28.9
21	5	54	7H	25.95	7	0.73	84.0	55.3	36.8
22	4	51	7H	3.97	1	0.57	99.0	66.0	33.2
22	4	51	7H	4.19	2	0.35	99.0	60.0	24.9
22	4	51	7H	4.49	3	0.52	90.0	76.5	27.7
22	4	51	7H	4.60	4	0.34	84.0	65.3	27.7
22	4	51	7H	4.28	5	0.33	99.0	65.6	22.2
22	4	51	7H	7.72	6	0.33	87.0	52.5	22.2
22	4	51	7H	8.16	7	0.15	82.0	44.9	19.4
22	4	51	7H	8.36	8	0.22	68.0	50.4	19.4
22	4	51	7H	8.81	9	0.46	84.0	60.5	22.2
22	4	51	7H	9.28	10	0.16	79.0	52.5	19.4
22	4	51	7H	9.73	11	0.41	98.0	62.1	22.2
22	4	51	7H	10.17	12	0.43	74.0	57.2	24.9
22	4	51	7H	10.98	13	0.38	95.0	61.2	24.9
22	4	51	7H	11.18	14	0.33	92.0	57.3	24.9
22	4	51	7H	11.42	15	0.37	97.0	66.0	25
22	4	51	7H	11.73	16	0.22	79.0	46.3	22.1
22	4	51	7H	12.34	17	0.38	84.0	55.3	19.4
22	4	51	7H	12.80	18	0.29	95.0	51.6	25
22	4	51	7H	21.59	19	0.43	100.0	40.9	22.1
22	4	51	7H	21.43	20	0.18	84.0	66.3	24.9
22	4	51	7H	21.63	21	0.40	92.0	54.8	22.2
22	10	19	7H	14.90	1	0.37	92.0	55.7	32.9
22	10	19	7H	16.28	2	0.21	74.0	48.4	19.2
23	3	86	7H	18.30	1	0.56	75.0	45.4	22.4
23	3	86	7H	18.42	2	0.29	89.0	47.0	21.4
23	3	93	7H	18.35	1	0.50	72.0	56.0	22.6
23	4	52	7H	22.02	1	1.15	71.0	55.0	36.6
24	5	60	7H	4.30	1	1.10	88.0	67.9	36
24	5	60	7H	14.51	2	0.70	80.0	49.7	24.9
24	5	60	7H	14.95	3	0.90	73.0	53.2	38.7
24	5	62	7H	4.31	1	0.52	97.0	58.8	28.4
24	5	62	7H	4.67	2	2.48	100.0	89.8	78.9
24	5	62	7H	4.97	3	0.28	63.0	41.0	25.2
24	5	62	7H	5.45	4	0.23	49.0	34.9	15.8

TABLE 3 – INDICATION LISTING WITH +POINT RESULTS

SG	ROW	COL	LOC	ELEV	IND #	MAX VOLTS	MAX DEPTH	AVG DEPTH	LENGTH
24	5	62	7H	9.27	5	1.21	71.0	45.8	28.4
24	5	62	7H	9.52	6	0.86	67.0	47.3	41
24	5	62	7H	10.89	7	0.12	56.0	38.7	19
24	5	62	7H	11.30	8	1.54	100.0	83.4	85.2
24	5	62	7H	11.57	9	0.35	79.0	43.8	22.1
24	5	62	7H	12.58	10	1.77	100.0	77.9	82.2
24	5	62	7H	12.95	11	1.37	100.0	78.4	69.5
24	5	62	7H	13.30	12	1.52	100.0	24.2	78.9
24	5	62	7H	14.13	13	0.33	88.0	49.1	25.2
24	5	62	7H	14.50	14	2.23	100.0	89.9	91.6
24	5	62	7H	14.77	15	1.31	100.0	86.6	88.4
24	5	62	7H	15.71	16	0.27	92.0	54.2	15.8
24	5	62	7H	16.04	17	2.01	100.0	83.7	91.6
24	5	62	7H	16.40	18	1.42	100.0	82.9	75.8
24	5	62	7H	17.25	19	0.15	83.0	50.6	12.6
24	5	62	7H	17.71	20	1.25	99.0	70.6	101.1
24	5	62	7H	17.88	21	0.55	88.0	63.9	44.2
24	5	62	7H	19.04	22	0.25	92.0	47.7	28.4
24	5	62	7H	19.59	23	3.04	100.0	89.8	126.4
24	5	62	7H	21.06	24	0.54	100.0	72.1	34.7
24	5	62	7H	21.30	25	0.59	99.0	65.6	47.4
24	5	62	7H	22.46	26	0.58	100.0	67.0	41.1
24	5	62	7H	22.68	27	0.55	100.0	60.1	37.9
24	5	62	7H	23.08	28	0.68	99.0	72.9	66.4
24	5	62	7H	23.29	29	0.52	92.0	67.9	37.9
24	5	62	7H	23.89	30	1.23	100.0	18.5	75.7
24	5	62	7H	24.15	31	0.25	79.0	45.0	34.7
24	5	62	7H	24.80	32	1.18	100.0	73.6	91.5
24	5	62	7H	25.52	33	0.49	98.0	53.8	41.1
24	5	62	7H	25.76	34	1.90	100.0	89.1	104.2
24	5	62	7H	26.07	35	0.33	100.0	47.5	34.7
24	5	68	7H	25.61	1	0.31	97.0	51.1	38.5
24	5	68	7H	18.30	2	0.36	99.0	52.2	27.5
24	5	68	7H	17.56	3	0.30	68.0	48.4	30.2
24	5	68	7H	16.43	4	0.69	65.0	48.2	33
24	5	68	7H	12.89	5	0.21	89.0	42.1	22
24	6	23	7H	30.20	1	0.42	74.0	50.3	25.5
24	6	23	7H	29.31	2	0.40	98.0	60.8	22.7
24	6	23	7H	28.38	3	0.64	71.0	53.8	28.4
24	6	23	7H	27.46	4	0.17	65.0	38.8	17
24	6	23	7H	15.82	5	0.48	77.0	48.1	22.6
24	6	53	7H	27.55	1	0.85	97.0	52.2	36
24	7	52	7H	4.32	1	0.24	84.0	51.7	30.7
24	7	52	7H	11.97	2	0.21	96.0	55.9	25.1
24	7	52	7H	13.30	3	0.11	99.0	44.8	22.4
24	7	52	7H	13.81	4	0.16	95.0	54.7	22.4
24	7	52	7H	15.77	5	0.14	66.0	36.0	19.9
24	7	52	7H	16.49	6	0.30	73.0	45.5	19.9
24	7	52	7H	16.79	7	0.25	69.0	46.7	22.7
24	7	52	7H	18.53	8	0.35	98.0	62.9	25.5
24	7	52	7H	19.18	9	0.25	99.0	60.0	28.3

Angular Position Verification

The angular position of the indications in tube SG 24 R5-C62 was verified using a magnetic indexing reference probe. This probe consists of a long sheath with a high strength magnet at its tip. The probe is inserted into a tube immediately adjacent to a flawed tube and the magnet is positioned near the flaw of interest. The flawed tube is then scanned with a rotating eddy current probe in order to image the flaw and magnet response in one scan. For this test the magnet was positioned 6 inches into the bend region of 4 tubes adjacent to R5-C62, one at a time, and tube R5-C62 was scanned each time with a rotating +Point probe. The signal response from the magnet was related to the flaw response in order to determine the angular position of the flaw. The result of this test is shown below and the view presented is from the hot leg of the steam generator. This test was repeated with a rotating pancake probe later for different application.

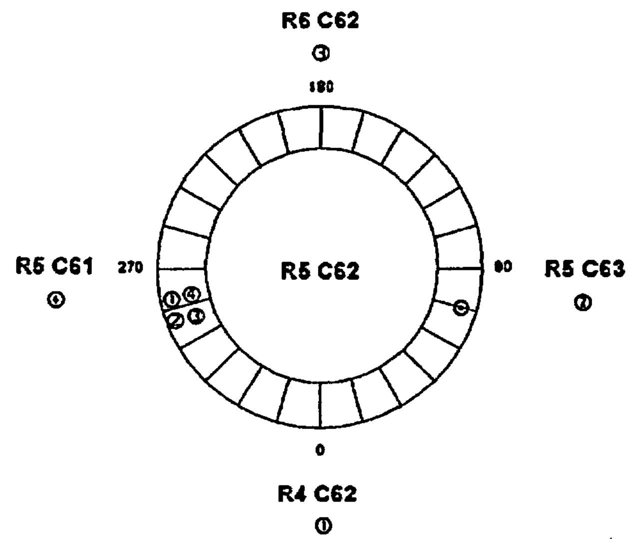


FIGURE 3 – INDICATION LOCATIONS BASED ON MAGNETIC INDEXING PROBE

①②③④ Angular position of the same indication as obtained by 4 acquisitions from neighboring tubes using a magnet.
10° ccw from R5-C61
80° cw from R4-C62
160° cw from R5-C63
255° cw from R6-C62

⊙ Angular position of the sole indication on the opposite side of the tube measured from the magnets and from the larger indication.

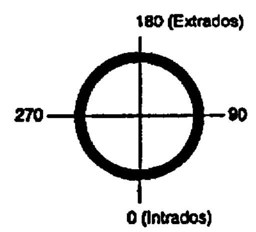
Angular Position Based On Down Locator

The flexible U-bend rotating probes incorporate a down locator module designed to locate the intrados of the tube. The module houses a cylindrical race with a single ball bearing inside it. The ball bearing is held at the bottom of the race by gravity and reacts with the magnetic fields of four nearby electrical coils as the module's body rotates. The signal response from the down locator is used as a reference to identify the intrados of the tube allowing angular positioning of the flaw.

The table below attempts to locate the angular (circumferential) position of the flaw(s), in degrees, in relation to the intrados of the tube using the rotating probe's down locator. The result of the magnetic indexing probe, discussed on the previous page, verifies the methodology used here with the down locator is correct since the magnetic indexing probe method is absolute and the two methods agree for tube R5-C62. Based on the variability of the down locator's response in the data acquired this outage, the accuracy of the measurements is believed to be ±20°. The positions given are based on a view of the tube from the hot leg side of the steam generator as shown in table's diagram.

TABLE 4 – ANGULAR POSITION OF THE INDICATIONS BASED ON THE DOWN LOCATOR

SG	ROW	COL	POSITION (degree)	POSITION (For Indication on Opposite Side)
21	5	54	277°	-
22	4	51	272°	89°
22	10	19	272°	-
23	3	86	300°	105°
23	3	93	302°	-
23	4	52	302°	-
24	5	60	287°	-
24	5	62	278°	88°
24	5	68	299°	-
24	6	23	294°	-
24	6	53	-	86°
24	7	52	273°	-



Defect Orientation Reference Viewed From the Hot Leg

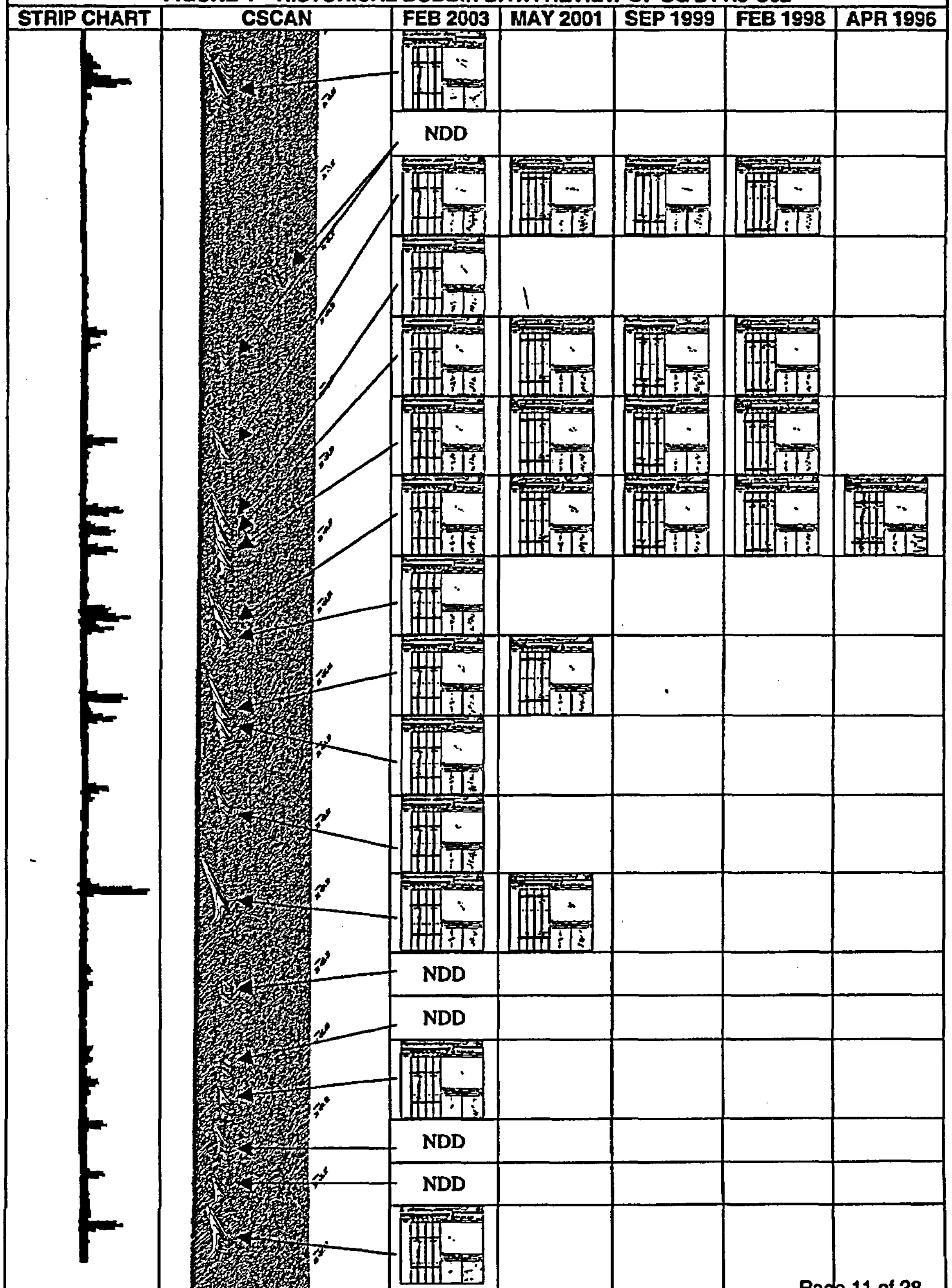
Historical Data Review

The table below presents all of the U-bend flaws in Rows 3 thru 10 along with the results of a review of historical bobbin data. None of these tubes has ever been examined with the +Point probe in the past therefore no review of this technique could be performed. The possible number of flaws that could be seen by bobbin was determined based on spacing between the flaws since some of the flaws are very close to one another. The actual number of circumferential indications is larger than the number that can be individually resolved by the bobbin probe, seen in the following table. The number of outages reviewed is evidenced by the numeric values in the Table below and represent the number of bobbin detectable indications. The process followed for the historical review started with the current outage data and proceeded backwards in time until two outages with no detection were encountered. Some tubes received a further review for various reasons and for others when their data existed on a calibration group being reviewed for another tube. Baseline data was also reviewed for a number of the tubes to investigate the possibility of manufacturing anomalies. Only one tube, SG 24 R5-C62, had any bobbin detectable indications. The bent condition of the tube and the circumferential orientation of the flaws are the expected reasons for the lack of bobbin detection. The tangents are especially challenging and the horizontal probe motion of the bobbin probe also degrades performance in the smaller radius bends. Additional reasons for the non-detection are offered in the table below for specific flaws. The +Point amplitude is also an important factor and Figure 6 shows the correlation between those indications detected with the filtered bobbin data channel and their +Point voltage, which explains why only the indications in tube R5-C62 were detected. The indications detected in R5-C62 with bobbin were those with the largest +Point voltages. Figure 4 on the following page presents a snapshot, over time, of the bobbin detectability for R5-C62 showing evidence of the degradation since 1996.

TABLE 5 - BOBBIN DATA REVIEW

SG	Row	Col	Nov 1982	Mar 1993	Sep 1994	Apr 1996	Feb 1998	Sep 1999	May 2001	Feb 2003	Number Of Flaws Possible For Bobbin	Partial Reason For No Bobbin Detection and *(notes)*	Tube Chatter
21	5	54	0				0	0	0	0	4	1 – Tangent area 3 – Amplitude	No
22	4	51	0				0	0	0	0	8	2 – Tangent area 6 – Amplitude	No
22	10	19							0	0	2	2 – Amplitude	No
23	3	86							0	0	1	Tangent	No
23	3	93	0				0	0	0	0	1	Tangent	No
23	4	52							0	0	1	Tangent area	Yes
24	5	60						0	0	0	3	1 – Tangent 2 – Amplitude	Yes
24	5	62	0	0	0	1	4	4	6	13	18	Amplitude	Yes
24	5	68	0		0	0	0	0	0	0	5	1 – Tangent area 3 – Amplitude 1 – Probe Motion	No
24	6	23	0				0	0	0	0	4	3 – Tangent area 1 – Amplitude	Yes
24	6	53	0				0	0	0	0	1	Tangent area	Yes
24	7	52						0	0	0	4	1 – Tangent 3 – Amplitude	No

FIGURE 4 – HISTORICAL BOBBIN DATA REVIEW OF SG 24 R5-C62



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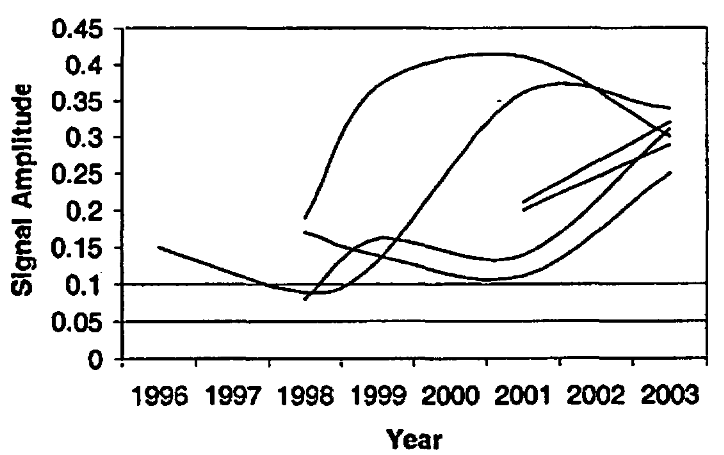
Growth Based on Bobbin Amplitude

A review of the current outage and historical bobbin data resulted in detection of some of the indications in only one tube. The detection was possible using a filtered data channel which showed some of the indications were present as far back as 1996. The slow growth is evidenced by the fact that indications can be seen in the data as far back as 1996 with an increase in both the number of indications and the indication's amplitude over time. The following table and graph provides the results of this review. It must be mentioned that the depth estimates (%TW) are not a good indicator of true depth or of growth. The best indicator of growth is the signal amplitude (volts).

TABLE 6 – SG 24 R5-C62 HISTORICAL BOBBIN DATA REVIEW

Elevation	Feb 2003		May 2001		Sept 1999		Feb 1998		April 1996	
Above 7H	Volts	%TW	Volts	%TW	Volts	%TW	Volts	%TW	Volts	%TW
4.56	0.42	97								
11.01	0.30	51	0.41	22	0.37	21	0.19	50		
12.64	0.30	93								
12.99	0.31	99	0.14	59	0.16	96	0.08	50		
13.26	0.25	89	0.11	91	0.14	59	0.17	21		
14.55	0.34	86	0.36	86	0.13	95	0.09	37	0.15	44
14.81	0.15	94								
16.03	0.29	95	0.20	96						
16.45	0.27	69								
17.72	0.11	76								
19.63	0.32	84	0.21	92						
23.19	0.11	84								
25.87	0.22	83								

FIGURE 5 - VOLTAGE GROWTH



Correlation Between +Point and Bobbin Detection

Figure 6 shows the correlation between the +Point max voltage for each indication and the detection of the bandpass filtered bobbin data channel. There were a total of 92 +Point indications in the 12 affected tubes of which 13 were detectable in the bobbin data with pre-knowledge of the +Point results. Nine were detectable without pre-knowledge and produced clear Lissajous signals for analysis. The results show that bobbin detection is well correlated to +Point volts. The lowest +Point voltage detected was 1.23 Vpp and the highest voltage not detected was 1.21 Vpp. The Bandpass filter was applied to the 200 kHz differential channel with a low cut of 33, a high cut of 171 and a sharpness of 23. The +Point voltage was measured from the 300 kHz channel normalized to 20 Vpp on the 100% Circumferential EDM in the Axial Lissajous window. Figure 7 shows the correlation between bobbin detection and +Point average depth, calculated from the line-by-line sizing.

FIGURE 6 - Comparison of Filtered Bobbin Detection to +Point Volts

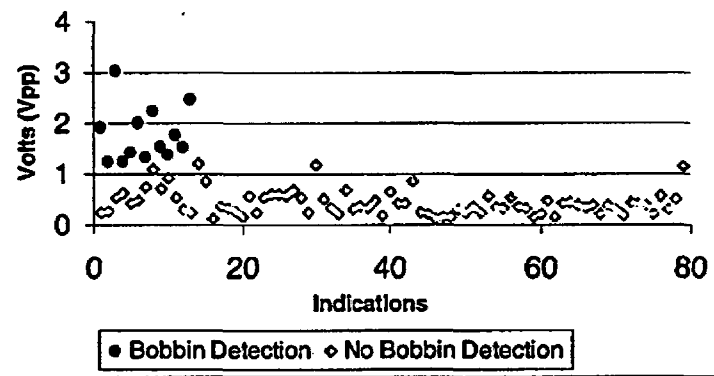
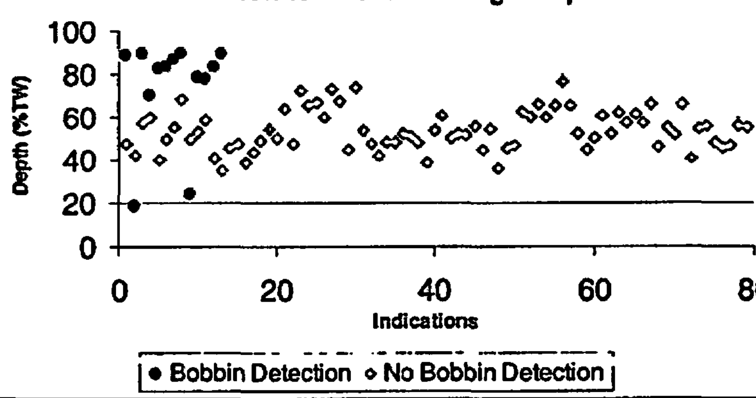


FIGURE 7 - Comparison of Filtered Bobbin Detection to +Point Average Depth



Indicators of Susceptibility

A review of the bobbin and +Point eddy current data was performed in order to see if anything was different between the tubes with U-bend indications and those without. This review involved an analysis of all of the data channels looking for anything peculiar and a side-by-side comparison of the flawed and non-flawed tubes. These peculiarities would be differences in the data between flawed and non-flawed tubes, specifically either localized or broad signal responses that were common to one group and absent in the other. There was nothing identified in either the bobbin or +Point data that could be considered an indicator of susceptibility. Early in the inspection there was thought to be an association with mandrel chatter because the first few tubes with U-bend indications also displayed chatter signals in the bobbin data. All of the tubes with U-bend indications were reviewed for chatter and it was determined to be unrelated when only 5 of the 12 tubes displayed this condition and numerous other non-flawed tubes also displayed this condition (See Table 5).

Investigation of "Ridges"

An investigation was performed to determine the source of the "ridges" in the eddy current C-scan plots since they have a high correlation with the indications. The indications are all located within the "ridge" signals seen by the +Point probe, with one exception. The exception is one indication in SG 23 R4-C52 where the indication is outside, but immediately adjacent to the ridge. These "ridge" signals are attributed to ovalization of the tube as confirmed by the pancake probe and the X-Probe. It is also understood that some degree of tube wall thickness variation exists in this area which may cause a signal response. These "ridge" signals are coincident with the sides or flanks of the tube as confirmed with the down locator in the +Point probe and their correlation with the X-Probe's profilometry plots. The indications are very similar in that, for the most part, they remain within the width of the "ridge".

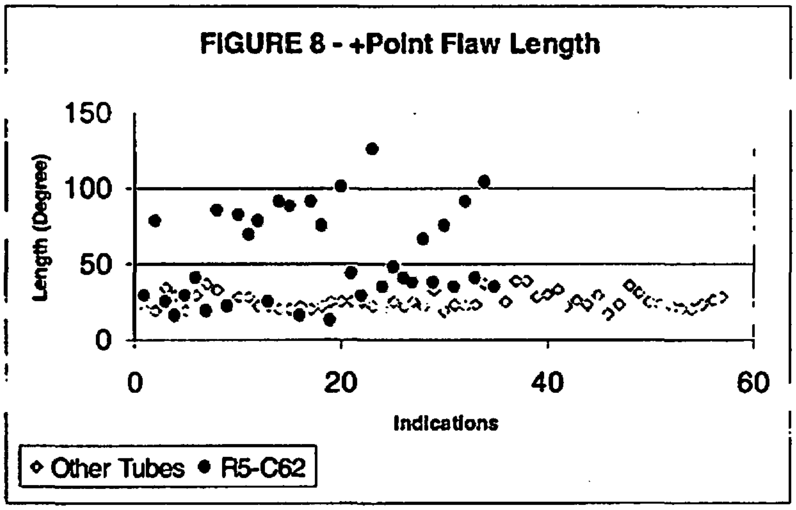
Other plant data was reviewed for these "ridge" signals and they were found in all of the data reviewed. The types of data reviewed included all four steam generators in DCPP Unit 2, data from DCPP Unit 1 which contains both Blairsville and Huntington tubing, data from two other operating plants' steam generators and data from replacement steam generator tubing prior to installation. A common factor for all of the data reviewed is a tendency for the magnitude of the "ridges" to dissipate with increasing row, expected as the tube ovality and wall thickness variation decreases.

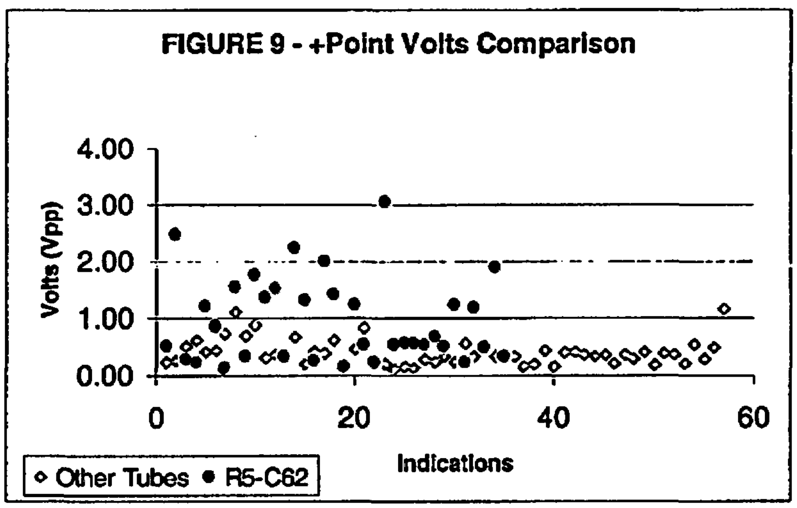
Comparison With Row 1 Indications

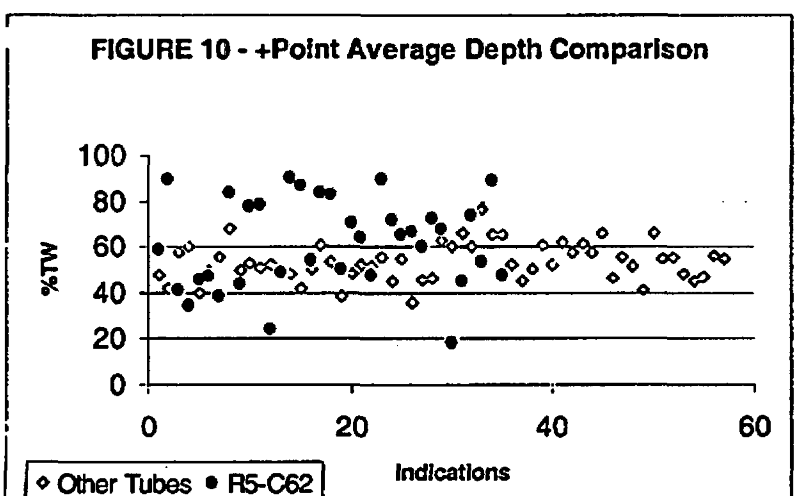
The indications in Rows 1 thru 10 are postulated to be PWSCC. The indications in Rows 3 thru 10 were compared to indications in Row 1 to evaluate similarity. The data for Row 1 tubes included those discovered in 3 tubes during the 2R11 inspection, indications in 9 tubes from previous DCPP Unit 2 inspections, indications in 4 tubes from previous DCPP Unit 1 inspections and 2 tubes from another plant. There were more differences than similarities leading to a conclusion that the indications in Rows 3 thru 10 are not exactly the same as those in Row 1.

The differences are that a few of the indications reviewed are axial in nature and all of the indications in Rows 3 thru 10 are circumferential. All of the Row 1 indications are located on either the intrados or extrados where the Rows 3 thru 10 indications are on the sides of the tube. Being on the top or bottom of the tube, the Row 1 indications are not located within "ridges". The signal formation of the Row 1 indications show some differences, primarily due to influences from the tangents or their large amplitudes, and their arc lengths vary widely. All of the indications in Rows 1 thru 10 were ID originated and produced linear crack-like responses. A couple of the Row 1 indications are located on the edges of the tangent, placing them close to the tube flanks, and have similar amplitude and appearance to the Row 3 thru 10 indications.

Comparison of R5-C62 With The Other 11 Tubes







Observations For Rows 3 thru 10

Summary of Observations

- The indications are restricted to Rows 3 thru 10.
- The majority of the indications, for all steam generators, are concentrated in a few basic areas of the tube bundle.
- The indications originate from the inside surface of the tube.
- The indications are circumferential but slightly off-axis based on pancake coil and visual.
- The indications off-axis angle is similar for multiple flaws.
- The indications are aligned within a "ridge" signal except for one indication.
- Most tubes have indications along only one "ridge" meaning they are at the same angular (circumferential) position and only 3 of the tubes have indications on two sides of the tube.
- The "ridges" were determined to be caused by tube ovalization and are common to all plants reviewed including new replacement SG tubing.
- The flaw lengths are short and, for the most part, contained within the "ridge" signal.
- Tubes with a single indication have it at the tangent, except for one.
- Tubes with a single indication have it located at the cold leg tangent.
- A number of the indications in SG 24 R5-C62 have considerably higher +Point voltages than the other 11 tubes. This also explains why bobbin detection exists for only this tube.
- The two angular positioning methods used (magnetic indexing probe and down locator in the rotating probe) agree on the position of the indications in SG 24 R5-C62.
- The angular position of the indications in 11 tubes is the same, meaning the indications are on the same side of the tube in these cases.
- The angular position of the sole indication in SG 24 R6-C53 is the same as the 3 tubes with indications on both sides of the tube.
- A special calibration using a filtered data channel greatly improves the bobbin detection, from 3 indications using the raw unfiltered data to 13 indications with the filter (applying knowledge of the +Point results in both cases). The filter also produces clear forming Lissajous signals that are easy to recognize for 9 of these indications.
- An excellent correlation between bobbin detection and +Point volts exists for SG 24 R5-C62 showing that the lack of bobbin detection in the other 11 tubes is due primarily to the depth of the indications (voltage being a reasonable indicator of depth for cracks and R5-C62 known to be leaking). This is supported by a similar comparison to +Point average depth.
- A review of historical bobbin data for SG 24 R5-C62 shows evidence of indications as far back as 1996.
- A review of the historical bobbin data for SG 24 R5-C62 shows an increase in the number of detectable indications between 1996 and 2003 as well as an increase in the bobbin voltages of these signals.
- There were no indicators in the bobbin or +Point data that could be used to identify susceptible tubes.
- The Row 1 indications displayed more differences than similarities in the eddy current data, due primarily to their location and dimensional characteristics, even though all of the indications are suspect of being PWSCC.

FIGURE 11 - SG 21 Row 5 Column 54

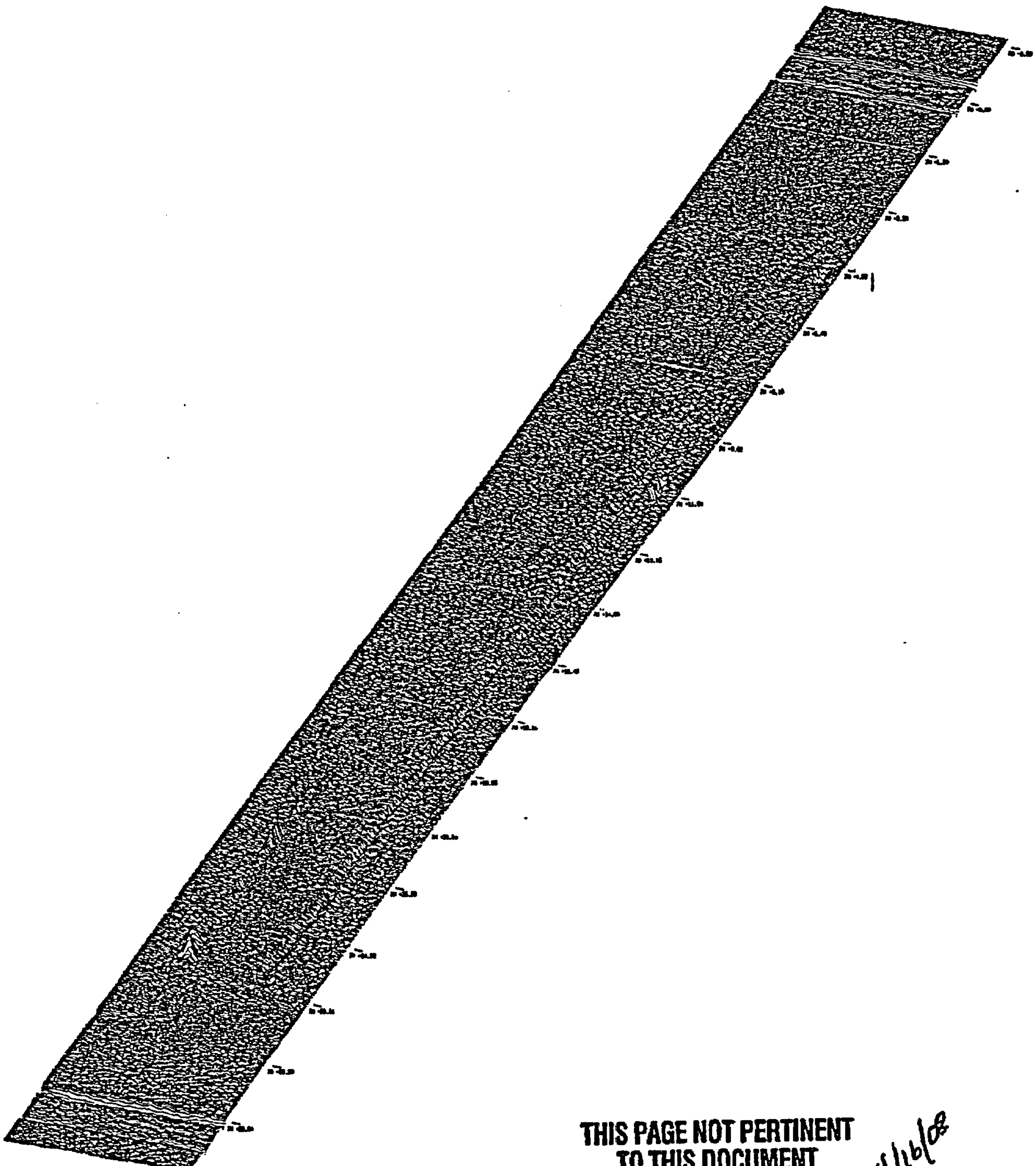


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FIGURE 12 – SG 22 Row 4 Column 51

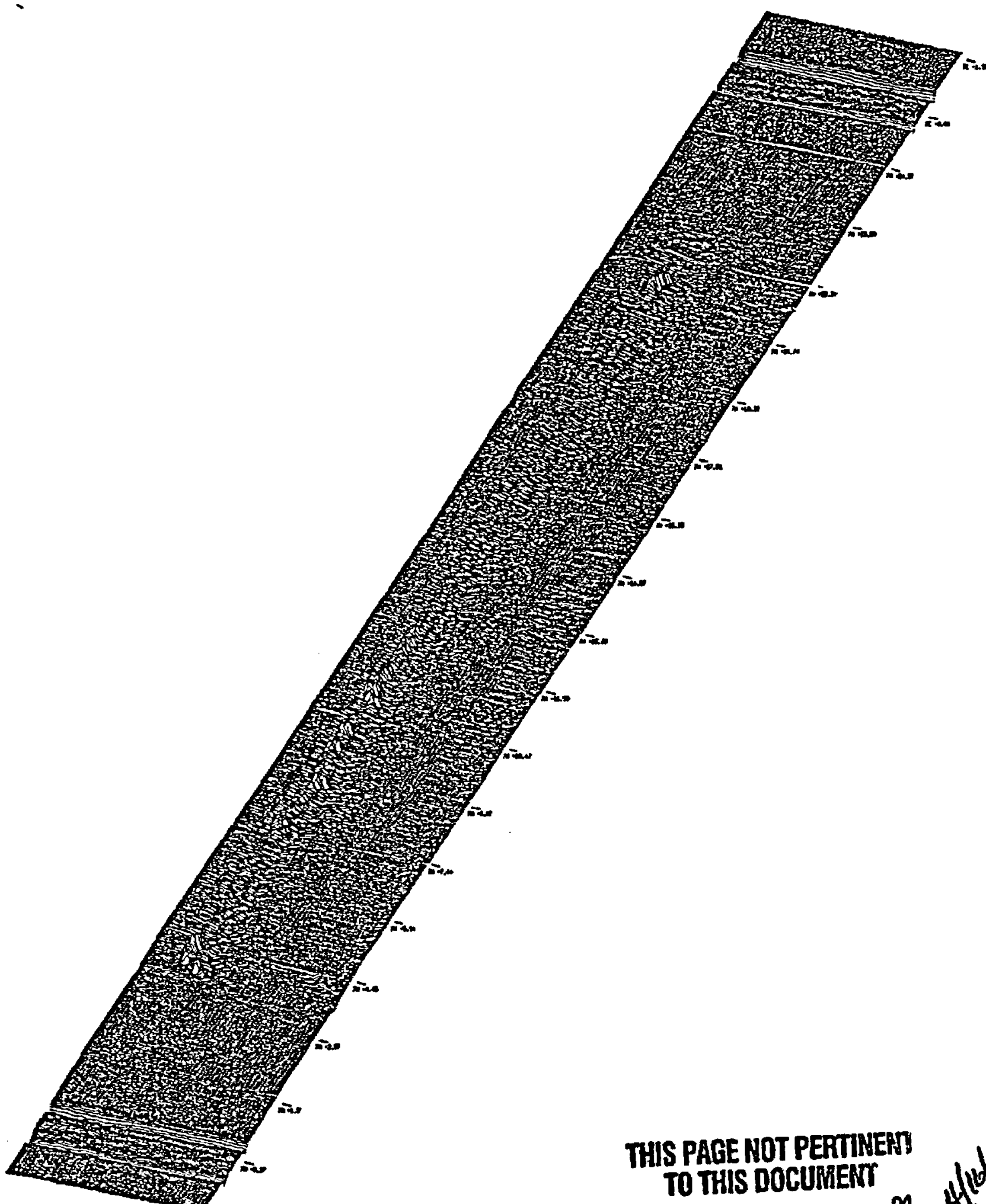

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FIGURE 13 – SG 22 Row 10 Column 19

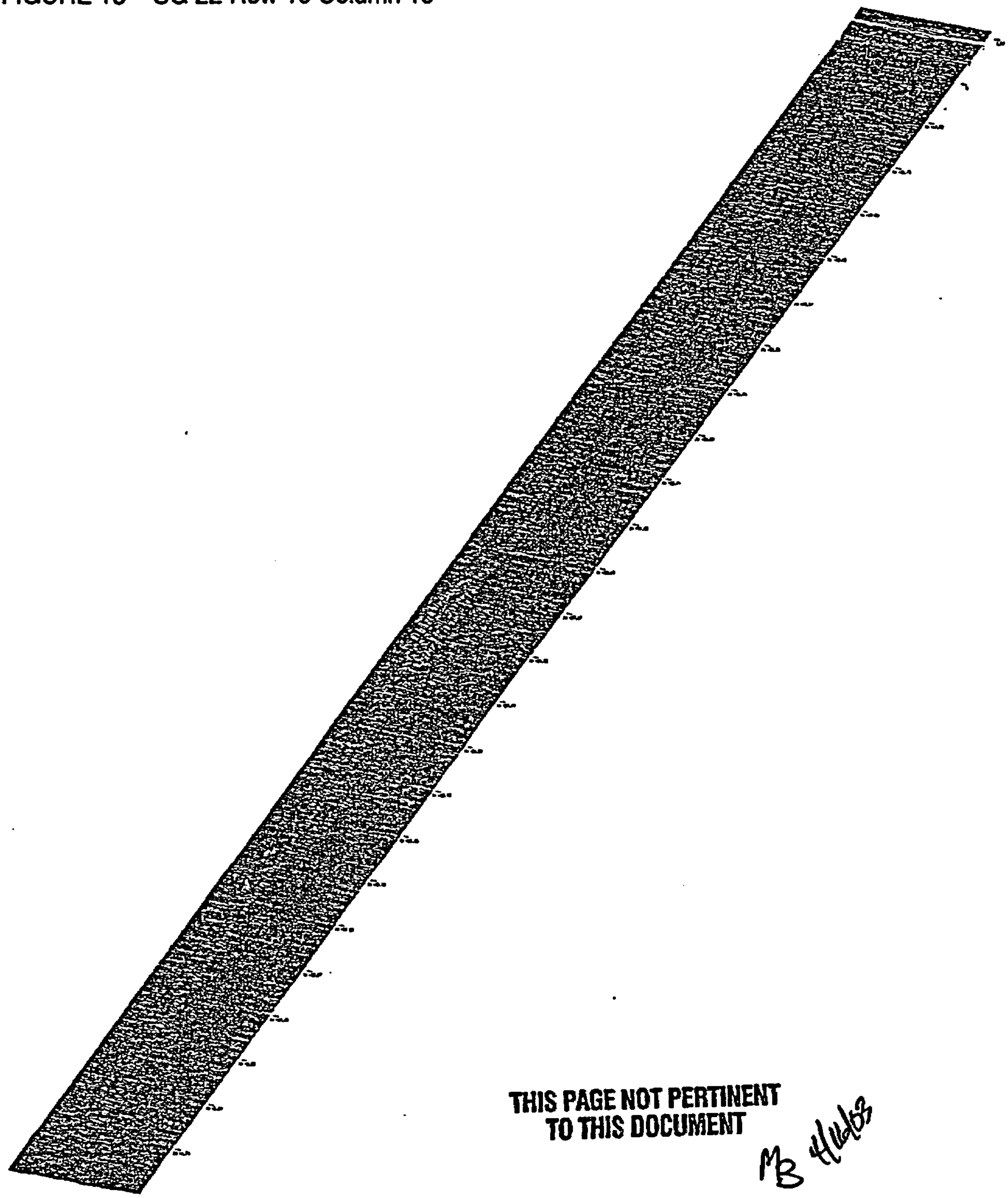

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FIGURE 14 – SG 23 Row 3 Column 86

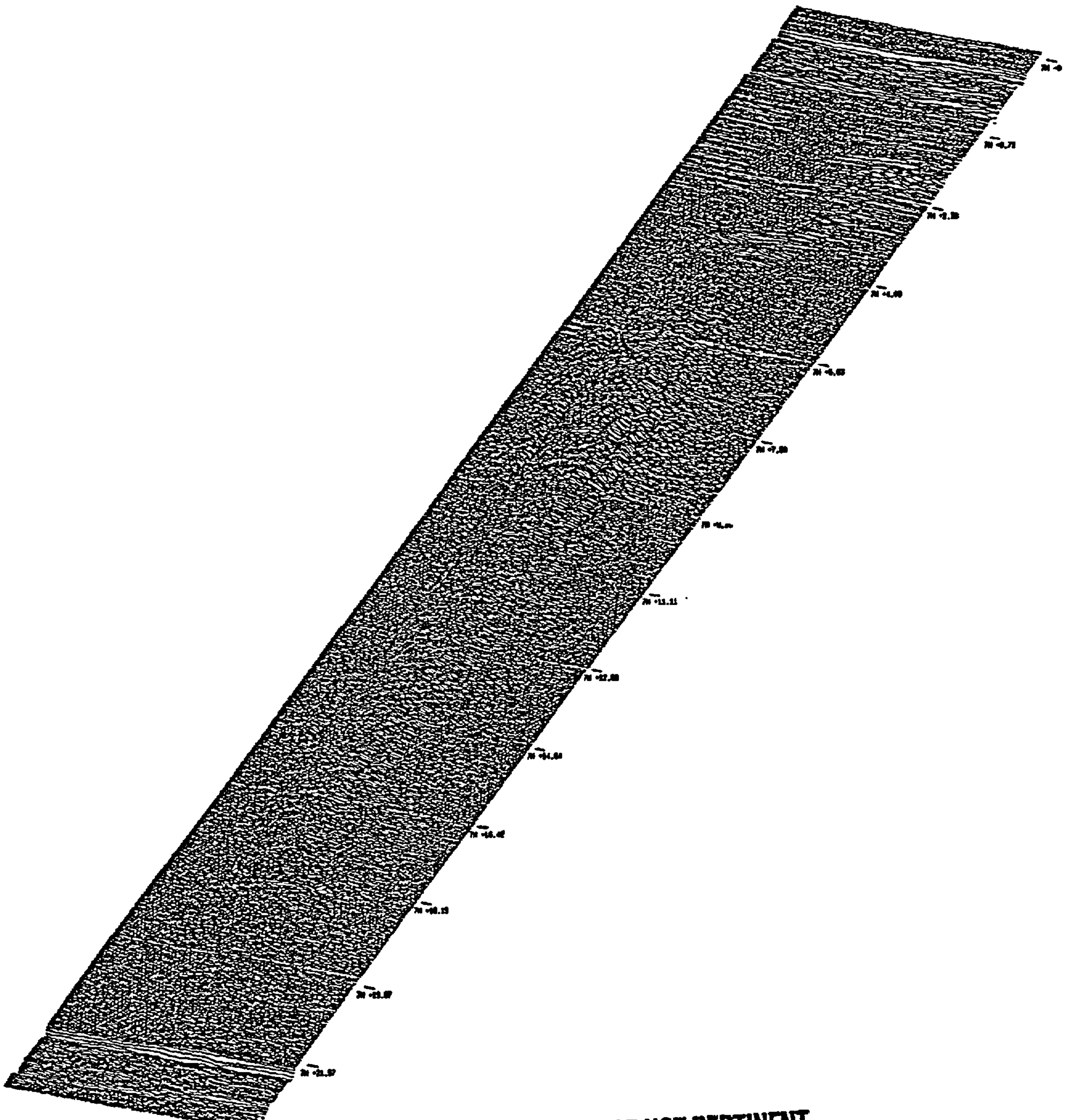

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FIGURE 15 – SG 23 Row 3 Column 93

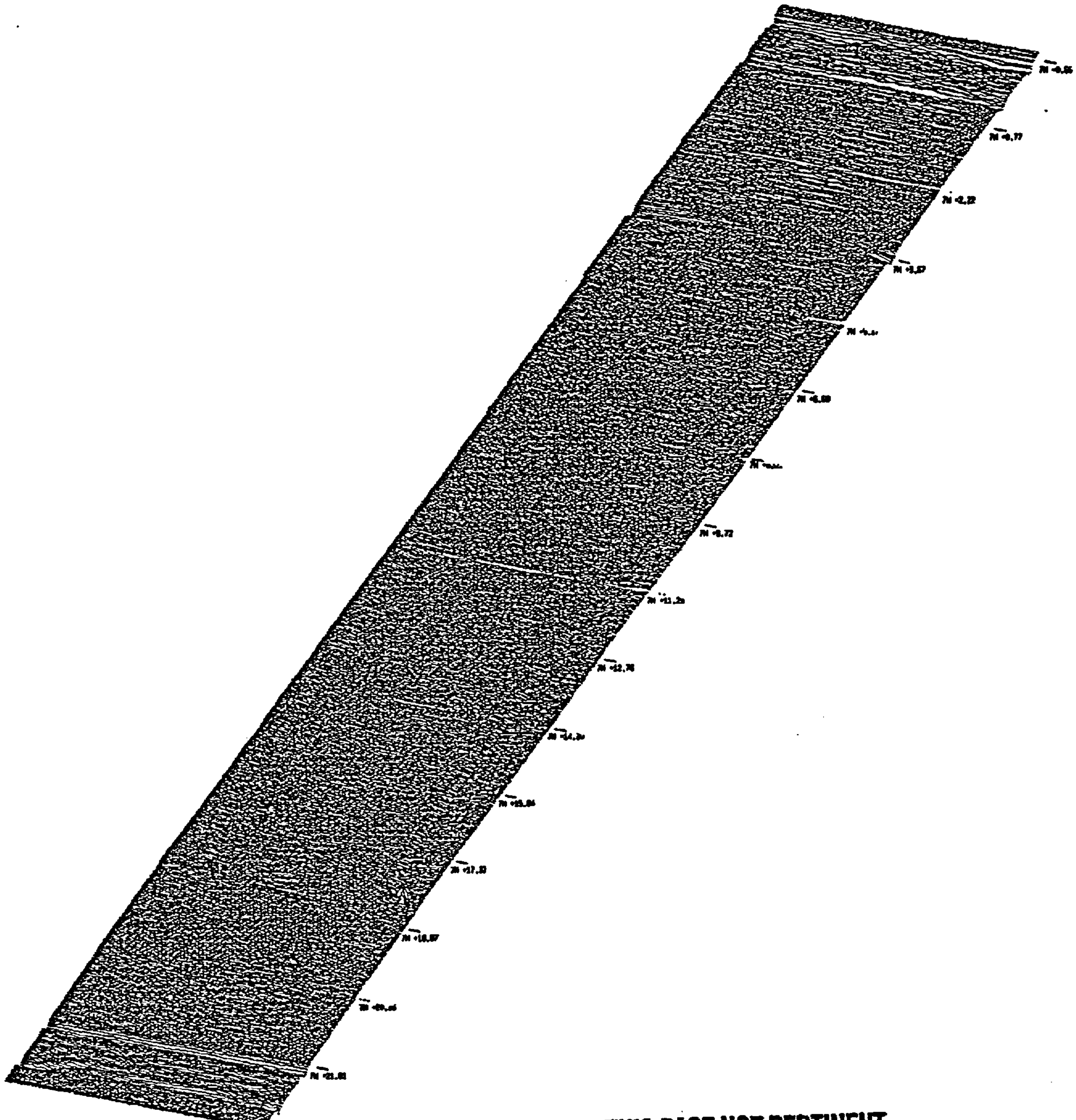

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FIGURE 16 – SG 23 Row 4 Column 52

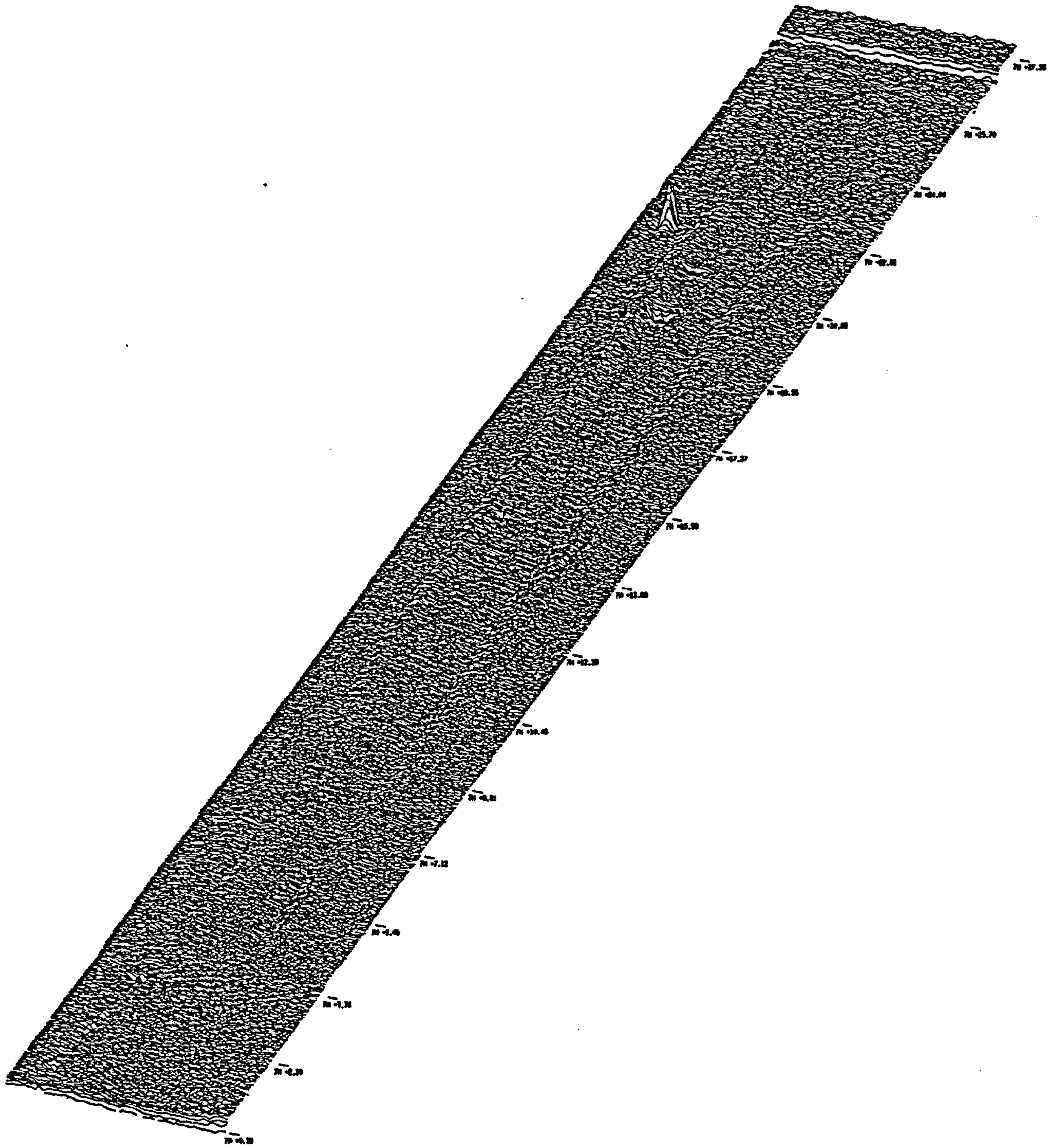

FIGURE 17 – SG 24 Row 5 Column 60

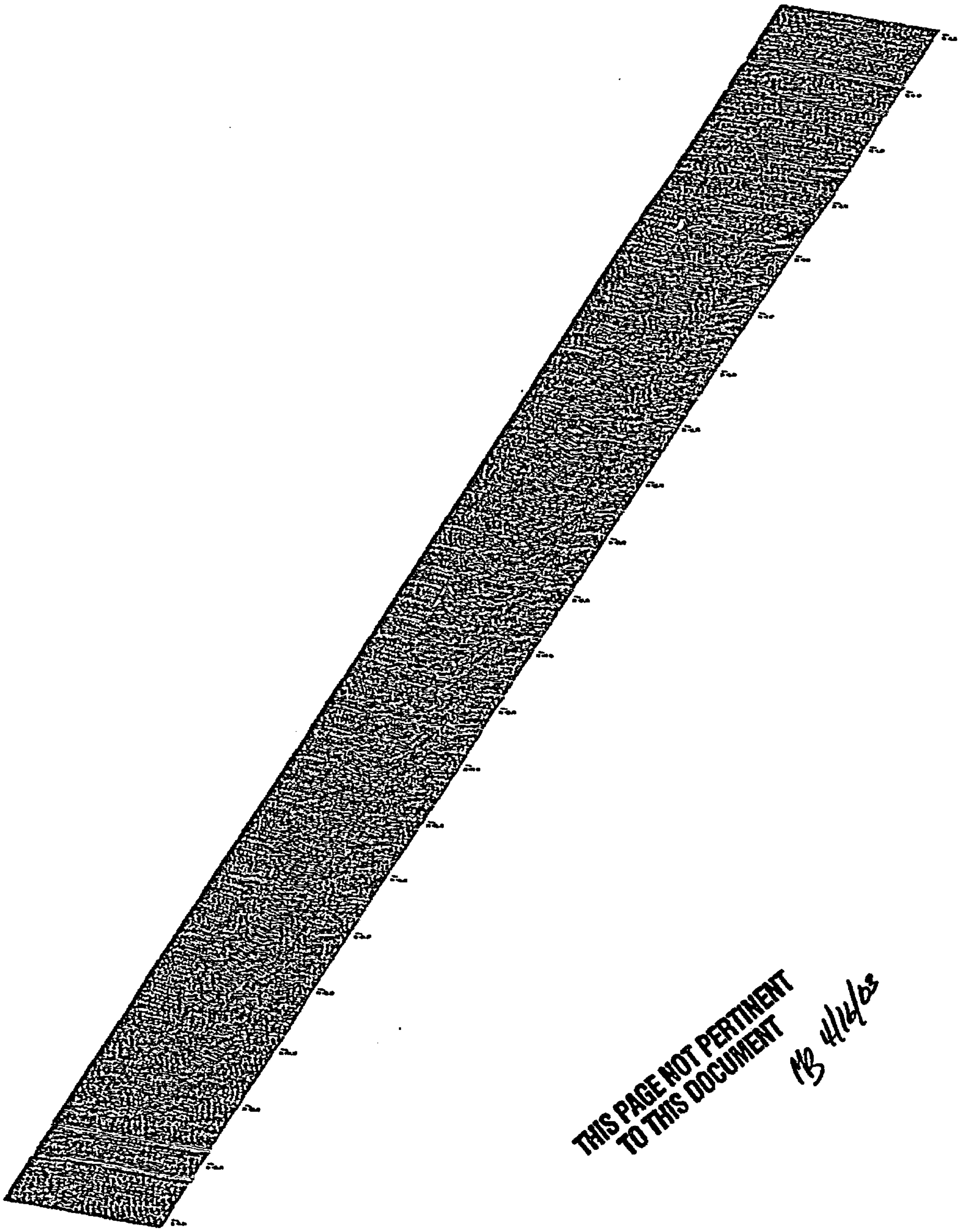

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FIGURE 18 – SG 24 Row 5 Column 62

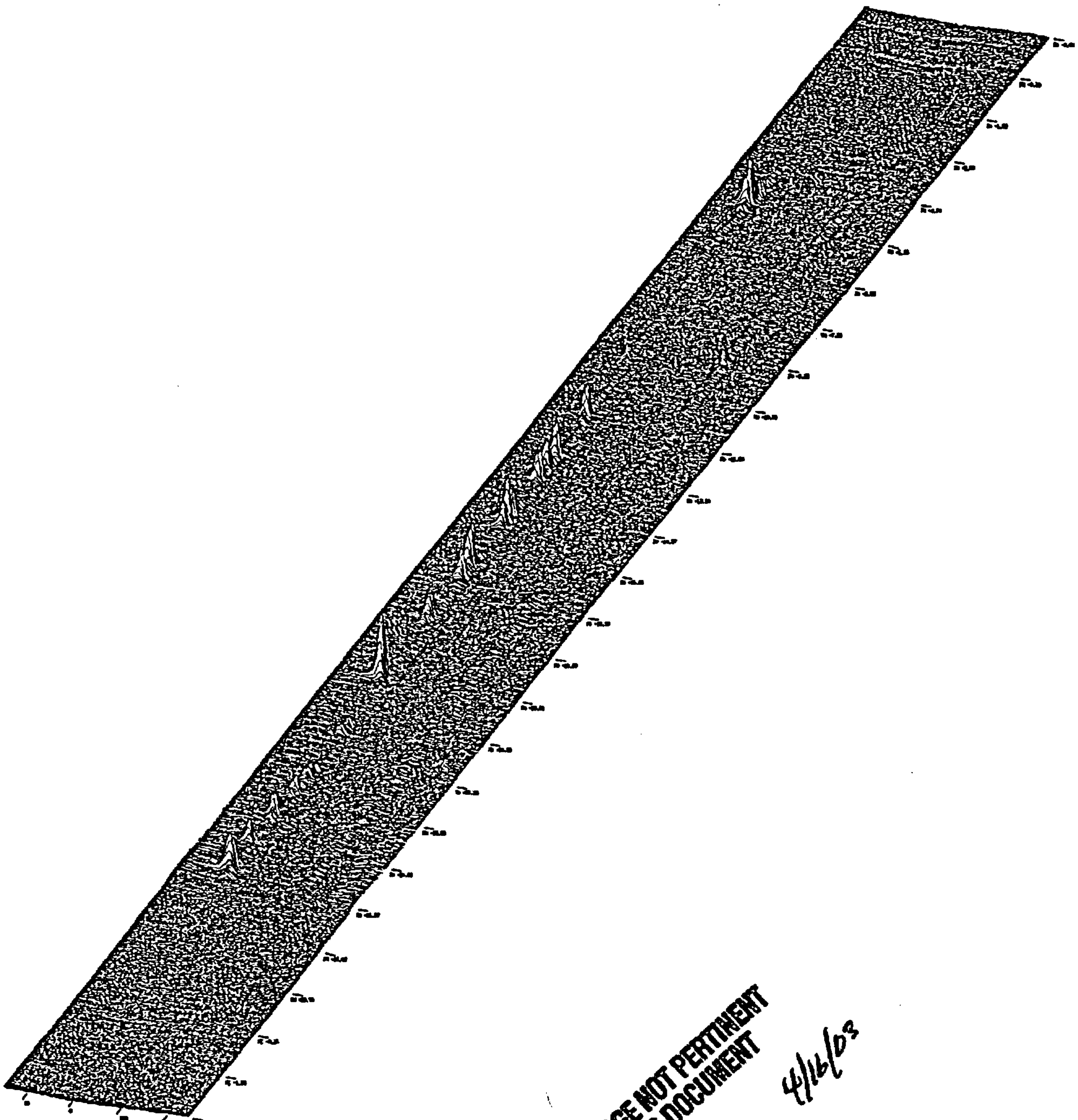

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FIGURE 19 – SG 24 Row 5 Column 68

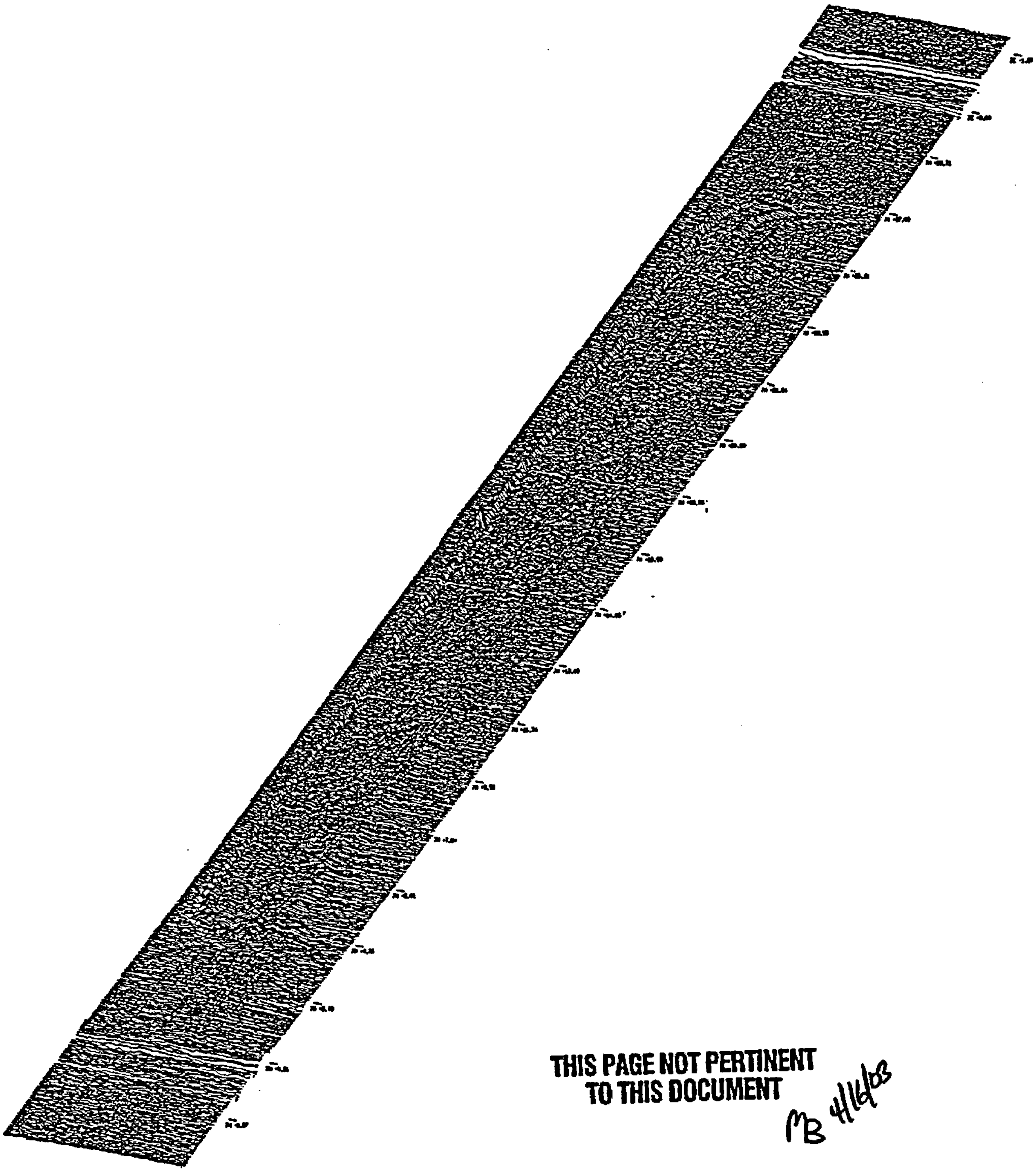

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FIGURE 20 – SG 24 Row 6 Column 23

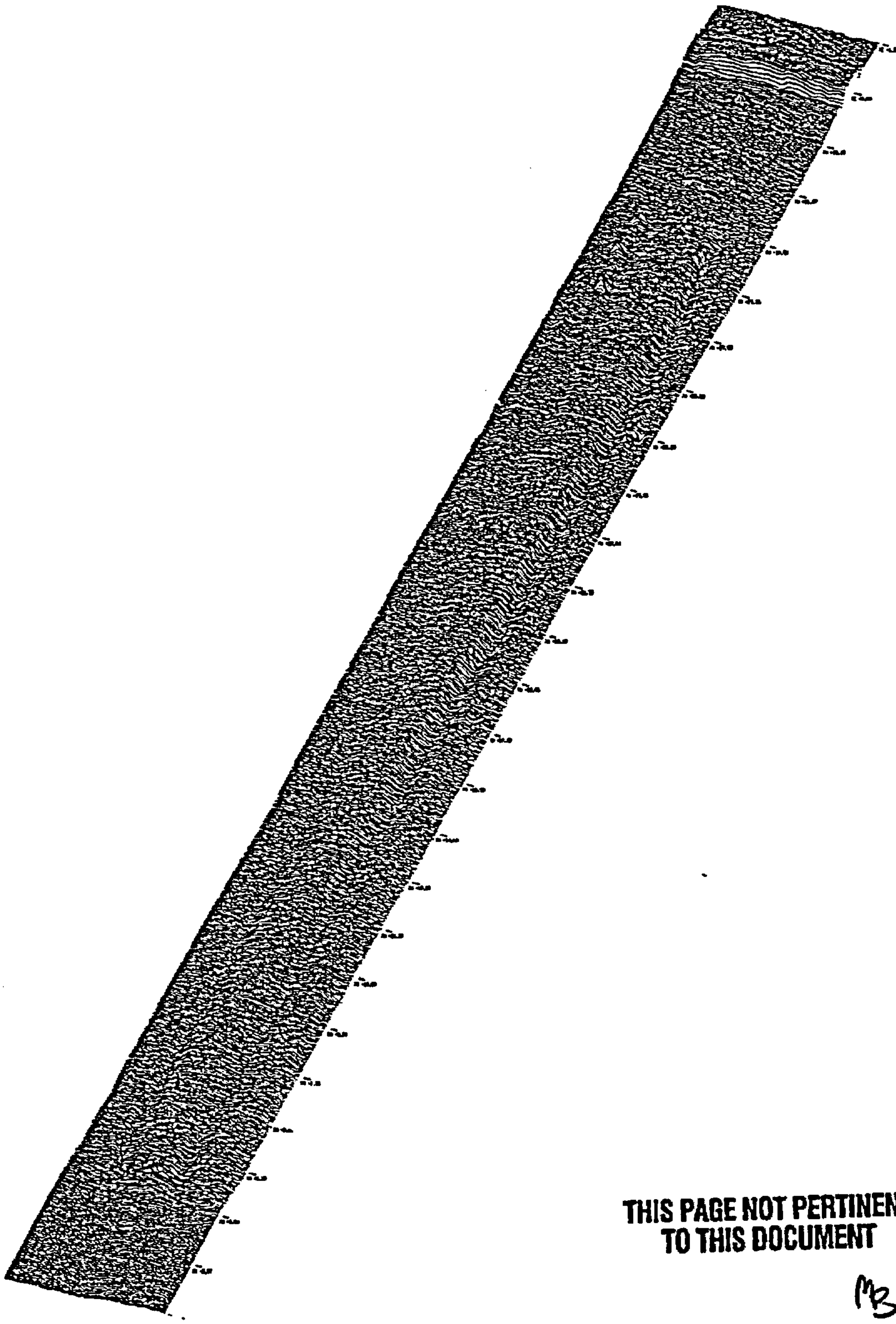

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FIGURE 21 – SG 24 Row 6 Column 53

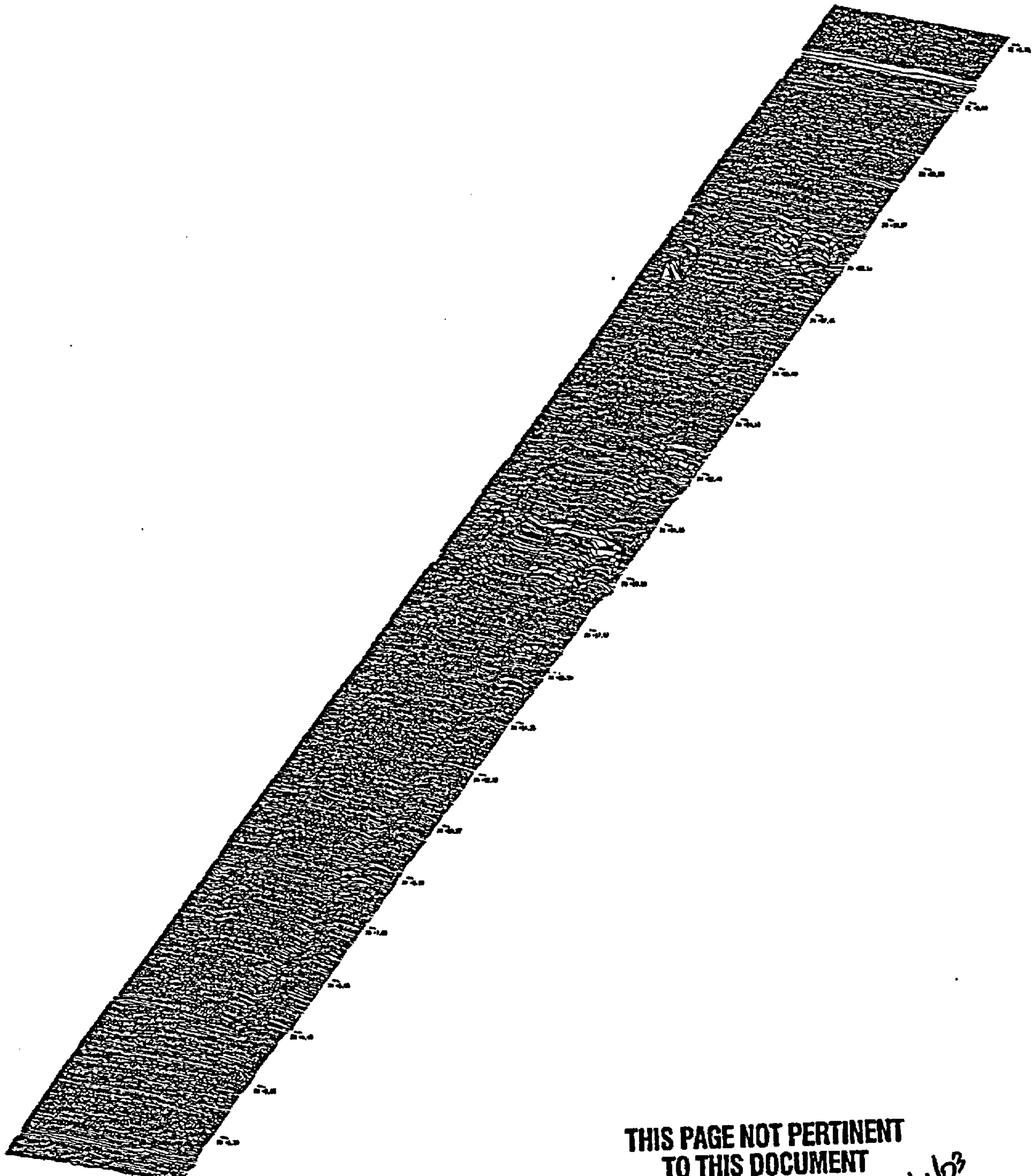

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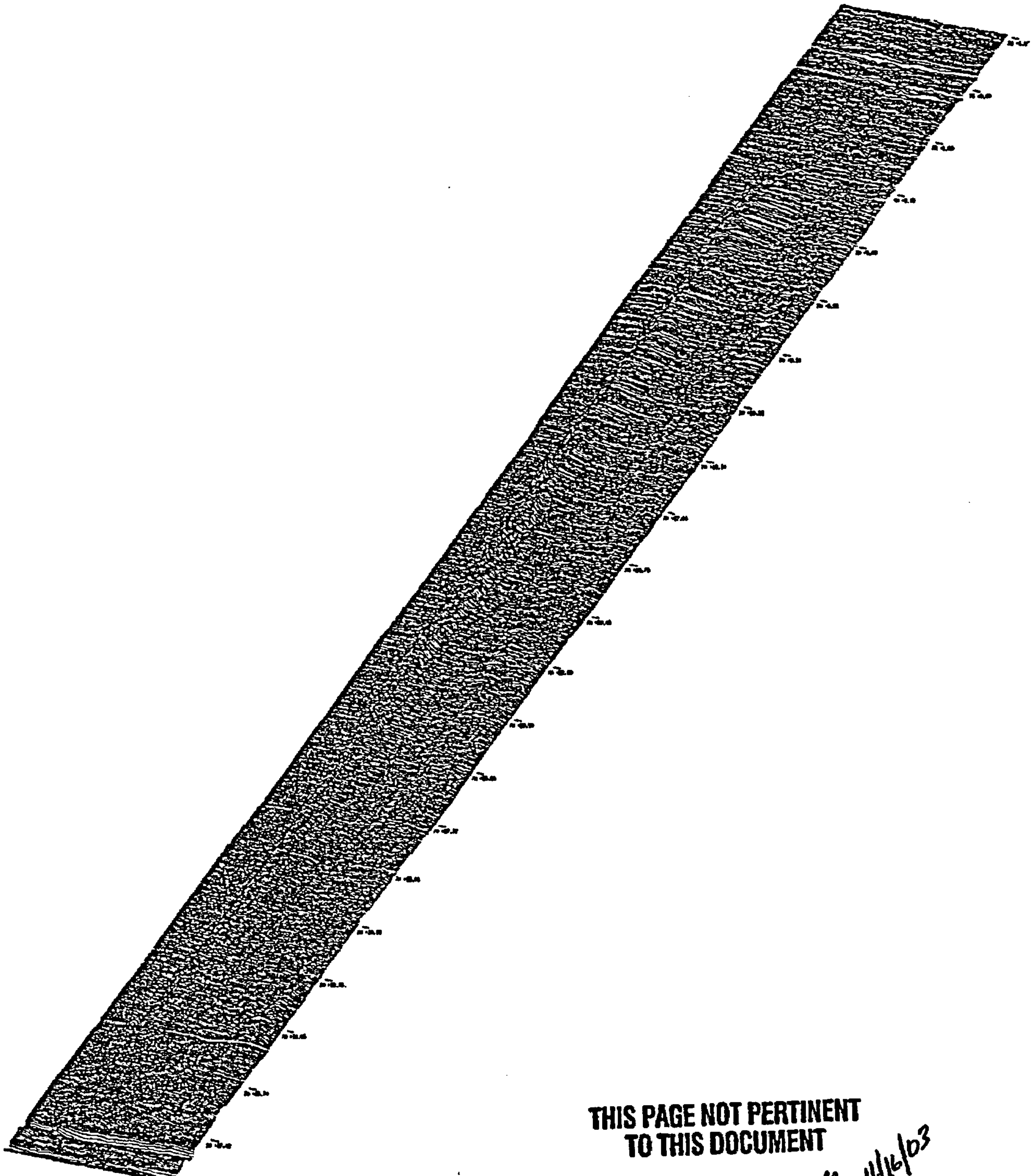
FIGURE 22 – SG 24 Row 7 Column 52



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SPECIAL REPORT 03-02

ENCLOSURE 4

FRAMATOME ANP REPORT 86-5029429-00
"DCPP 2R11 BOBBIN VOLTAGE ARC 90 DAY SUMMARY REPORT"

20697-6 (2/2002)

FRAMATOME ANP

CALCULATION SUMMARY SHEET (CSS)

Document Identifier 86 - 5029429 - 00

Title DCPP 2R11 BOBBIN VOLTAGE ARC 90 DAY SUMMARY REPORT

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		METHOD: ☒ DETAILED CHECK ☐ INDEPENDENT CALCULATION	
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TITLE MANAGER	DATE 6/23/03	TITLE ENGINEER IV	DATE 6/23/03
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PURPOSE AND SUMMARY OF RESULTS:

This report summarizes the Diablo Canyon Unit 2 - 2R11 February 2003 inspection of the steam generator tubing with respect to the implementation of the Voltage-based Repair Criteria as specified in NRC Generic Letter 95-05. This document provides the "as-found" and final operational assessment probability of burst and leak rate calculations needed for cycle 12 operation. This report provides a non-proprietary summary of the results. The supporting proprietary calculations and necessary code verifications required for safety-related calculations are contained in Ref. 23.

THE FOLLOWING COMPUTER CODES HAVE BEEN USED IN THIS DOCUMENT:

CODE/VERSION/REV	CODE/VERSION/REV
LKR97VB2 Rev 2 and 3	POB97VB2 1.1 and 2

THE DOCUMENT CONTAINS ASSUMPTIONS THAT MUST BE VERIFIED PRIOR TO USE ON SAFETY-RELATED WORK

☐ YES ☒ NO

RECORD OF REVISIONS

Revision Number	Affected Page(s)	Description of Change(s)
0	All	Original Release

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LIST OF TABLES AND FIGURES

Glossary of Acronyms

Term	Definition
AONDB	Axial ODSCC Not Detected by Bobbin
ARC	Alternate Repair Criteria
BOC	Beginning of Cycle
CPDF	Cumulative Probability Distribution Function
CFR	Code of Federal Regulations
CLT	Cold-Leg Thinning
DCPP	Diablo Canyon Power Plant
DIS	Distorted ID Support Signal with possible Indication
DOS	Distorted OD Support Signal with possible Indication
DNF	Degradation Not Found
EFPD	Effective Full Power Day
EFPY	Effective Full Power Year
ECT	Eddy Current Test
EOC	End of Cycle
FS	Free Span
FANP	Framatome Advanced Nuclear Power
GL	NRC Generic Letter 95-05
GPM	Gallons per Minute
ISI	In-service Inspection
LRL	Lower Repair Limit
LU	Lookup
MSLB	Main Steam Line Break
NDE	Non Destructive Examination
NDD	No Degradation Detected
NRC	Nuclear Regulatory Commission
ODSCC	Outside Diameter Stress Corrosion Cracking
PG&E	Pacific Gas and Electric Company
POB	Probability of Burst
POD	Probability of Detection
POPCD	Probability of Prior Cycle Detection
POL	Probability of Leak
PWSCC	Primary Water Stress Corrosion Cracking
RPC	Rotating Pancake Coil
RSS	Retest Support Plate Signal
RTS	Return to Service
SG	Steam Generator
SER	Safety Evaluation Report
TS	Technical Specification
TSP	Tube Support Plate
VDG	Voltage Dependent Growth

1.0 Introduction

The Diablo Canyon Power Plant (DCPP) Unit 2 completed the eleventh cycle of operation and subsequent steam generator ISI in March 2003. The unit employs four Westinghouse-designed Model 51 SGs with ⅞-inch OD mill annealed alloy 600 tubing and ¾-inch carbon steel drilled-hole tube support plates.

In accordance with the Generic Letter 95-05, ARC implementation requires a pre-startup assessment (Ref. 1) and a 90-day post-startup tube integrity assessment. The NRC Generic Letter 95-05, Ref. 2, outlines an alternate repair criterion (ARC) for allowing tubes containing ODSCC indications to remain in service if the indications are contained within the TSP structure and the measured Bobbin voltage is $\leq$2.0 volts. A complete list of criteria for excluding TSP intersections from ARC application is provided in section 1.b of Ref. 2 and in Ref. 3. The NRC has approved implementation of the voltage-based repair criteria at both DCPP units per Ref. 3. The steam generator TSP inspection results and the postulated MSLB leak rate and tube burst probabilities are summarized in this report. FANP uses Monte Carlo codes, as described in Refs. 4 and 5, to provide the burst and leak rate analysis simulations. These evaluations are based on the methods in Ref. 6 (for burst) and the new slope sampling method for calculating the leak rate as defined in Ref. 8.

2.0 Executive Summary

During Cycle 11 at DCPP Unit 2, the tubes experienced a higher than predicted voltage dependent growth (VDG) of the axial ODSCC indications that remained inservice at EOC-10. Included in this population was tube SG 2-4 R44C45, that grew from 2.0 volts (bobbin) to 21.5 volts during Cycle 11. Based on the number and the size of the indications, SG 2-4 is predicted to be the limiting generator for Diablo Canyon Unit 2 at the end of Cycle 12. SG 2-4 experienced higher than predicted voltage dependent growth, where the larger indications that were returned to service at EOC-11 grew faster than the smaller indications, as measured by bobbin voltage. These results coupled with the 21.5-volt bobbin indication detected in SG 2-4, did not permit satisfaction of the GL 95-05 1% POB reporting threshold for any cycle length using the NRC approved POD (probability of detection) of 0.6. Satisfaction of the POB reporting threshold was achieved with the use of a POD of 1.0 for the 21.5-volt flaw. The use of this POD was subsequently approved by the NRC in Ref. 22. Meetings and correspondence with NRC Staff requested NRC approval of a voltage-dependent POD, or POPCD (probability of prior cycle detection), strategy for DCPP-2 Cycle 12. NRC approval of POPCD for use in Cycle 12 is pending. The use of DCPP POPCD in combination with a VDG strategy results in meeting the GL 95-05 acceptance criteria for leak and POB at EOC-12.

The breakdown of all indications, including those axial indications not detectable by bobbin coil (AONDB), applicable to the voltage-based repair criteria for condition monitoring is as follows: 350 in SG 2-1, 278 in SG 2-2, 263 in SG 2-3, and 982 in SG 2-4, for a total of 1873. The BOC-12 (beginning of cycle) distributions were calculated using both a POD of 0.6 and DCPP POPCD for inservice tubes and then subtracting the repaired indications. In the cases where the NRC POD of 0.6 was used, a POD of 1.0 was used for the 21.5-volt indication in SG 2-4. For the application of the DCPP POPCD, the transformation was performed during the Monte Carlo simulation process, as described in Ref. 10.

During 2R11, 88 DOS indications greater than the lower repair limit of 2.0 volts were detected in all four SGs. All of these indications confirmed as axial ODSCC and were removed from service by plugging. In addition to tubes requiring repair, the decision was made during the outage to repair confirmed DOS indications >1.2 Volts to aid in reducing the potential for fast growing indications, as well as justifying a full cycle of operation based on POPCD, voltage dependent growth, and worst case burst pressure result assumptions from the pulled tubes from DCPP-2. Using the NRC approved POD combination (0.6 for all indications except 1.0 for R44C45) in conjunction with VDG for Unit 2 Cycle 12 planned operation of 1.54 EFPY, results in exceeding the POB threshold of $1x10^{-2}$ at EOC-12 in two SGs. SG 2-4 is the limiting SG, surpassing the threshold at approximately 0.53 EFPY into Cycle 12. Even though the large indication is removed from the BOC distribution, the remaining fractional population of higher voltage indications in SG 2-4 that are assumed to be present at BOC-12 from the application of the 0.6 POD in combination with the potential of another indication growing at 11.9 v/EFPY, projects very high voltages at EOC-12, and thus a high POB. Utilizing a DCPP-specific POPCD in conjunction with VDG, the EOC-12 POB is predicted to be $5.5x10^{-3}$ for SG 2-4, thus meeting the POB threshold. Predicted MSLB leakage using either POD of 0.6, a combination POD (0.6./1.0 for R44C45), or POPCD, does not exceed the DCPP-2 leakage criteria of 10.5 gpm at EOC-12.

A total of 1864 DOS indications were found in active tubes during the EOC-11 inspection, of which 338 were over 1 volt, and 88 were over 2 volts. Of the 855 Plus-point inspections of DOS indications, 752 were confirmed yielding an overall confirmation rate of about 88%. All hot leg indications > 1.2 volts were confirmed by Plus-point inspection and repaired by plugging, as previously stated. 9 additional indications in active tubes were identified as AONDB (axial ODSCC not detected by bobbin). All of the inferred voltages for these indications were less than 1 volt, but only three of these indications were actually returned to service (RTS) for Cycle 12, most being repaired for other reasons in the affected tubes.

The leak rate and burst pressure correlations for the CM analysis were based on the latest NRC approved database for 7/8" tubing (Ref. 8). The operational assessment utilized the revised database that included the two pulled tube specimens from DCPP Unit 2 this outage. The FANP *Leaker* and *Burst* Monte Carlo codes that are based on Refs. 6, 8, and 10 methods, are used to provide the burst and leak rate analysis results for this report.

3.0 EOC-11 Inspection Results and Voltage Growth Rates

3.1 EOC-11 Inspection Results

The DCPP 2R11 bobbin coil inspection consisted of a 100% complete full-length bobbin coil examination of tubes in all four steam generators. 0.720" replaceable feet bobbin probes were used for the straight length examinations including all TSP intersections in the hot and cold legs. Special interest Plus-point examinations were conducted as follows in support of the voltage-based ARC.

- 100% of DOS greater than 2 volts (as identified in Ref. 12)
- 100% of DOS greater than 1.0 volts in all SGs and 100% of DOS less than 1.0 volt in SG 2-1 (as augmented during 2R11)
- 100% of DOS in dented intersections (as identified in Ref. 12)
- 100% of DIS (distorted ID support signal at dented intersection)
- Dented TSP examinations (as identified in Ref. 12)
- Other Special Interest or test programs that may test TSP intersections (as identified in Ref. 12)

Based upon the 100% bobbin inspection of all steam generators, a total of 1864 DOS indications were identified. The results of the inspections are summarized as follows:

1. A single indication of 21.5 volts was detected in SG 2-4, the largest indication to date detected in all US Westinghouse Series-51 operating plants.
2. Voltage Dependent Growth was dominant in SG 2-4 and also increased in the other SGs.
3. 88 DOS indications were greater than the lower repair limit (LRL- 2.0 volts). Each of the indications were confirmed as ODSCC, required repair by plugging, and were distributed as follows: 10 in SG 2-1, 5 in SG 2-2, 5 in SG 2-3 and 68 in SG 2-4. Table 3-1 lists the DOS indications that were above the LRL (2.0 volts).
4. 9 indications were identified as AONDB (axial ODSCC not detected by bobbin). Table 3-2 lists the indications that were identified as AONDB. These are Plus-Point indications of axial ODSCC that have no signal present in the bobbin coil data (no DOS signal). These locations are typically smaller voltage ODSCC, by Plus-Point, and can be accompanied by a dent that masks the bobbin voltage. Per Ref. 8, a methodology has been developed to assign a bobbin voltage based on a correlation to the Plus-Point voltage. Once the calculated voltages are obtained, the locations are subjected to exclusion criteria defined in Ref. 12.
5. During the course of 2R11, the decision to repair DOS > 1.2 volts, preventively, was executed in all SGs to aid in reducing the potential of fast growing indications as well as permitting analyses to justify a full cycle of operation during Cycle 12.
6. Overall, 363 DOS/AONDB indications were repaired during 2R11. The breakdown is: 38 in SG 2-1, 28 in SG 2-2, 32 in SG 2-3, and 265 in SG 2-4. This population was used in computing the BOC-12 distributions for the OA calculations.

The average voltage was 0.76 volts, including AONDB indications. The 2R10 average was 0.72 volts. The majority of the largest voltages were detected in SG 2-4 and 2-1, and SG 2-4 had the highest average voltage of 0.89 volts.

Table 3-3 summarizes the voltage distributions for the as-found condition of the indications, the repaired indications, indications returned to service that were either confirmed by Plus-point or not inspected with Plus-point, and finally, the total indications returned to service. Eighty-eight confirmed DOS had to be repaired because they exceeded the 2-volt repair limit. 164 confirmed DOS were repaired between 1.2 and 2.0 volts. The other main reasons for repair of the other 111 DOS included DOS > 1.2v at different intersections in the same tube, the wedge exclusion criterion, and combined ID/OD degradation at the same intersection, as well as other degradation occurring elsewhere in the tubes.

The Plus-point inspections required for DOS indications were accomplished as a part of the special interest exams. The 2R11 Plus-point inspection scope also included greater than 2 volt dents based on criteria in the degradation assessment (Ref. 9). 855 Plus-point inspections were performed where DOS indications were called by bobbin, excluding the AONDB intersections. Of these inspections, 752 were confirmed yielding an overall confirmation rate of about 88%.

Figures 3-1 and 3-2 show the actual bobbin voltage distribution for all tubes that were in service during Cycle 11. Figures 3-3 and 3-4 show the indications removed from service at 2R11. Figures 3-5 and 3-6 illustrate all the indications returned to service following the 2R11 ECT inspection. Table 3-1 shows all of the indications greater than the 2.0-volt lower repair limit. As previously stated, all of these indications were confirmed as axial ODSCC and were removed from service by plugging.

The DOS voltage distribution as a function of TSP elevation is provided in Table 3-5. Table 3-5 and Figure 3-7 show that the ODSCC mechanism is most active at the lower hot leg TSPs, and the number of indications tends to decrease as a function of higher TSP elevations. This distribution shows the temperature dependence of ODSCC. At DCPP-2, potential cold leg ODSCC indications are separated from cold leg thinning indications by requiring that bobbin indications in the region of occurrence for cold leg thinning per Ref. 12, be confirmed as volumetric indications by Plus-Point at the first occurrence of the bobbin indication. However, no cold leg ODSCC has been detected to date at DCPP-2.

3.2 *Voltage Growth Rates*

For projection of leak rates and tube burst probabilities at the EOC-12 operation, voltage growth rates were developed from the 2R11 inspection data. Cycle 11 was 1.643 EFPY in length per Ref. 18. For indications not reported during the 2R10 inspection (i.e. new at 2R11), the indications were sized using the 2R10 ECT signals based on a lookup review. There were 1009 newly reported DOS indications in 2R11. Of these 1009 new indications, 998 were detected during the 2R10 lookup and were assigned a 2R10 voltage. The remaining 11 indications were not detectable during the lookup (LU) and were, therefore, not included in the growth rate calculations per GL 95-05. The highest 2R11 voltage of a 2R10 NDD-LU indication is 0.38, indicating that indications initiating during Cycle 11 were not growing at a fast rate. Additionally, the average upper 95% growth rate of all new indications was 0.25v/EFPY, again indicating that new indications are not growing fast. Table 3-4 provides a summary of indications with the largest growth during Cycle 11. Table 3-5 provides the maximum and average voltage growth distribution by TSP. Table 3-6 provides the average BOC voltage, average growth rate data and average percent growth for the last four cycles at DCPP-2. Figure 3-29 depicts this information graphically and shows the increase in growth rate and the slight

decrease in average BOC voltage, reflecting the impact of a large number of new low voltage indications detected in 2R11. Table 3-7 shows the voltage independent growth distributions for each SG and the composite for all four SGs. The cumulative probability distribution function is also provided here. Figures 3-8 and 3-9 show the voltage growth distributions depicted in bar charts. The negative growth values were included as zero growth rates, as required by Generic Letter 95-05. Reviewing the average and maximum voltage growth for all indications for each SG as well as the number of new indications in each SG shows that the ODSCC mechanism is most active in SG 2-4. This phenomenon of a leading SG in plants affected by ODSCC is common in the industry. Reviewing Table 3-6 and Figures 3-8 and 3-9 also supports this conclusion. As shown in the table and figures, the largest growth rates occurred in SG 2-4. Cycles 10 and 11 voltage independent growth rates for each SG are provided in Figure 3-30, and Figure 31, respectively.

3.2.1 Dependency of Voltage Growth on BOC Voltage

For Cycle 11, growth rates were plotted against the BOC voltage for all steam generators. Their data are shown in Figures 3-10 through 3-13. As is demonstrated by the figures, a positive slope exists in all SGs, indicating that voltage growth at DCPP-2 is in fact a function of the BOC voltage. This phenomenon is known as voltage dependent growth (VDG) and the initiation of it was previously observed in the Cycle 10 data for SGs 2-3 and 2-4, as documented in the 2R10 90-day report. Another observation is that the new indications are not exhibiting as much VDG as repeat indications. Figure 3-14 depicts all of the Cycle 11 data for SG 2-4, including R44C45 that grew from 2.0 volts to 21.5 during Cycle 11. This graph supports the conclusion that the growth rate of this indication is not indicative of the remaining population of the indications at DCPP-2, and is a separate growth issue confined to this indication. A cause assessment of the high growth rate of this indication is provided in Section 4 of this report. A VDG strategy was employed for the previous cycle 90-day report analyses for SGs 2-3 and 2-4, and to evaluate the similarities between the two cycles, the Cycle 10 growth data is provided with the Cycle 11 data in Figures 3-15 through 3-18. VDG is not a new concept, and has been documented by the European SGs affected by ODSCC. Because of their higher repair limits, their data encompasses a much broader and higher range of data than at DCPP and the US plants and provides significant basis for the VDG approach.

3.2.2 VDG Analysis of Cycle 10 and 11 Data

A significant amount of analysis and evaluation was performed during 2R11 on voltage growth for ODSCC at TSPs. The evaluations primarily involved statistical breakpoint analysis to determine where the data suggests a change in the slope of the regression curve that defines the Cycles 10 and 11 growth data, not including R44C45 growth. Ultimately the conclusions reached by a Westinghouse statistical evaluation (Ref. 14, submitted by PG&E in a separate attachment to the 90 day report), determined that Cycle 10 and Cycle 11 data were statistically related and defined very similar breakpoints in the SG with the most active ODSCC growth (SG 2-4). The Cycle 10 data analysis defined breakpoints at 0.69 and 1.17v, and the Cycle 11 analysis resulted in breakpoints at 0.61 and 1.66v (Figures 3-30 and 3-29). The 30 largest data points from Cycle 10 (in the >1.17 bin) were then added to the SG 2-4 Cycle 11 data, and defined new breakpoints at three different categories of BOC voltages for voltage dependent growth(<=0.59V, 0.60 to 1.66 V, and >1.66V). Figure 3-21 provides the combined data in the upper voltage range and the final breakpoints that were used to define growth for the Cycle 12

operational assessment calculations. By comparing Figures 19 and 21, it is seen that combining Cycle 11 growth with the 30 largest Cycle 10 growths has no effect on the upper bin breakpoints and only a small effect on the first breakpoint.

Tables 3-8 through 3-10 contain the three different sets of growth rates based on BOC voltages, broken at the points defined by the Westinghouse evaluation. It is considered appropriate to apply the SG 2-4 VDG breakpoints for all SGs since SG 2-4 has a more mature population and will better reflect expectations in the other SGs over the next cycle. The composite low bin has 1411 indications, the composite middle bin has 420 indications, and the composite high bin has 22 indications. Figure 3-22 shows these growth rate distributions for three different ranges of BOC voltages for all SGs combined. As shown in the figure, there is a consistent shift toward higher growth for larger BOC voltages. Similar charts were prepared for each steam generator individually and are shown in Figures 3-23 through 3-26. The upper bin curve becomes much more "choppy" for those SGs that have limited data in that bin for Cycle 11. Figure 3-27 shows SG 2-4 with the three different bin ranges and a line noted as "Independent Curve" which represents the "voltage independent growth" distribution with the data not binned into the three different voltage ranges. This helps to demonstrate the differences between the analyses when three binned curves are used in the Cycle 12 Monte Carlo analyses, versus an independent curve applied to all of the data. Results of benchmarking and sensitivity studies are provided later in this report.

For the operational assessment, the SG-specific VD growth rates developed for Cycle 11 were also evaluated against the Generic Letter requirements. The GL requires that the most limiting of the two growth distributions from the previous two cycles should be used. Cycle 11 voltage dependent data, provided in Tables 3-8, 3-9, and 3-10 were assembled for each of the voltage bins. Graphically the data is shown in Figures 3-23 to 3-26, and combined in Figure 3-22. Cycle 10 VDG data binned in the same manner is shown in Figure 3-28 for all SGs. Comparing Cycle 10 to Cycle 11 data, demonstrates that the Cycle 11 data is bounding Cycle 10, therefore it should be used in Cycle 12 projections. Additionally, Cycle 11 depicts a more mature population of growth data. In comparing the Cycle 11 data between the SGs, again it was determined that SG 2-4 contained the most conservative VDG curves. Therefore a composite curve was developed for all Cycle 11 data, which bounded SGS 2-1, 2-2, and 2-3, in all bins.

In the cases where VD growth was used in Cycle 12 projections, Table 3-12 presents the growth rates used in the simulations. In the Cycle 12 OA calculations for SGs 2-1, 2-2, and 2-3, a composite Cycle 11 growth distribution (all SGs) was used for the upper and lower growth bins. Note that the upper bin included the 11.9v/EFPY growth from SG 2-4, R44C45. The middle bin used a composite Cycle 11 growth distribution also, however, the growth values were all increased by 10% from the actual Cycle 11 results. The increase was accomplished by multiplying each individual growth data point in the BOC mid-voltage range by 1.1 prior to binning the results. By comparing the data in the middle bins in Figure 3-22 and 3-28, an apparent shift in the middle bin growth is present during Cycle 11. Additionally, the overall Cycle 11 average growth rate increased by about 10% compared to the Cycle 10 average growth rate, as shown in Figure 3-29. Although this increase is attributed to the fact that the DCPP-2 population of indications was relatively immature at BOC-11 and merely the fast growing indications leading the rest of the population, a conservative 10% increase was applied to this bin for all Cycle 12 VDG projections. For SG 2-4, SG-specific growth was used for the lower and middle bins. For the upper-most bin in SG 2-4, all data points from Cycle 10 growth in this bin (3 points: 0.8, 1.7, and 1.8 v/EFPY) from SG 2-4 were added to the Cycle 11 growth data since

the VDG analysis demonstrated that the data was statistically related. Additionally, a single growth point from the Cycle 11 high bin of SG 2-1 was added into the SG 2-4 growth data to ensure that the upper bin contained the three largest Cycle 11 growth points in all Cycle 12 projections. This brings the total number of data points in the SG 2-4 upper bin to 21 (Table 3-12). Adding the SG 2-1 data point is in accordance with Addendum 5 recommendations when utilizing a voltage dependent POD to predict EOC conditions, and bounds all of the Cycle 10 and Cycle 11 SG-specific growth distributions.

By evaluating Cycle 10 and 11 growth data, the following conclusions can be made: VDG is occurring in all SGs, with dominance in SG 2-4; similar characteristics exist in both Cycles 10 and 11; VDG affects repeat indications more so than new indications; and, VDG in the worst case SG (2-4) has not drastically changed or increased from Cycle 10 to Cycle 11 except for the special case of R44C45 addressed in Section 4.

3.2.3 Independent Voltage Growth Analysis

Growth data for Cycle 11, independent of BOC-11 voltage, is contained in Table 3-7 for each SG. These results are presented graphically in Figure 3-31. The Cycle 10 SG-specific growth rates are shown in Figure 3-30. GL 95-05 requires that the most limiting of the two growth distributions from the previous two cycles should be used. Comparing these distributions against these requirements, it was determined that the Cycle 11 data was more conservative than Cycle 10 data. Therefore, for EOC-12 projections, Cycle 11 data should be used. Additionally, it was determined that SG 2-4 had the most conservative growth rates during Cycle 11. Therefore a composite curve for all SGs was developed and determined to be more conservative than the SG specific curves for SGs 2-1, 2-2 and 2-3. Therefore, for Cycle 12 projections, a composite curve was utilized for these SGs, and the SG specific curve was used for SG 2-4. Table 3-11 presents the data that was used in the Cycle 12 OA calculations that utilized a voltage independent growth approach.

3.3 Probe Wear Criteria

The first NRC requirement regarding probe wear is to minimize the potential for tubes to be inspected with a probe that had failed the probe wear check. This was accomplished by implementing the bobbin Examination Technique Specification Sheet (ETSS) #1 (Ref. 11), which required the probe have its feet replaced when failing the probe wear check, or in the case of non-changeable feet probes, the probe discarded.

If the DOS voltage is at the retest threshold (1.5 volts or higher) and the Cal is designated as "ARC Out" on the cal board, the indication code is changed from a DOS to an RSS (retest support plate signal) indicating that a retest is required with a new probe. No new indications were detected in the tubes when retested with the new probe.

The 2R11 eddy current inspection resulted in 30 bobbin indications greater than or equal to 1.5 volts that were inspected with a worn probe. These indications are shown in Table 3-13. The RSS and DOS voltage variation was tabulated for each worn probe inspection. The retest voltage values compare reasonably with the final acceptable DOS voltage, generally within about ±8.5%) of the RSS voltage. Figure 3-32 shows a comparison of the worn probe and good probe voltages. This figure shows that the voltages do not change significantly between the

worn probes and the good probes. Therefore, continued use of the 1.5-volt retest threshold is justified (Ref. 13).

All RSS bobbin indications were inspected in accordance with the Ref. 11 analysis guidelines. Review of the probe wear log sheets and the eddy current test results indicate that no tubes were inspected with a probe known to have failed the probe wear check. These reviews in conjunction with the results in Table 3-13 address the NRC requirements listed in Ref. 15.

Another NRC requirement involves monitoring tubes that contain new DOS indications that were inspected with probes that failed the wear check in the previous outage. This evaluation is intended to look for "new" large indications or a non-proportionately large percentage of "new" indications in tubes that failed the check in the previous outage. The new 2R11 >= 0.5 volts DOS indications in tubes that failed the probe wear check in 2R10 are shown in Table 3-14 sorted by descending Bobbin voltages per steam generator.

Overall there were 1864 DOS indications detected in the 2R11 inspection of the active tube population and no tubes were deplugged during this outage. 1009 or ~54% of the DOS indications were new indications. Table 3-15 is presented to assess the number of new indications against the probe wear requirements. Of the 1009 total new indications, 336 (~33%) were in tubes inspected with a worn probe in 2R10 and 673 were in tubes inspected with a good probe in 2R10. When these numbers are compared to the total number of inspections in 2R10, the results shown in Table 3-16 are obtained. This table shows the approximate percentage of (31%) tubes inspected with a worn probe in 2R10. The results are categorized based on whether the previous inspection was performed with a worn probe or a good probe. Additionally, the number of new indications ≥ 0.5 volts was determined to be 317. Out of these, again about 33% (106/317) were in tubes that were inspected with a worn probe in 2R10. This confirms that the number of new indications is approximately equivalent in both data sets.

Additionally, based on a review the overall 2R10 inspection results as shown on Table 3-16, the number of tubes inspected during 2R10 that were ARC out was 4355, compared to 9791 inspections that were made with an ARC in probe. This total number of examinations is greater than the number of tubes in service because several tubes have multiple examinations. The ratio of ARC out tubes inspected to the total number of bobbin inspections is about 0.31 (or 31%). This percentage compares reasonably with the ratio of the number of new DOSs and the number of new ≥ 0.5 volt DOSs in regard to the number inspected with an ARC out probe. This demonstrates that the number of new indications is not biased towards the tubes that were inspected with worn probes in 2R10.

The largest "new" indication detected in 2R11 was a 2.30 volt DOS at 2H in SG 2-4 and it was NDD with a good probe in 2R10. Based on the look-ups performed, this indication should have been called in 2R10 at 0.29 volts. The next largest "new" indication, also detected in SG 2-4, was a 1.61-volt DOS at 2H and it was also inspected with a good probe in 2R10. In actuality, the majority of the new indications have signals in the previous inspection data but were not identified by production analysis. About 90% of the new 2R11 indications were ≤ 0.5 volts in 2R10, based on the historical lookups performed. This indicates that these new indications are more a result of probability of detection rather than whether the tube was inspected with a worn probe in 2R10. These percentages are not considered to indicate a disproportionate number of new DOS are present in tubes that were inspected with a worn probe in the previous outage. The largest "new" indications inspected with a worn probe were 1.28 volt DOSs in SGs 2-3 and 2-4.

Again, based on the look-ups performed, these indications should have been called in 2R10 at 0.45 volts and 0.65 volts, respectively.

In summary, the NRC analysis requirements regarding probe wear monitoring were met during the 2R11 bobbin coil inspection and a more stringent wear tolerance is not required at DCPP.

3.4 *Upper Voltage Repair Limit*

Per Generic Letter 95-05, the upper repair limit must be calculated prior to each outage, and the more conservative of the plant-specific average growth rate per EFPY or 30 percent per EFPY should be used as the anticipated growth rate input for this calculation. The upper voltage repair limit was calculated following growth rate analysis of the 2R11 data and was determined to be 5.10 volts (Ref. 12) based on the following formula. This calculation conservatively used a 45.3 percent per EFPY growth based on the SG 2-4 Cycle 11 growth rates. One point of interest is that the removal of the 11.9v/EFPY point from this average calculation only reduces the value to 43%/EFPY.

$$V_{URL} = \frac{V_{SL}}{1 + \frac{\%V_{NDE}}{100} + \frac{\%V_{CG}}{100}}$$

where: V_{URL} = upper voltage repair limit,
V_{NDE} = NDE voltage measurement uncertainty = 20%,
V_{CG} = voltage growth anticipated between inspections = 45.3%/EFPY x 1.54 EFPY = 69.76%,
V_{SL} = voltage structural limit from the burst pressure – Bobbin voltage correlation, where the limit of 9.62 volts was used based on Ref. 8.

3.5 *NDE Uncertainty Distributions*

NDE uncertainties must be taken into account when projecting the end-of-cycle voltages for the next operating cycle. The NDE uncertainties used in the calculations of the EOC-12 voltages are described in Ref. 6. The acquisition uncertainty was sampled from a normal distribution with a mean of zero, a standard deviation of 7%, and a cutoff limit of 15% based on the use of the probe wear standard. The analyst uncertainty was sampled from a normal distribution with a mean of zero, a standard deviation of 10.3%, and no cutoff limit. These uncertainty distributions are shown in Table 3-17 and Figure 3-33.

Table 3-1: 2R11 DOS Indications > 2.0 volts

SG	Row	Col	Ind	Elev	Volts
21	31	51	DOS	1H	6.54
21	37	45	DOS	2H	6.18
21	30	41	DOS	1H	5.1
21	7	33	DOS	1H	4.4
21	35	71	DOS	2H	3.43
21	28	48	DOS	1H	3.29
21	37	24	DOS	1H	2.88
21	27	33	DOS	1H	2.83
21	34	31	DOS	1H	2.73
21	36	41	DOS	2H	2.27
22	38	40	DOS	1H	6.31
22	22	67	DOS	2H	4.58
22	13	72	DOS	2H	3.42
22	14	75	DOS	1H	2.44
22	19	51	DOS	2H	2.4
23	9	23	DOS	1H	4.04
23	28	24	DOS	2H	3.05
23	14	55	DOS	1H	2.84
23	17	13	DOS	2H	2.3
23	32	52	DOS	2H	2.06
24	44	45	DOS	2H	21.5
24	18	76	DOS	2H	6.64
24	12	38	DOS	1H	6.2
24	3	50	DOS	2H	5.64
24	24	74	DOS	2H	5.5
24	5	50	DOS	1H	5.46
24	13	76	DOS	2H	5.27
24	35	57	DOS	2H	5.09
24	29	48	DOS	2H	5.04
24	19	84	DOS	2H	5
24	1	52	DOS	1H	4.99
24	15	80	DOS	2H	4.93
24	31	39	DOS	1H	4.82
24	25	60	DOS	2H	4.64
24	7	48	DOS	2H	4.55
24	18	80	DOS	2H	4.49
24	40	58	DOS	3H	4.36
24	7	84	DOS	2H	4.24
24	38	43	DOS	2H	4.17
24	26	59	DOS	2H	4.15
24	11	77	DOS	2H	4.04

Table 3-1: 2R11 DOS Indications > 2.0 volts

SG	Row	Col	Ind	Elev	Volts
24	35	45	DOS	1H	3.78
24	34	43	DOS	2H	3.74
24	28	54	DOS	1H	3.58
24	27	74	DOS	2H	3.42
24	2	47	DOS	1H	3.4
24	9	65	DOS	1H	3.38
24	6	39	DOS	1H	3.35
24	39	57	DOS	2H	3.27
24	4	50	DOS	1H	3.21
24	10	86	DOS	2H	3.14
24	16	55	DOS	2H	3.1
24	7	52	DOS	1H	3.09
24	11	89	DOS	2H	2.97
24	6	54	DOS	1H	2.96
24	7	54	DOS	2H	2.94
24	7	72	DOS	1H	2.9
24	40	59	DOS	2H	2.86
24	38	32	DOS	1H	2.84
24	18	52	DOS	1H	2.81
24	38	23	DOS	3H	2.79
24	21	84	DOS	2H	2.75
24	3	55	DOS	1H	2.65
24	6	53	DOS	1H	2.64
24	10	80	DOS	2H	2.64
24	11	47	DOS	2H	2.56
24	16	51	DOS	1H	2.55
24	17	25	DOS	1H	2.55
24	9	82	DOS	2H	2.5
24	3	55	DOS	2H	2.44
24	40	49	DOS	2H	2.44
24	2	58	DOS	2H	2.4
24	2	56	DOS	2H	2.4
24	4	68	DOS	2H	2.37
24	28	61	DOS	2H	2.37
24	8	60	DOS	1H	2.36
24	11	68	DOS	1H	2.34
24	23	76	DOS	2H	2.32
24	30	68	DOS	2H	2.32
24	44	48	DOS	2H	2.3
24	1	66	DOS	2H	2.27
24	8	79	DOS	2H	2.27
24	39	62	DOS	2H	2.27
24	6	59	DOS	1H	2.21

Table 3-1: 2R11 DOS Indications > 2.0 volts

SG	Row	Col	Ind	Elev	Volts
24	15	84	DOS	2H	2.21
24	30	20	DOS	2H	2.17
24	20	64	DOS	1H	2.16
24	24	38	DOS	1H	2.02
24	4	40	DOS	3H	2

Table 3-2: 2R11 AONDB Indications

SG	Row	Col	Elev	Dent Voltage	Plus Pt Voltage	Assigned DOS Voltage
22	8	30	1H	2.22	0.15	0.46
22	24	58	2H	1.08	0.22	0.52
22	12	71	1H	4.63	0.16	0.47
24	5	62	2H		0.11	0.42
24	5	68	2H		0.18	0.49
24	5	68	4H		0.23	0.53
24	6	53	4H		0.35	0.65
24	10	29	3H	1.91	0.12	0.43
24	30	36	3H	3.59	0.2	0.50

Table 3-3: Summary of Inspection and Repair for Tubes Affected by ODSCC at TSPs

	SG21				SG22				SG23			
Voltage Bin	As-Found EOC-11	Repaired Tubes	DOSs Returned to Service		As-Found EOC-11	Repaired Tubes	DOSs Returned to Service		As-Found EOC-11	Repaired Tubes	DOSs Returned to Service	
			Conf. OD-SCC or Not Insp. w/+Pt	Total (1)			Conf. OD-SCC or Not Insp. w/+Pt	Total (1)			Conf. OD-SCC or Not Insp. w/+Pt	Total (1)
0.1	0	0	0	0	0	0	0	0	0	0	0	0
0.2	21	0	11	21	13	0	12	13	17	0	15	17
0.3	66	3	52	63	50	1	43	49	42	3	38	39
0.4	59	2	46	57	45	3	38	42	58	3	50	55
0.5	51	1	39	50	47	3	41	44	39	0	38	39
0.6	36	1	31	35	31	1	28	30	28	1	26	27
0.7	34	0	23	34	27	2	25	25	19	1	17	18
0.8	21	0	18	21	11	0	11	11	19	1	18	18
0.9	11	0	9	11	18	1	17	17	3	0	3	3
1	5	0	5	5	7	0	7	7	4	0	4	4
1.1	11	0	10	11	7	0	7	7	4	0	4	4
1.2	4	0	4	4	5	0	3	5	7	0	7	7
1.3	11	11	0	0	5	5	0	0	6	6	0	0
1.4	2	2	0	0	1	1	0	0	1	1	0	0
1.5	4	4	0	0	1	1	0	0	3	3	0	0
1.6	0	0	0	0	0	0	0	0	3	3	0	0
1.7	1	1	0	0	2	2	0	0	1	1	0	0
1.8	1	1	0	0	1	1	0	0	1	1	0	0
1.9	2	2	0	0	0	0	0	0	2	2	0	0
2	0	0	0	0	2	2	0	0	1	1	0	0
2.1	0	0	0	0	0	0	0	0	1	1	0	0
2.2	0	0	0	0	0	0	0	0	0	0	0	0
2.3	1	1	0	0	0	0	0	0	1	1	0	0
2.4	0	0	0	0	1	1	0	0	0	0	0	0
2.5	0	0	0	0	1	1	0	0	0	0	0	0
2.6	0	0	0	0	0	0	0	0	0	0	0	0
2.7	0	0	0	0	0	0	0	0	0	0	0	0
2.8	1	1	0	0	0	0	0	0	0	0	0	0
2.9	2	2	0	0	0	0	0	0	1	1	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0
3.1	0	0	0	0	0	0	0	0	1	1	0	0
3.2	0	0	0	0	0	0	0	0	0	0	0	0
3.3	1	1	0	0	0	0	0	0	0	0	0	0
3.4	0	0	0	0	0	0	0	0	0	0	0	0
3.5	1	1	0	0	1	1	0	0	0	0	0	0
3.6	0	0	0	0	0	0	0	0	0	0	0	0
3.7	0	0	0	0	0	0	0	0	0	0	0	0
3.8	0	0	0	0	0	0	0	0	0	0	0	0
3.9	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0
4.1	0	0	0	0	0	0	0	0	1	1	0	0
4.2	0	0	0	0	0	0	0	0	0	0	0	0
4.3	0	0	0	0	0	0	0	0	0	0	0	0
4.4	1	1	0	0	0	0	0	0	0	0	0	0
4.5	0	0	0	0	0	0	0	0	0	0	0	0
4.6	0	0	0	0	1	1	0	0	0	0	0	0
4.7	0	0	0	0	0	0	0	0	0	0	0	0
4.8	0	0	0	0	0	0	0	0	0	0	0	0
4.9	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0
6	1	1	0	0	0	0	0	0	0	0	0	0
7	2	2	0	0	1	1	0	0	0	0	0	0
>20	0	0	0	0	0	0	0	0	0	0	0	0
Total	350	38	248	312	278	28	232	250	263	32	220	231
>1V	46	31	14	15	29	17	10	12	34	23	11	11
>1.2	31	31	0	0	17	17	0	0	23	23	0	0
>2V	10	10			5	5			5	5		

(1) Total includes all DOS/AONDB indications returned to service (confirmed, not inspected, and not confirmed with Plus Point).

Table 3-3 (cont): Summary of Inspection and Repair for Tubes Affected by ODSCC at TSPs

	SG24				Composite of All SGs			
Voltage Bin	As-Found EOC-11	Repaired Tubes	DOSs Returned to Service: Conf. OD-SCC or Not Insp. w/+Pt	DOSs Returned to Service: Total (1)	As-Found EOC-11	Repaired Tubes	DOSs Returned to Service: Conf. OD-SCC or Not Insp. w/+Pt	DOSs Returned to Service: Total (1)
0.1	0	0	0	0	0	0	0	0
0.2	14	1	12	13	65	1	50	64
0.3	91	8	83	83	249	16	216	234
0.4	135	13	119	122	297	21	253	276
0.5	139	16	122	124	276	19	240	257
0.6	106	11	95	95	201	14	180	187
0.7	94	13	80	81	174	16	145	158
0.8	81	6	75	75	132	7	122	125
0.9	60	7	53	53	92	8	82	84
1	33	5	28	28	49	5	44	44
1.1	22	2	20	20	44	2	41	42
1.2	26	3	23	23	42	3	37	39
1.3	20	20	0	0	42	42	0	0
1.4	18	18	0	0	22	22	0	0
1.5	12	12	0	0	20	20	0	0
1.6	16	16	0	0	19	19	0	0
1.7	16	16	0	0	20	20	0	0
1.8	12	12	0	0	15	15	0	0
1.9	10	10	0	0	14	14	0	0
2	9	9	0	0	12	12	0	0
2.1	1	1	0	0	2	2	0	0
2.2	2	2	0	0	2	2	0	0
2.3	6	6	0	0	8	8	0	0
2.4	8	8	0	0	9	9	0	0
2.5	3	3	0	0	4	4	0	0
2.6	3	3	0	0	3	3	0	0
2.7	3	3	0	0	3	3	0	0
2.8	2	2	0	0	3	3	0	0
2.9	4	4	0	0	7	7	0	0
3	3	3	0	0	3	3	0	0
3.1	2	2	0	0	3	3	0	0
3.2	1	1	0	0	1	1	0	0
3.3	2	2	0	0	3	3	0	0
3.4	3	3	0	0	3	3	0	0
3.5	1	1	0	0	3	3	0	0
3.6	1	1	0	0	1	1	0	0
3.7	0	0	0	0	0	0	0	0
3.8	2	2	0	0	2	2	0	0
3.9	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0
4.1	1	1	0	0	2	2	0	0
4.2	2	2	0	0	2	2	0	0
4.3	1	1	0	0	1	1	0	0
4.4	1	1	0	0	2	2	0	0
4.5	1	1	0	0	1	1	0	0
4.6	1	1	0	0	2	2	0	0
4.7	1	1	0	0	1	1	0	0
4.8	0	0	0	0	0	0	0	0
4.9	1	1	0	0	1	1	0	0
5	3	3	0	0	3	3	0	0
6	6	6	0	0	7	7	0	0
7	2	2	0	0	5	5	0	0
>20	1	1	0	0	1	1	0	0
Total	982	265	710	717	1873	363	1410	1510
>1V	229	186	43	43	338	257	78	81
>1.2	181	181	0	0	252	252	0	0
>2V	68	68			88	88		

Table 3-4: Summary of Largest Voltage Growth Rates per EFPY

SG	Row	Col	Elev	Volts	Previous Volts (2R10)	Growth/ EFPY	Plus Pt Result	New?
24	44	45	2H	21.5	2	11.869	SAI	Repeat
24	18	76	2H	6.64	1.73	2.988	SAI	Repeat
21	31	51	1H	6.54	1.84	2.861	SAI	Repeat
22	38	40	1H	6.31	1.94	2.660	SAI	Repeat
24	12	38	1H	6.2	1.9	2.617	SAI	Repeat
21	37	45	2H	6.18	1.96	2.568	SAI	Repeat
24	24	74	2H	5.5	1.38	2.508	SAI	Repeat
24	13	76	2H	5.27	1.19	2.483	SAI	Repeat
24	3	50	2H	5.64	1.68	2.410	SAI	Repeat
24	31	39	1H	4.82	0.94	2.362	SAI	Repeat
24	29	48	2H	5.04	1.29	2.282	SAI	Repeat
21	30	41	1H	5.1	1.46	2.215	SAI	Repeat
24	15	80	2H	4.93	1.37	2.167	SAI	Repeat
24	1	52	1H	4.99	1.44	2.161	SAI	Repeat
24	5	50	1H	5.46	1.92	2.155	SAI	Repeat
24	35	57	2H	5.09	1.56	2.149	SAI	Repeat
24	7	48	2H	4.55	1.39	1.923	SAI	Repeat
24	25	60	2H	4.64	1.62	1.838	SAI	Repeat
23	9	23	1H	4.04	1.04	1.826	SAI	Repeat
24	19	84	2H	5	2	1.826	SAI	Repeat

Table 3-5: DOS Voltage and Growth Distribution by TSP Elevation

Growth units are volts/EFPY

Tube Support Plate	Steam Generator 2-1					Tube Support Plate	Steam Generator 2-2				
	No. of Indications	Maximum Voltage	Average Voltage	Maximum Growth	Average Growth		No. of Indications	Maximum Voltage	Average Voltage	Maximum Growth	Average Growth
1H	238	6.54	0.65	2.86	0.14	1H	91	6.31	0.67	2.66	0.13
2H	60	6.18	0.69	2.57	0.19	2H	111	4.58	0.66	1.67	0.12
3H	16	0.91	0.50	0.18	0.04	3H	37	1.21	0.47	0.26	0.07
4H	3	0.53	0.34	0.01	-0.01	4H	12	1.16	0.51	0.11	0.01
5H	16	0.82	0.51	0.10	0.02	5H	3	0.46	0.36	0.03	-0.03
6H	2	0.71	0.51	0.08	0.04	6H	1	0.21	0.21	-0.07	-0.07
7H	0	0.00	0.00	0.00	0.01	7H	2	0.53	0.39	0.04	0.00
CL	15	0.82	0.51	0.15	0.00	CL	18	0.83	0.37	0.22	0.00
All Inds	350	6.54	0.63	2.86	0.13	All Inds	275	6.31	0.60	2.66	0.10

Tube Support Plate	Steam Generator 2-3					Tube Support Plate	Steam Generator 2-4				
	No. of Indications	Maximum Voltage	Average Voltage	Maximum Growth	Average Growth		No. of Indications	Maximum Voltage	Average Voltage	Maximum Growth	Average Growth
1H	146	4.04	0.60	1.83	0.14	1H	355	6.20	0.81	2.62	0.20
2H	76	3.05	0.61	1.07	0.15	2H	450	21.50	1.05	11.87	0.30
3H	21	1.89	0.60	0.44	0.10	3H	127	4.36	0.72	1.46	0.14
4H	3	0.32	0.31	0.09	0.01	4H	29	1.71	0.58	0.72	0.11
5H	4	0.63	0.39	0.14	0.03	5H	2	0.51	0.35	0.01	0.01
6H	3	0.63	0.35	0.26	0.10	6H	1	0.25	0.25	0.00	0.00
7H	0	0.00	0.00	0.00	0.00	7H	0	0.00	0.00	0.00	0.00
CL	10	0.42	0.30	0.14	0.02	CL	12	1.24	0.44	0.10	0.01
All Inds	263	4.04	0.58	1.83	0.13	All Inds	976	21.50	0.90	11.87	0.23

Tube Support Plate	Composite of All Four SGs				
	No. of Indications	Maximum Voltage	Average Voltage	Maximum Growth	Average Growth
1H	830	6.54	0.68	2.86	0.15
2H	697	21.50	0.75	11.87	0.19
3H	201	4.36	0.57	1.46	0.09
4H	47	1.71	0.43	0.72	0.03
5H	25	0.82	0.40	0.14	0.01
6H	7	0.71	0.33	0.26	0.02
7H	2	0.53	0.10	0.04	0.00
CL	55	1.24	0.41	0.22	0.01
All Inds	1864	21.50	0.68	11.87	0.15

Table 3-6: Voltage Growth for Cycles 8-11

Growth History for DCPP-2

		SG21	SG22	SG23	SG24	All
Cycle 8	Avg BOC Volts	0.338	0.358	0.403	0.415	0.385
	Average Growth Per EFPY	0.054	0.054	-0.008	0.059	0.051
	Average Percent Growth Per EFPY	16.0%	15.2%	-1.9%	14.3%	13.3%
Cycle 9	Avg BOC Volts	0.388	0.362	0.324	0.387	0.377
	Avg Growth Per EFPY	0.036	0.087	0.168	0.173	0.134
	Average Percent Growth Per EFPY	9.2%	24.2%	52.0%	44.7%	35.6%
Cycle 10	Avg BOC Volts	0.42	0.43	0.48	0.53	0.49
	Avg Growth Per EFPY	0.14	0.08	0.12	0.2	0.16
	Average Percent Growth Per EFPY	33.2%	19.0%	25.5%	37.5%	33.4%
Cycle 11	Avg BOC Volts	0.423	0.437	0.379	0.514	0.467
	Avg Growth Per EFPY	0.131	0.103	0.131	0.233	0.181
	Average Percent Growth Per EFPY	30.9%	23.5%	34.7%	45.3%	38.7%

Table 3-7: Summary of Independent Cycle 11 Voltage Growth per EFPY

Delta Volts	SG21		SG22		SG23		SG24		Total	
	No. of Obs.	CPDF	No. of Obs.	CPDF	No. of Obs.	CPDF	No. of Obs.	CPDF	No. of Obs.	CPDF
<=-0.5	2	0.01	0	0.00	0	0.00	0	0.00	2	0.00
-0.4	0	0.01	0	0.00	0	0.00	0	0.00	0	0.00
-0.3	0	0.01	0	0.00	0	0.00	0	0.00	0	0.00
-0.2	0	0.01	1	0.00	0	0.00	1	0.00	2	0.00
-0.1	4	0.02	6	0.03	0	0.00	4	0.01	14	0.01
0	46	0.15	56	0.23	29	0.11	71	0.08	202	0.12
0.1	170	0.64	131	0.71	116	0.57	359	0.45	776	0.54
0.2	74	0.86	39	0.85	63	0.81	258	0.71	434	0.77
0.3	21	0.92	24	0.94	24	0.91	111	0.83	180	0.87
0.4	9	0.94	4	0.96	8	0.94	48	0.88	69	0.91
0.5	10	0.97	4	0.97	5	0.96	26	0.90	45	0.93
0.6	0	0.97	2	0.98	6	0.98	22	0.93	30	0.95
0.7	1	0.98	3	0.99	0	0.98	11	0.94	15	0.95
0.8	0	0.98	0	0.99	2	0.99	7	0.94	9	0.96
0.9	2	0.98	1	0.99	0	0.99	7	0.95	10	0.96
1	0	0.98	0	0.99	0	0.99	7	0.96	7	0.97
1.1	0	0.98	0	0.99	1	0.99	6	0.97	7	0.97
1.2	1	0.99	0	0.99	0	0.99	3	0.97	4	0.97
1.3	1	0.99	0	0.99	1	1.00	6	0.97	8	0.98
1.4	1	0.99	1	1.00	0	1.00	2	0.98	4	0.98
1.5	0	0.99	0	1.00	0	1.00	5	0.98	5	0.98
1.6	1	0.99	0	1.00	0	1.00	4	0.99	5	0.99
1.7	1	1.00	1	1.00	0	1.00	1	0.99	3	0.99
1.8	0	1.00	0	1.00	0	1.00	2	0.99	2	0.99
1.9	0	1.00	0	1.00	1	1.00	2	0.99	3	0.99
2	0	1.00	0	1.00	0	1.00	1	0.99	1	0.99
>2	3	1.00	1	1.00	0	1.00	12	1.00	16	1.00
Total	347	NA	274	NA	256	NA	976	NA	1853	NA

Table 3-8: Cycle 11 Voltage Dependent Growth (BOC-11 Voltage ≤ 0.59 Volts)

Delta Volts	SG21		SG22		SG23		SG24		Total	
	No. of Obs.	CPDF	No. of Obs.	CPDF	No. of Obs.	CPDF	No. of Obs.	CPDF	No. of Obs.	CPDF
0	35	0.13	48	0.22	21	0.10	48	0.93	152	0.11
0.1	153	0.68	115	0.75	115	0.63	307	0.97	690	0.60
0.2	65	0.91	32	0.90	57	0.90	220	0.97	374	0.86
0.3	12	0.96	18	0.98	15	0.97	79	0.98	124	0.95
0.4	3	0.97	2	0.99	3	0.98	24	0.99	32	0.97
0.5	8	1.00	1	1.00	3	1.00	5	1.00	17	0.98
0.6	0	1.00	1	1.00	1	1.00	8	1.00	10	0.99
0.7	0	1.00	0	1.00	0	1.00	5	1.00	5	1.00
0.8	0	1.00	0	1.00	0	1.00	3	1.00	3	1.00
0.9	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00
1	0	1.00	0	1.00	0	1.00	1	1.00	1	1.00
1.1	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00
1.2	1	1.00	0	1.00	0	1.00	0	1.00	1	1.00
1.3	0	1.00	0	1.00	0	1.00	1	1.00	1	1.00
1.4	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00
1.5	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00
1.6	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00
1.7	0	1.00	0	1.00	0	1.00	1	1.00	1	1.00
1.8	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00
1.9	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00
2	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00
2.1	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00
2.2	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00
2.3	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00
2.4	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00
2.5	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00
2.6	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00
2.7	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00
2.8	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00
2.9	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00
3	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00
11.8	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00
11.9	0	1.00	0	1.00	0	1.00	0	0.00	0	1.00
12	0	1.00	0	1.00	0	1.00	0	0.00	0	1.00
>12	0	1.00	0	1.00	0	1.00	0	0.00	0	1.00
Total	277	NA	217	NA	215	NA	702	NA	1411	NA

Table 3-9: Cycle 11 Voltage Dependent Growth (BOC-11 Voltage from 0.60 to 1.66 Volts)

Delta Volts	SG21		SG22		SG23		SG24		Total	
	No. of Obs.	CPDF	No. of Obs.	CPDF	No. of Obs.	CPDF	No. of Obs.	CPDF	No. of Obs.	CPDF
0	17	0.25	15	0.27	8	0.20	28	0.56	68	0.16
0.1	17	0.51	16	0.56	1	0.22	50	0.65	84	0.36
0.2	9	0.64	7	0.69	6	0.37	37	0.74	59	0.50
0.3	9	0.78	6	0.80	9	0.59	29	0.79	53	0.63
0.4	6	0.87	2	0.84	5	0.71	24	0.81	37	0.72
0.5	2	0.90	3	0.89	2	0.76	21	0.82	28	0.78
0.6	0	0.90	1	0.91	5	0.88	13	0.85	19	0.83
0.7	1	0.91	3	0.96	0	0.88	6	0.88	10	0.85
0.8	0	0.91	0	0.96	2	0.93	4	0.90	6	0.87
0.9	2	0.94	1	0.98	0	0.93	7	0.91	10	0.89
1	0	0.94	0	0.98	0	0.93	6	0.93	6	0.90
1.1	0	0.94	0	0.98	1	0.95	6	0.93	7	0.92
1.2	0	0.94	0	0.98	0	0.95	3	0.95	3	0.93
1.3	1	0.96	0	0.98	1	0.98	5	0.96	7	0.95
1.4	1	0.97	1	1.00	0	0.98	1	0.96	3	0.95
1.5	0	0.97	0	1.00	0	0.98	3	0.96	3	0.96
1.6	0	0.97	0	1.00	0	0.98	3	0.97	3	0.97
1.7	1	0.99	0	1.00	0	0.98	0	0.97	1	0.97
1.8	0	0.99	0	1.00	0	0.98	2	0.97	2	0.97
1.9	0	0.99	0	1.00	1	1.00	1	0.98	2	0.98
2	0	0.99	0	1.00	0	1.00	1	0.99	1	0.98
2.1	0	0.99	0	1.00	0	1.00	0	0.99	0	0.98
2.2	0	0.99	0	1.00	0	1.00	3	1.00	3	0.99
2.3	1	1.00	0	1.00	0	1.00	1	1.00	2	0.99
2.4	0	1.00	0	1.00	0	1.00	1	1.00	1	1.00
2.5	0	1.00	0	1.00	0	1.00	1	1.00	1	1.00
2.6	0	1.00	0	1.00	0	1.00	1	1.00	1	1.00
2.7	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00
2.8	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00
2.9	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00
3	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00
11.8	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00
11.9	0	1.00	0	1.00	0	1.00	0	0.00	0	1.00
12	0	1.00	0	1.00	0	1.00	0	0.00	0	1.00
>12	0	1.00	0	1.00	0	1.00	0	0.00	0	1.00
Total	67	NA	55	NA	41	NA	257	NA	420	NA

Table 3-10: Cycle 11 Voltage Dependent Growth (BOC-11 Voltage >1.66 Volts)

Delta Volts	SG21		SG22		SG23		SG24		Total	
	No. of Obs.	CPDF	No. of Obs.	CPDF	No. of Obs.	CPDF	No. of Obs.	CPDF	No. of Obs.	CPDF
0	0	0.00	0	0.00	0	0.00	0	0.35	0	0.00
0.1	0	0.00	0	0.00	0	0.00	2	0.35	2	0.09
0.2	0	0.00	0	0.00	0	0.00	1	0.35	1	0.14
0.3	0	0.00	0	0.00	0	0.00	3	0.41	3	0.27
0.4	0	0.00	0	0.00	0	0.00	0	0.41	0	0.27
0.5	0	0.00	0	0.00	0	0.00	0	0.41	0	0.27
0.6	0	0.00	0	0.00	0	0.00	1	0.41	1	0.32
0.7	0	0.00	0	0.00	0	0.00	0	0.41	0	0.32
0.8	0	0.00	0	0.00	0	0.00	0	0.41	0	0.32
0.9	0	0.00	0	0.00	0	0.00	0	0.41	0	0.32
1	0	0.00	0	0.00	0	0.00	0	0.41	0	0.32
1.1	0	0.00	0	0.00	0	0.00	0	0.47	0	0.32
1.2	0	0.00	0	0.00	0	0.00	0	0.59	0	0.32
1.3	0	0.00	0	0.00	0	0.00	0	0.65	0	0.32
1.4	0	0.00	0	0.00	0	0.00	1	0.65	1	0.36
1.5	0	0.00	0	0.00	0	0.00	2	0.65	2	0.45
1.6	1	0.33	0	0.00	0	0.00	1	0.71	2	0.55
1.7	0	0.33	1	0.50	0	0.00	0	0.71	1	0.59
1.8	0	0.33	0	0.50	0	0.00	0	0.71	0	0.59
1.9	0	0.33	0	0.50	0	0.00	1	0.76	1	0.64
2	0	0.33	0	0.50	0	0.00	0	0.76	0	0.64
2.1	0	0.33	0	0.50	0	0.00	0	0.76	0	0.64
2.2	0	0.33	0	0.50	0	0.00	1	0.82	1	0.68
2.3	0	0.33	0	0.50	0	0.00	0	0.82	0	0.68
2.4	0	0.33	0	0.50	0	0.00	0	0.88	0	0.68
2.5	0	0.33	0	0.50	0	0.00	1	0.88	1	0.73
2.6	1	0.67	0	0.50	0	0.00	0	0.88	1	0.77
2.7	0	0.67	1	1.00	0	0.00	1	0.94	2	0.86
2.8	0	0.67	0	1.00	0	0.00	0	0.94	0	0.86
2.9	1	1.00	0	1.00	0	0.00	0	1.00	1	0.91
3	0	1.00	0	1.00	0	0.00	1	1.00	1	0.95
11.8	0	1.00	0	1.00	0	0.00	0	1.00	0	0.95
11.9	0	1.00	0	1.00	0	0.00	1	0.00	1	1.00
12	0	1.00	0	1.00	0	0.00	0	0.00	0	1.00
>12	0	1.00	0	1.00	0	0.00	0	0.00	0	1.00
Total	3	NA	2	NA	0	0.00	17	NA	22	NA

Table 3-11: Independent Voltage Growth Distributions Used for Monte Carlo Simulations

Growth Distribution Used for SGs 2-1, 2-2, and 2-3 (All SGs Combined)	
Growth in Volts/EFPY	No. of Obs.
0	220
0.1	776
0.2	434
0.3	180
0.4	69
0.5	45
0.6	30
0.7	15
0.8	9
0.9	10
1	7
1.1	7
1.2	4
1.3	8
1.4	4
1.5	5
1.6	5
1.7	3
1.8	2
1.9	3
2	1
2.1	0
2.2	4
2.3	2
2.4	1
2.5	2
2.6	2
2.7	2
2.8	0
2.9	1
3	1
11.8	0
11.9	1
12	0
>12	0
Total	1853

Growth Distribution Used for SG 2-4 (SG 2-4 data only)	
Growth in Volts/EFPY	No. of Obs.
0	76
0.1	359
0.2	258
0.3	111
0.4	48
0.5	26
0.6	22
0.7	11
0.8	7
0.9	7
1	7
1.1	6
1.2	3
1.3	6
1.4	2
1.5	5
1.6	4
1.7	1
1.8	2
1.9	2
2	1
2.1	0
2.2	4
2.3	1
2.4	1
2.5	2
2.6	1
2.7	1
2.8	0
2.9	0
3	1
11.8	0
11.9	1
12	0
>12	0
Total	976

Table 3-12: VDG Distributions Used for Monte Carlo Simulations

Growth Distributions Used for SGs 2-1, 2-2, and 2-3 (All SGs combined)			
Growth in Volts/EFPY	BOC Voltage		
	<=0.59V	0.59V to 1.66V*	>1.66V
0	152	68	0
0.1	690	76	2
0.2	374	62	1
0.3	124	41	3
0.4	32	39	0
0.5	17	28	0
0.6	10	23	1
0.7	5	16	0
0.8	3	7	0
0.9	0	5	0
1	1	9	0
1.1	0	6	0
1.2	1	7	0
1.3	1	3	0
1.4	0	3	1
1.5	0	6	2
1.6	0	2	2
1.7	1	5	1
1.8	0	0	0
1.9	0	1	1
2	0	2	0
2.1	0	2	0
2.2	0	1	1
2.3	0	0	0
2.4	0	3	0
2.5	0	1	1
2.6	0	2	1
2.7	0	0	2
2.8	0	2	0
2.9	0	0	1
3	0	0	1
11.8	0	0	0
11.9	0	0	1
12	0	0	0
>12	0	0	0
Total	1411	420	22

Growth Distributions Used for SG 2-4 (Upper Bin Includes 1 Cycle 11 data point from SG 2-1 and 3 Cycle 10 data points from SG 2-4)			
Growth in Volts/EFPY	BOC Voltage		
	<=0.59V	0.59V to 1.66V*	>1.66V
0	48	28	0
0.1	307	44	2
0.2	220	39	1
0.3	79	23	3
0.4	24	22	0
0.5	5	23	0
0.6	8	14	1
0.7	5	12	0
0.8	3	5	1
0.9	0	3	0
1	1	6	0
1.1	0	6	0
1.2	0	6	0
1.3	1	3	0
1.4	0	1	1
1.5	0	5	2
1.6	0	1	1
1.7	1	5	1
1.8	0	0	1
1.9	0	0	1
2	0	2	0
2.1	0	1	0
2.2	0	1	1
2.3	0	0	0
2.4	0	3	0
2.5	0	0	1
2.6	0	2	0
2.7	0	0	1
2.8	0	2	0
2.9	0	0	1
3	0	0	1
11.8	0	0	0
11.9	0	0	1
12	0	0	0
>12	0	0	0
Total	702	257	21

* - Includes 10% increase from Cycle 11 actual growth values.

Table 3-13: Re-tested DOSs ≥ 1.5 Volts that Failed the Probe Wear Check

SG	Row	Col	Ind	Elev	Volts	Probe	Cal No.	ARC Out 2R11	% Diff
21	7	33	RSS	1H	4.93	720RF	12	Yes	12.0%
	7	33	DOS	1H	4.4	720RF	27		
	17	28	RSS	1H	1.56	720RF	11	Yes	9.1%
	17	28	DOS	1H	1.43	720RF	27		
	24	52	RSS	1H	1.53	720RF	11	Yes	-10.0%
	24	52	DOS	1H	1.7	720RF	27		
	27	33	RSS	1H	2.96	720RF	12	Yes	4.6%
	27	33	DOS	1H	2.83	720RF	34		
	31	51	RSS	1H	6.76	720RF	5	Yes	3.4%
	31	51	DOS	1H	6.54	720RF	27		
	36	41	RSS	2H	2.41	720RF	17	Yes	6.2%
	36	41	DOS	2H	2.27	720RF	34		
22	13	72	RSS	2H	3.65	720RF	13	Yes	6.7%
	13	72	DOS	2H	3.42	720RF	41		
	14	75	RSS	1H	2.42	720RF	13	Yes	-0.8%
	14	75	DOS	1H	2.44	720RF	41		
	18	84	RSS	1H	1.58	720RF	14	Yes	-9.2%
	18	84	DOS	1H	1.74	720RF	41		
	19	51	RSS	2H	2.21	720RF	14	Yes	-7.9%
	19	51	DOS	2H	2.4	720RF	41		
	22	67	RSS	2H	4.45	720RF	12	Yes	-2.8%
	22	67	DOS	2H	4.58	720RF	41		
	38	40	RSS	1H	5.85	720RF	7	Yes	-7.3%
	38	40	DOS	1H	6.31	720RF	41		
23	9	23	RSS	1H	4.03	720RF	9	Yes	-0.2%
	9	23	DOS	1H	4.04	720RF	34		
	28	24	RSS	2H	2.67	720RF	15	Yes	-12.5%
	28	24	DOS	2H	3.05	720RF	34		
24	11	7	RSS	1H	1.53	720RF	13	Yes	-13.1%
	11	7	RSS	1H	1.72	720RF	26	Yes	-2.3%
	11	7	DOS	1H	1.76	720RF	33		
	11	64	RSS	1H	1.77	720RF	14	Yes	7.3%
	11	64	RSS	1H	1.65	720RF	26	Yes	0.0%
	11	64	DOS	1H	1.65	720RF	33		
	14	58	RSS	2H	1.69	720RF	14	Yes	15.0%
	14	58	RSS	2H	1.43	720RF	26	Yes	-2.7%
	14	58	DOS	2H	1.47	720RF	33		
	16	55	RSS	2H	3.63	720RF	14	Yes	17.1%
	16	55	RSS	2H	3.07	720RF	26	Yes	-1.0%
	16	55	DOS	2H	3.1	720RF	36		
	16	61	RSS	2H	1.74	720RF	14	Yes	15.2%
	16	61	RSS	2H	1.52	720RF	26	Yes	0.7%
	16	61	DOS	2H	1.51	720RF	33		
	18	52	RSS	1H	2.59	720RF	14	Yes	-7.8%
	18	52	RSS	1H	2.72	720RF	26	Yes	-3.2%
	18	52	DOS	1H	2.81	720RF	33		
	20	64	RSS	1H	1.99	720RF	14	Yes	-7.9%
	20	64	RSS	1H	2.16	720RF	26	Yes	0.0%
	20	64	DOS	1H	2.16	720RF	33		
	24	64	RSS	4H	1.81	720RF	14	Yes	5.8%
	24	64	RSS	4H	1.63	720RF	26	Yes	-4.7%
	24	64	DOS	4H	1.71	720RF	36		

Table 3-14: New 2R11 DOSs >=0.5 Volts In Tubes Inspected With A Worn Probe In 2R10

SG	Row	Col	Ind	Elev	Volts	Cal	New?	ARC Out 2R11	ARC Out 2R10
21	17	10	DOS	1H	1.04	HC-4	New		Out
	46	54	DOS	1H	0.86	CC-4	New		Out
	1	40	DOS	4C	0.78	CC-22	New	Yes	Out
	30	54	DOS	1H	0.73	CC-3	New	Yes	Out
	14	77	DOS	1H	0.66	CC-27	New		Out
	1	33	DOS	4C	0.64	CC-22	New	Yes	Out
	17	88	DOS	2H	0.63	CC-8	New	Yes	Out
	15	80	DOS	3H	0.53	CC-8	New	Yes	Out
	2	26	DOS	5H	0.53	HC-11	New	Yes	Out
22	20	55	DOS	1H	1.04	CC-14	New	Yes	Out
	5	61	DOS	1H	0.83	HC-10	New	Yes	Out
	28	21	DOS	1H	0.64	CC-6	New		Out
	27	12	DOS	1H	0.64	CC-6	New		Out
	26	17	DOS	2H	0.54	CC-5	New		Out
23	5	77	DOS	1H	1.28	HC-15	New	Yes	Out
	10	65	DOS	1H	1.14	CC-6	New		Out
	5	66	DOS	3H	0.8	HC-15	New	Yes	Out
	24	45	DOS	1H	0.7	HC-5	New		Out
	5	59	DOS	1H	0.62	HC-15	New	Yes	Out
	17	59	DOS	2H	0.59	CC-6	New		Out
	3	49	DOS	1H	0.58	HC-13	New		Out
	5	87	DOS	2H	0.55	HC-15	New	Yes	Out
	3	7	DOS	3H	0.53	HC-12	New		Out
	22	42	DOS	2H	0.51	HC-5	New		Out

Table 3-14: (cont'd)

SG	Row	Col	Ind	Elev	Volts	Cal	New?	ARC Out 2R11	ARC Out 2R10
24	8	68	DOS	1H	1.28	CC-18	New		Out
	28	78	DOS	2H	1.16	CC-26	New	Yes	Out
	28	76	DOS	2H	0.93	CC-26	New	Yes	Out
	17	35	DOS	1H	0.92	HC-4	New		Out
	37	33	DOS	2H	0.9	CC-11	New		Out
	7	68	DOS	1H	0.88	CC-17	New		Out
	38	38	DOS	2H	0.86	CC-12	New		Out
	31	31	DOS	2H	0.83	CC-9	New		Out
	18	70	DOS	2H	0.82	CC-16	New		Out
	19	40	DOS	1H	0.81	HC-3	New		Out
	9	61	DOS	1H	0.8	CC-17	New		Out
	14	67	DOS	1H	0.79	CC-14	New	Yes	Out
	23	73	DOS	3H	0.79	CC-15	New		Out
	8	74	DOS	2H	0.79	CC-18	New		Out
	18	67	DOS	1H	0.78	CC-14	New	Yes	Out
	23	40	DOS	3H	0.78	HC-3	New		Out
	32	43	DOS	2H	0.78	CC-11	New		Out
	38	32	DOS	2H	0.77	CC-8	New		Out
	5	36	DOS	1H	0.76	HC-18	New		Out
	5	67	DOS	2H	0.76	HC-27	New		Out
	38	67	DOS	3H	0.74	CC-3	New		Out
	21	72	DOS	2H	0.74	CC-15	New		Out
	2	40	DOS	1H	0.71	HC-18	New		Out
	17	69	DOS	1H	0.7	CC-13	New		Out
	28	30	DOS	1H	0.7	CC-8	New		Out
	4	66	DOS	1H	0.68	HC-28	New		Out
	26	11	DOS	3H	0.68	CC-8	New		Out
	8	62	DOS	1H	0.67	CC-18	New		Out
	16	39	DOS	1H	0.67	HC-4	New		Out
	19	29	DOS	2H	0.67	HC-7	New		Out
	25	42	DOS	2H	0.67	HC-3	New		Out
	8	72	DOS	3H	0.66	CC-18	New		Out
	26	42	DOS	2H	0.66	CC-11	New		Out
	38	28	DOS	1H	0.66	CC-9	New		Out
	26	31	DOS	1H	0.66	CC-8	New		Out
	7	65	DOS	3H	0.65	CC-17	New		Out
	38	45	DOS	2H	0.65	CC-11	New		Out
	37	23	DOS	2H	0.65	CC-9	New		Out
	35	69	DOS	2H	0.64	CC-4	New		Out
	6	66	DOS	2H	0.63	CC-18	New		Out
	41	61	DOS	3H	0.62	CC-3	New		Out
	34	68	DOS	2H	0.62	CC-3	New		Out
	37	29	DOS	2H	0.62	CC-9	New		Out
	15	72	DOS	2H	0.61	CC-15	New		Out
	26	39	DOS	1H	0.61	CC-11	New		Out

Table 3-14: (cont'd)

SG	Row	Col	Ind	Elev	Volts	Cal	New?	ARC Out 2R11	ARC Out 2R10
24	22	33	DOS	1H	0.6	HC-6	New		Out
	27	72	DOS	2H	0.6	CC-4	New		Out
	38	25	DOS	1H	0.59	CC-8	New		Out
	28	77	DOS	3H	0.59	CC-26	New	Yes	Out
	22	65	DOS	2H	0.59	CC-14	New	Yes	Out
	26	74	DOS	3H	0.59	CC-3	New		Out
	15	24	DOS	2H	0.58	HC-7	New		Out
	2	40	DOS	2H	0.58	HC-18	New		Out
	36	45	DOS	2H	0.57	CC-11	New		Out
	8	67	DOS	1H	0.57	CC-18	New		Out
	11	72	DOS	1H	0.56	CC-15	New		Out
	9	61	DOS	2H	0.56	CC-17	New		Out
	31	71	DOS	2H	0.56	CC-4	New		Out
	8	72	DOS	2H	0.55	CC-18	New		Out
	35	40	DOS	3H	0.55	CC-12	New		Out
	41	61	DOS	4H	0.55	CC-3	New		Out
	36	38	DOS	1H	0.55	CC-12	New		Out
	36	35	DOS	2H	0.54	CC-12	New		Out
	8	26	DOS	1H	0.54	HC-16	New		Out
	18	61	DOS	3H	0.54	CC-14	New	Yes	Out
	3	30	DOS	2H	0.53	HC-20	New	Yes	Out
	26	65	DOS	1H	0.53	CC-3	New		Out
	23	63	DOS	3H	0.53	CC-13	New		Out
	14	72	DOS	2H	0.53	CC-16	New		Out
	8	62	DOS	2H	0.53	CC-18	New		Out
	26	34	DOS	1H	0.52	CC-12	New		Out
	27	77	DOS	3H	0.52	CC-26	New	Yes	Out
	19	35	DOS	2H	0.52	HC-4	New		Out
	27	33	DOS	1H	0.52	CC-11	New		Out
	25	43	DOS	1H	0.51	HC-3	New		Out
	44	41	DOS	1H	0.51	CC-11	New		Out
	37	67	DOS	3H	0.5	CC-4	New		Out
	14	66	DOS	3H	0.5	CC-14	New	Yes	Out
	22	37	DOS	4H	0.5	HC-4	New		Out
	24	74	DOS	3H	0.5	CC-16	New		Out
	25	31	DOS	1H	0.5	CC-26	New	Yes	Out
	17	39	DOS	2H	0.5	HC-3	New		Out

Table 3-15: Summary of New DOS Indications Sorted by Category

SG	2R11 DOSs in Active Tubes (Total)	New 2R11 Not Detected in 2R10	New 2R11 Ind. In Tubes Insp. w/ worn Probe in 2R10	New 2R11 Ind. In Tubes Insp. w/ Good Probe in 2R10	New 2R11 Ind. ≥0.5 Volts	New 2R11 Ind. ≥0.5 Volts w/ Worn Probe in 2R10
2-1	350	187	49	138	41	9
2-2	275	160	21	139	47	5
2-3	263	172	46	126	46	10
2-4	976	490	220	270	183	82
Total	1864	1009	336	673	317	106

Table 3-16: Summary of ARC Out Tube Inspections in 2R10

SG	# ARC Out Tubes (2R10)	# ARC In Tubes (2R10)	Total # of Inspections
2-1	1230	2335	3565
2-2	866	2680	3546
2-3	844	2669	3513
2-4	1415	2107	3522
	4355	9791	14146

Table 3-17: NDE Uncertainty Distributions

Analyst Uncertainty

Percent Variation	Cumulative Probability
-40.0%	0.00005
-38.0%	0.00011
-36.0%	0.00024
-34.0%	0.00048
-32.0%	0.00095
-30.0%	0.00179
-28.0%	0.00328
-26.0%	0.00580
-24.0%	0.00990
-22.0%	0.01634
-20.0%	0.02608
-18.0%	0.04027
-16.0%	0.06016
-14.0%	0.08704
-12.0%	0.12200
-10.0%	0.16581
-8.0%	0.21867
-6.0%	0.28011
-4.0%	0.34888
-2.0%	0.42302
0.0%	0.50000
2.0%	0.57698
4.0%	0.65112
6.0%	0.71989
8.0%	0.78133
10.0%	0.83419
12.0%	0.87800
14.0%	0.91296
16.0%	0.93984
18.0%	0.95973
20.0%	0.97392
22.0%	0.98366
24.0%	0.99010
26.0%	0.99420
28.0%	0.99672
30.0%	0.99821
32.0%	0.99905
34.0%	0.99952
36.0%	0.99976
38.0%	0.99989
40.0%	0.99995

Std Deviation = 10.3%
Mean = 0.0%
No Cutoff

Acquisition Uncertainty

Percent Variation	Cumulative Probability
<-15.0%	0.00000
-15.0%	0.01606
-14.0%	0.02275
-13.0%	0.03165
-12.0%	0.04324
-11.0%	0.05804
-10.0%	0.07656
-9.0%	0.09927
-8.0%	0.12655
-7.0%	0.15866
-6.0%	0.19568
-5.0%	0.23753
-4.0%	0.28385
-3.0%	0.33412
-2.0%	0.38755
-1.0%	0.44320
0.0%	0.50000
1.0%	0.55680
2.0%	0.61245
3.0%	0.66588
4.0%	0.71615
5.0%	0.76247
6.0%	0.80432
7.0%	0.84134
8.0%	0.87345
9.0%	0.90073
10.0%	0.92344
11.0%	0.94196
12.0%	0.95676
13.0%	0.96835
14.0%	0.97725
15.0%	0.98394
>15.0%	1.00000

Std Deviation = 7.0%
Mean = 0.0%
Cutoff = +/- 15.0%

Figure 3-1 : As-Found Voltage Distributions SGs 2-1 and 2-2

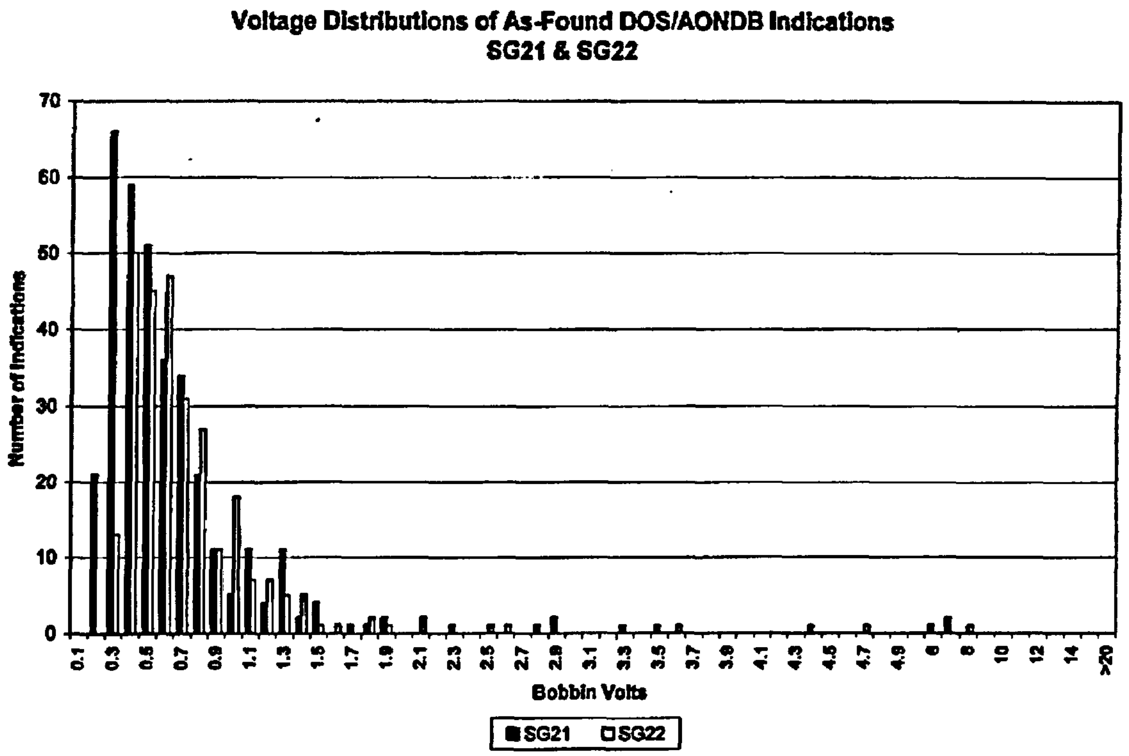


Figure 3-2 : As-Found Voltage Distributions SGs 2-3 and 2-4

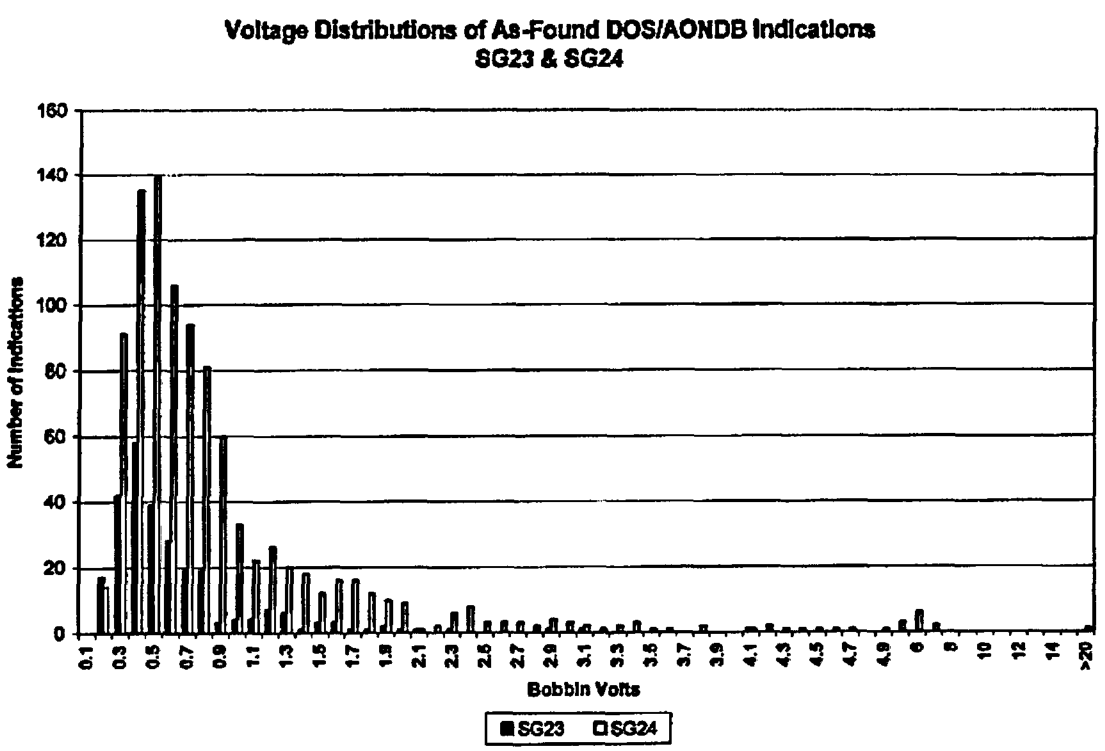


Figure 3-3: 2R11 Repaired Voltage Distributions SGs 2-1 and 2-2

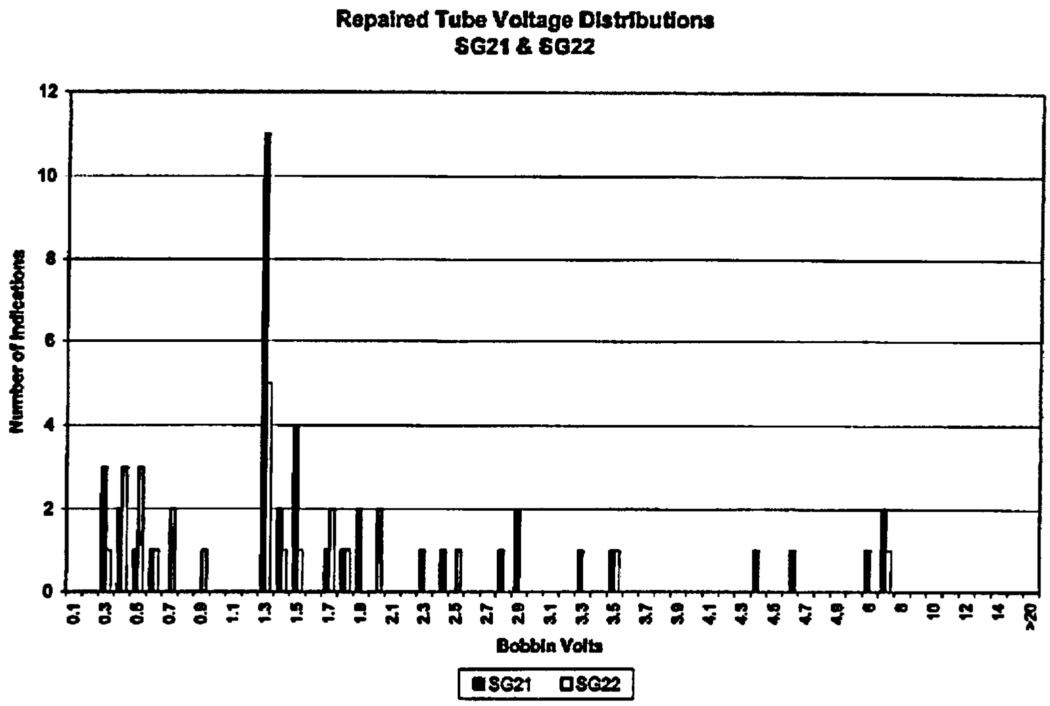


Figure 3-4: 2R11 Repaired Voltage Distributions SGs 2-3 and 2-4

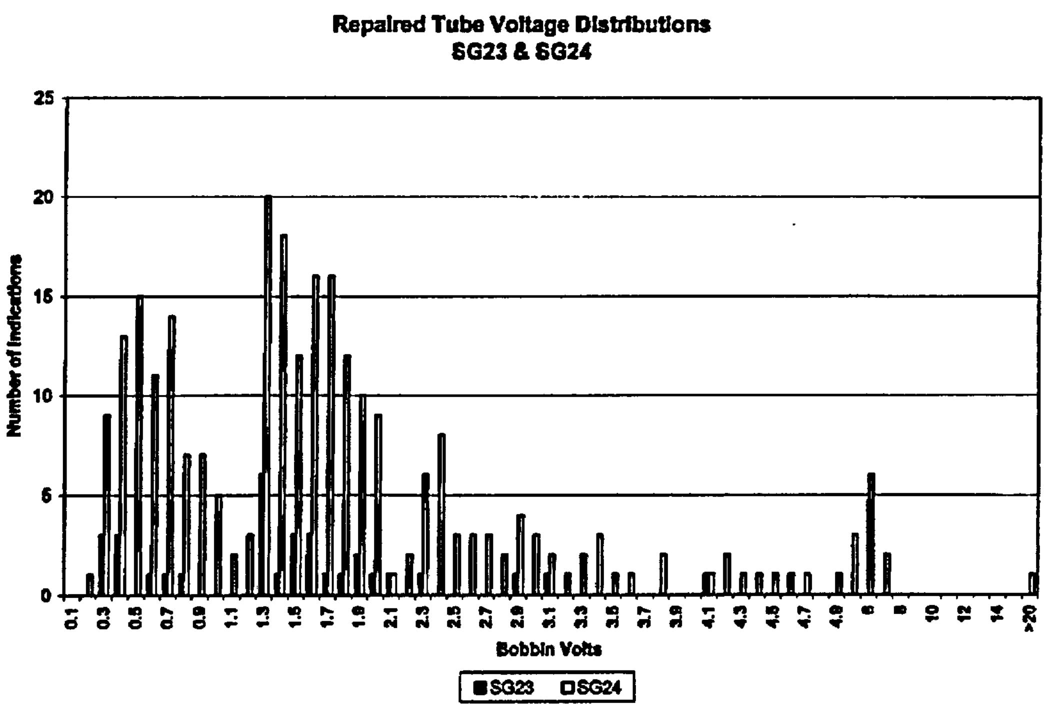


Figure 3-5: Indications RTS Voltage Distributions SGs 2-1 and 2-2

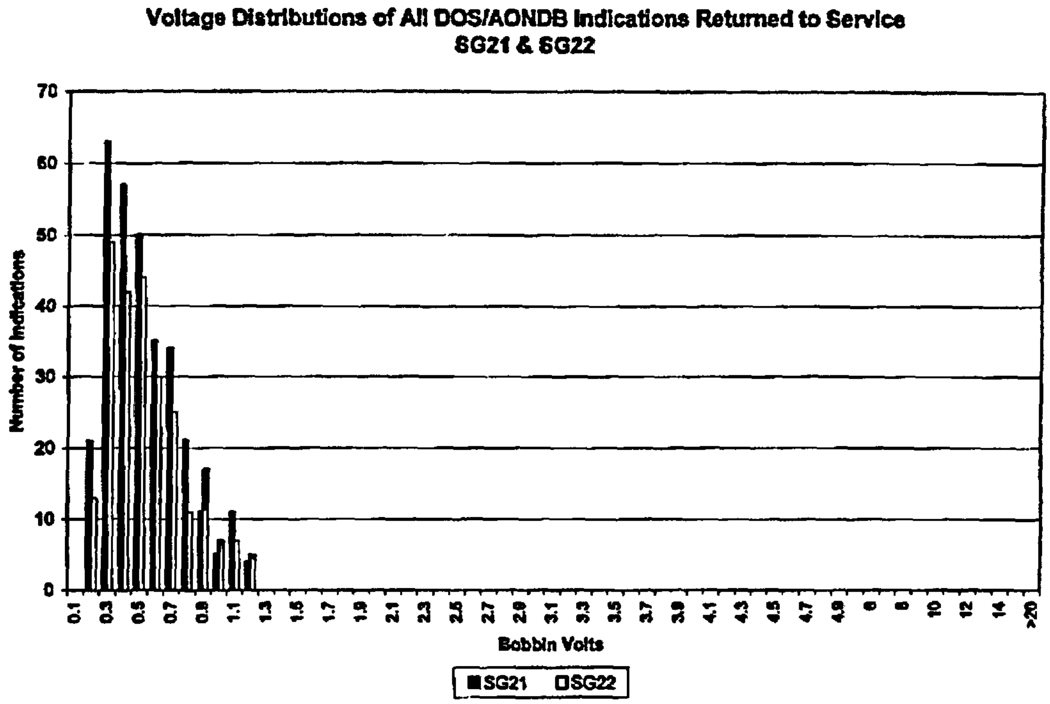


Figure 3-6: Indications RTS Voltage Distributions SGs 2-3 and 2-4

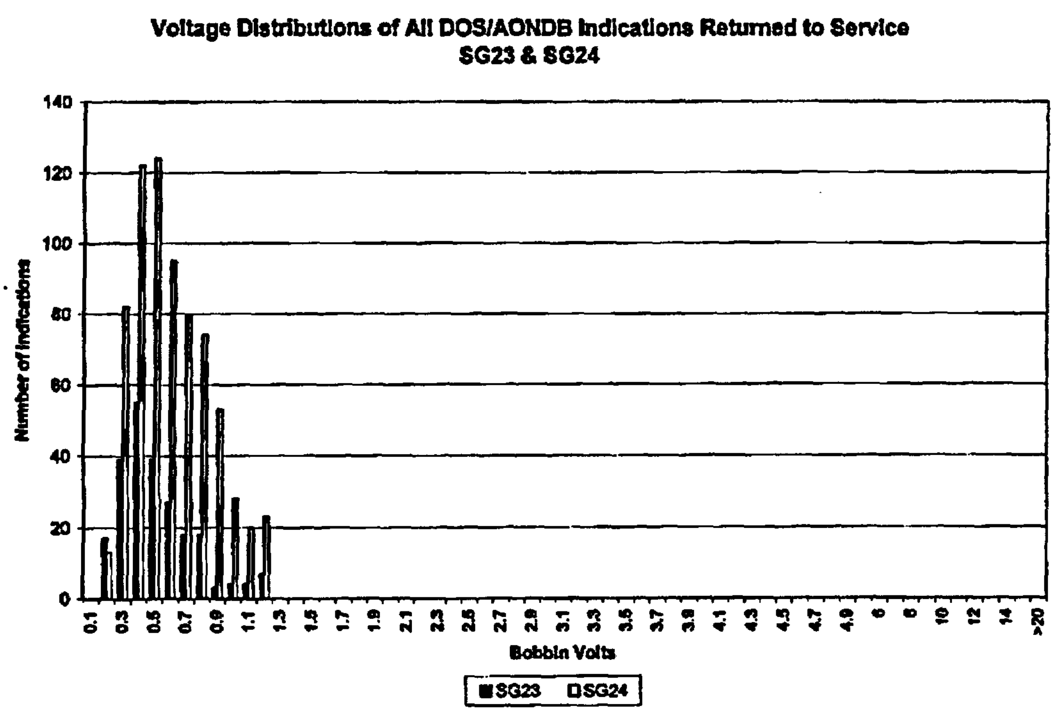
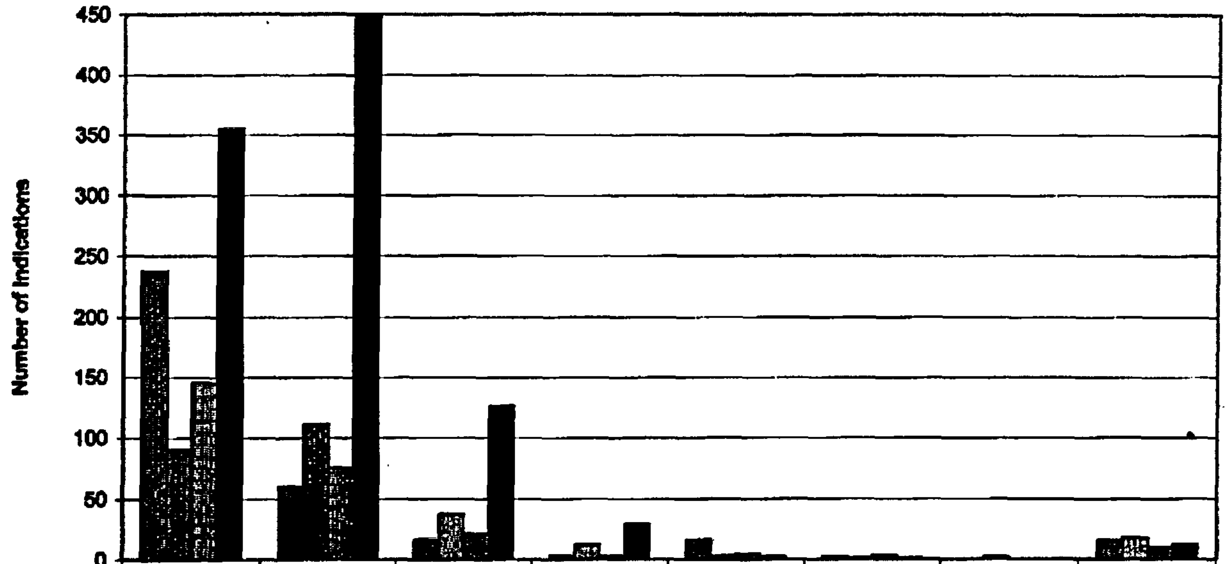


Figure 3-7 : 2R11 DOS vs. TSP Elevation

Distribution of Indications by TSP Location



	1H	2H	3H	4H	5H	6H	7H	CL
SG21	238	60	16	3	16	2	0	15
SG22	91	111	37	12	3	1	2	18
SG23	146	76	21	3	4	3	0	10
SG24	355	450	127	29	2	1	0	12

Tube Support Plate

Figure 3-8: Cycle 11 Growth Distributions SGs 2-1 and 2-2

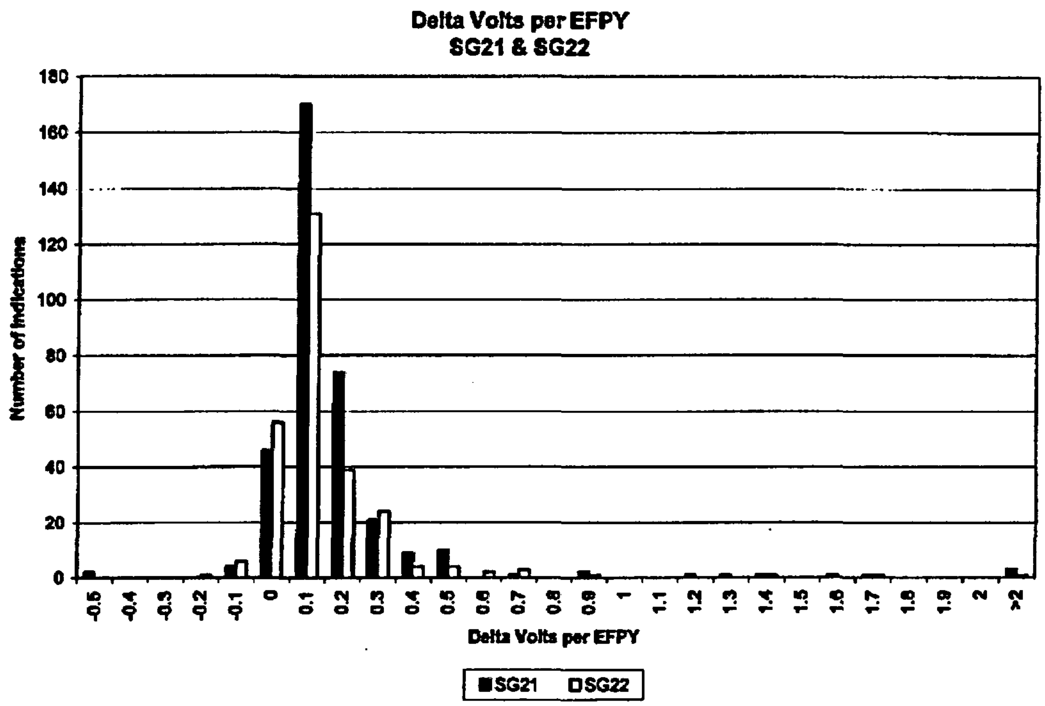


Figure 3-9: Cycle 11 Growth Distributions SGs 2-3 and 2-4

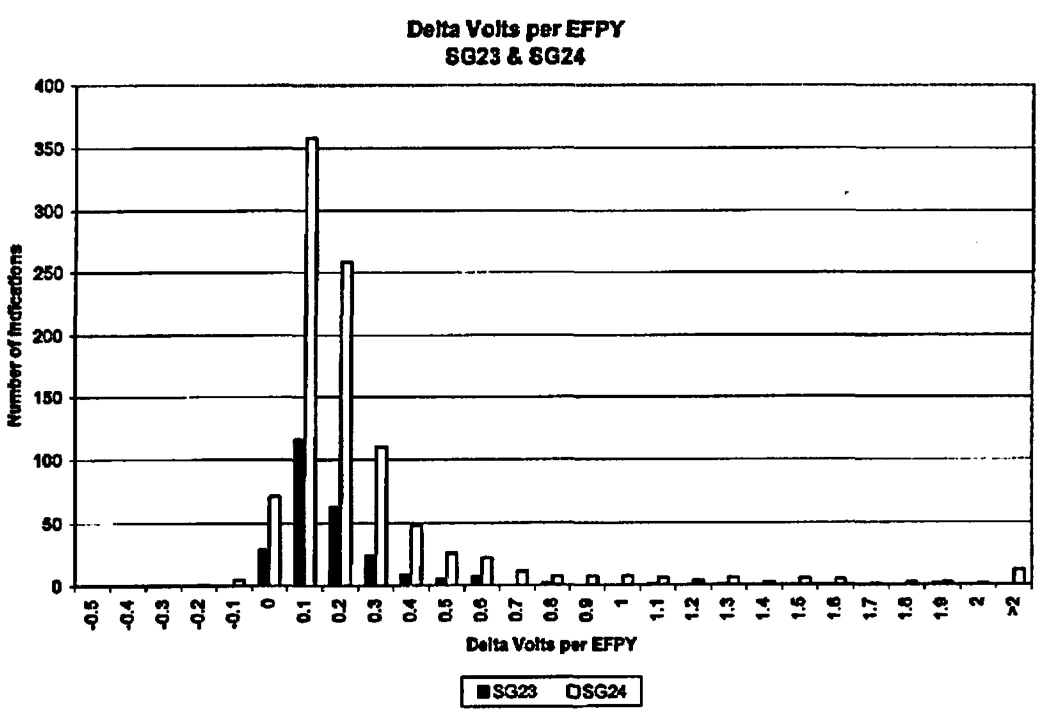


Figure 3-10: SG 2-1 Cycle 11 Growth vs. BOC Voltage

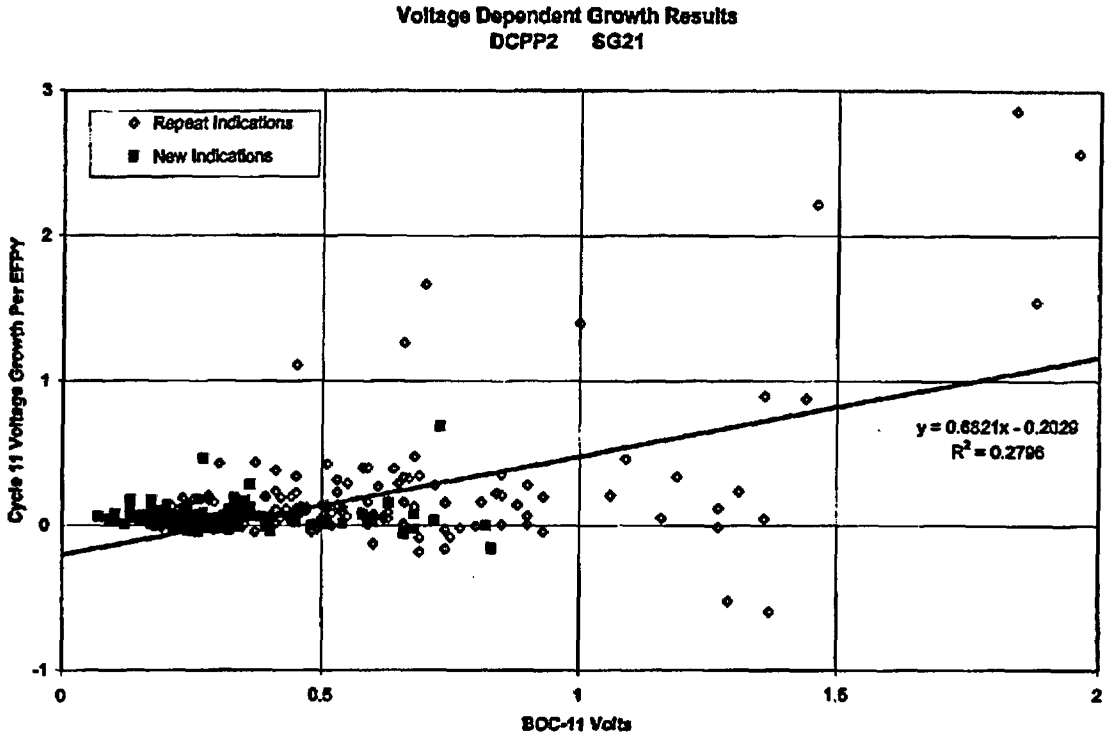


Figure 3-11: SG 2-2 Cycle 11 Growth vs. BOC Voltage

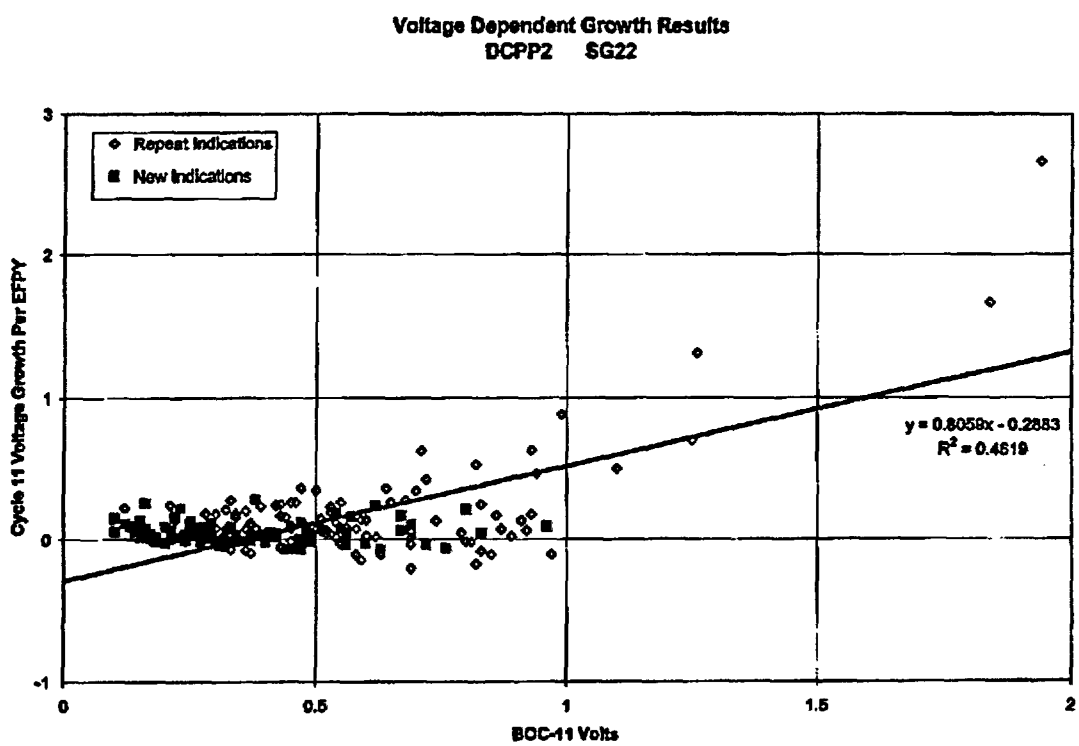


Figure 3-12: SG 2-3 Cycle 11 Growth vs. BOC Voltage

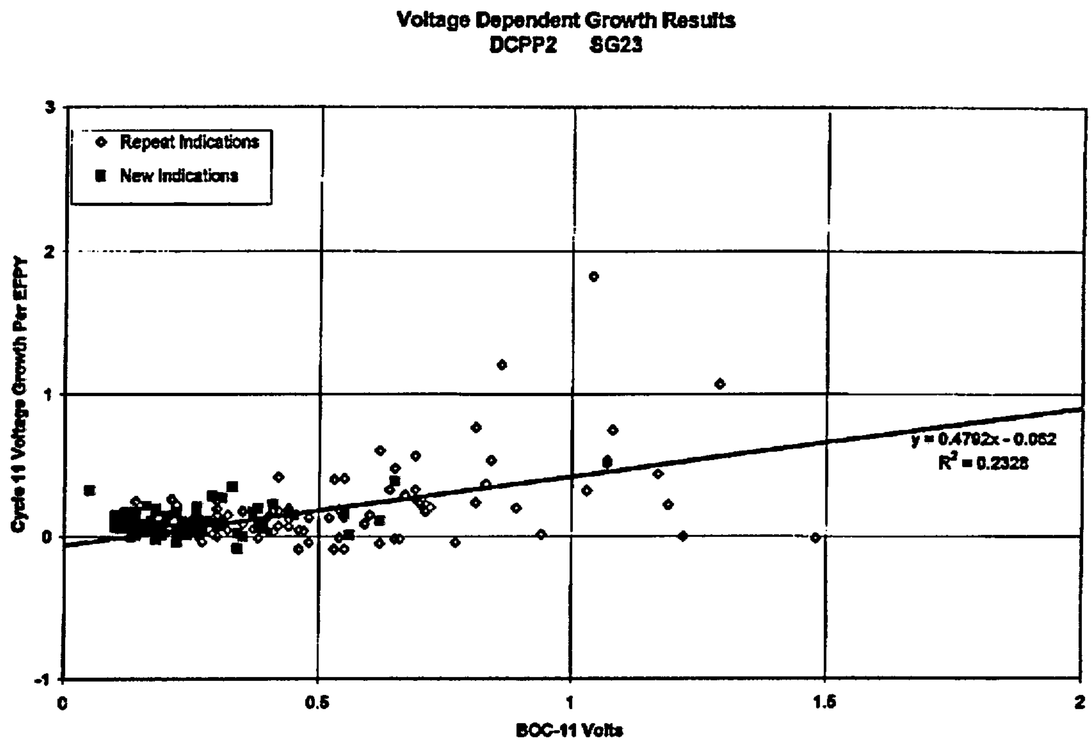


Figure 3-13: SG 2-4 Cycle 11 Growth vs. BOC Voltage (Does not include R44C45)

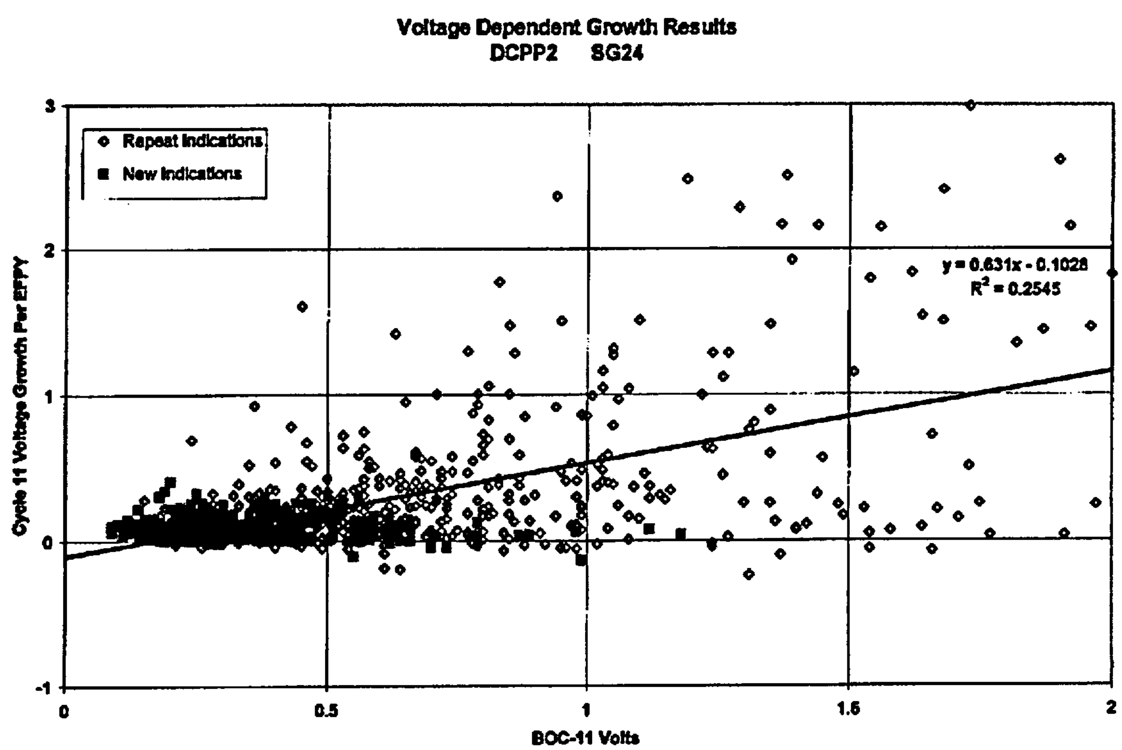


Figure 3-14: Comparison of R44C45 VDG to Remaining SG 2-4 Population

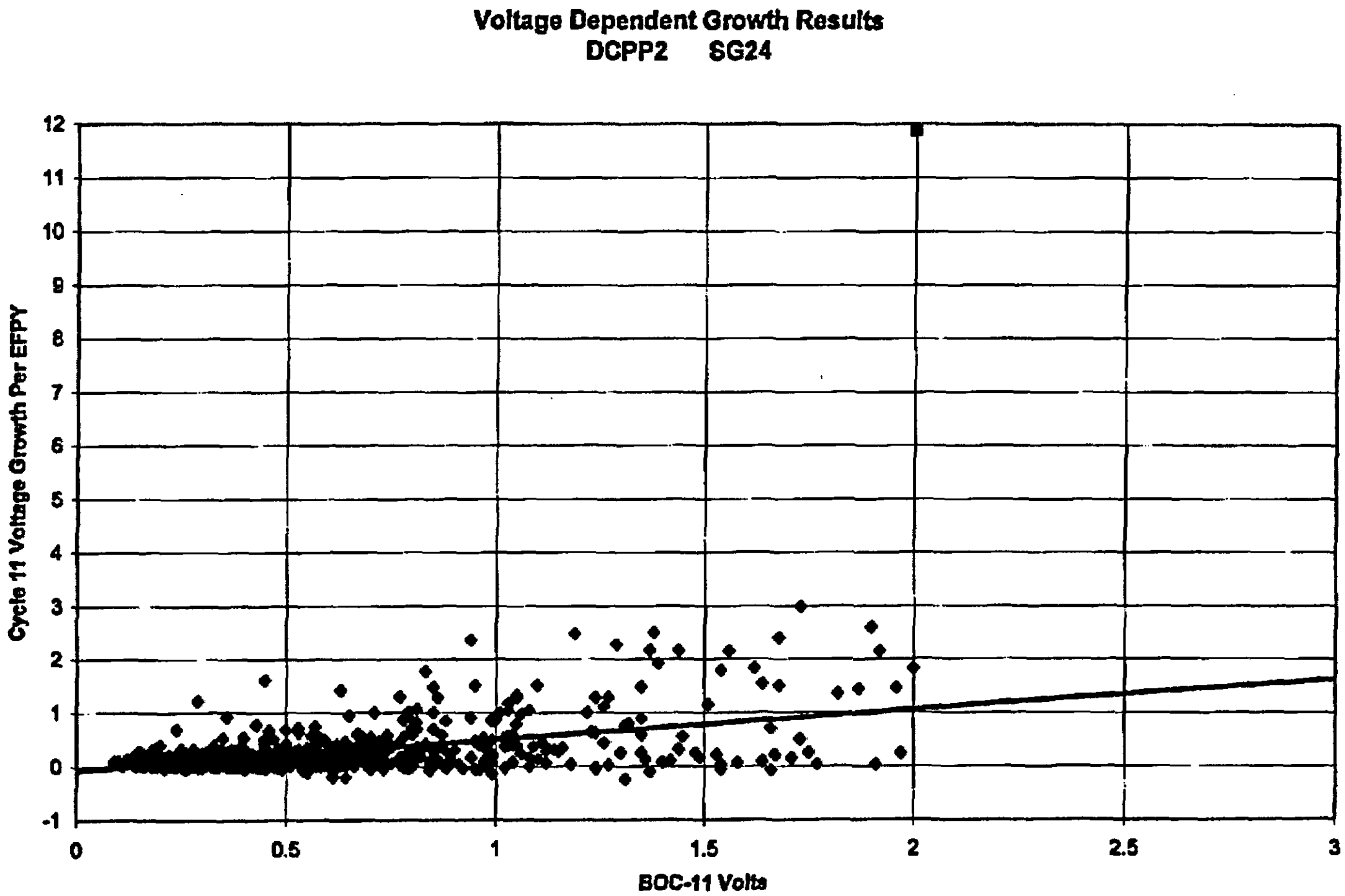


Figure 3-15: SG 2-1 Cycles 10 and 11 Growth vs. BOC Voltage

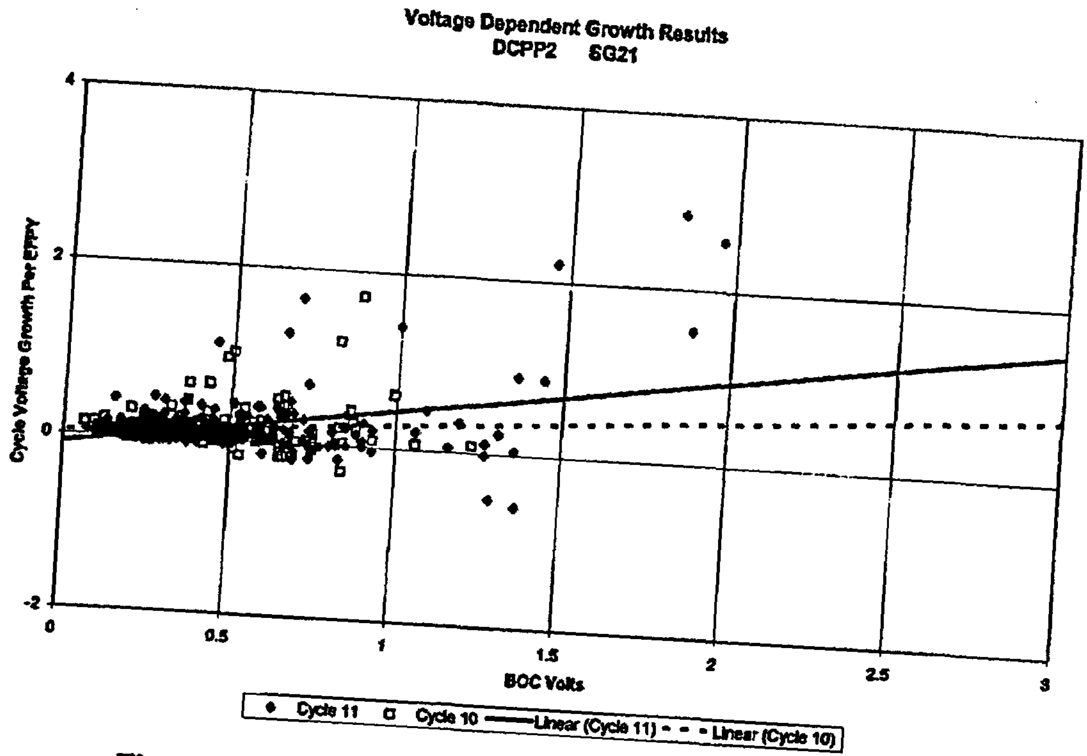


Figure 3-16: SG 2-2 Cycles 10 and 11 Growth vs. BOC Voltage

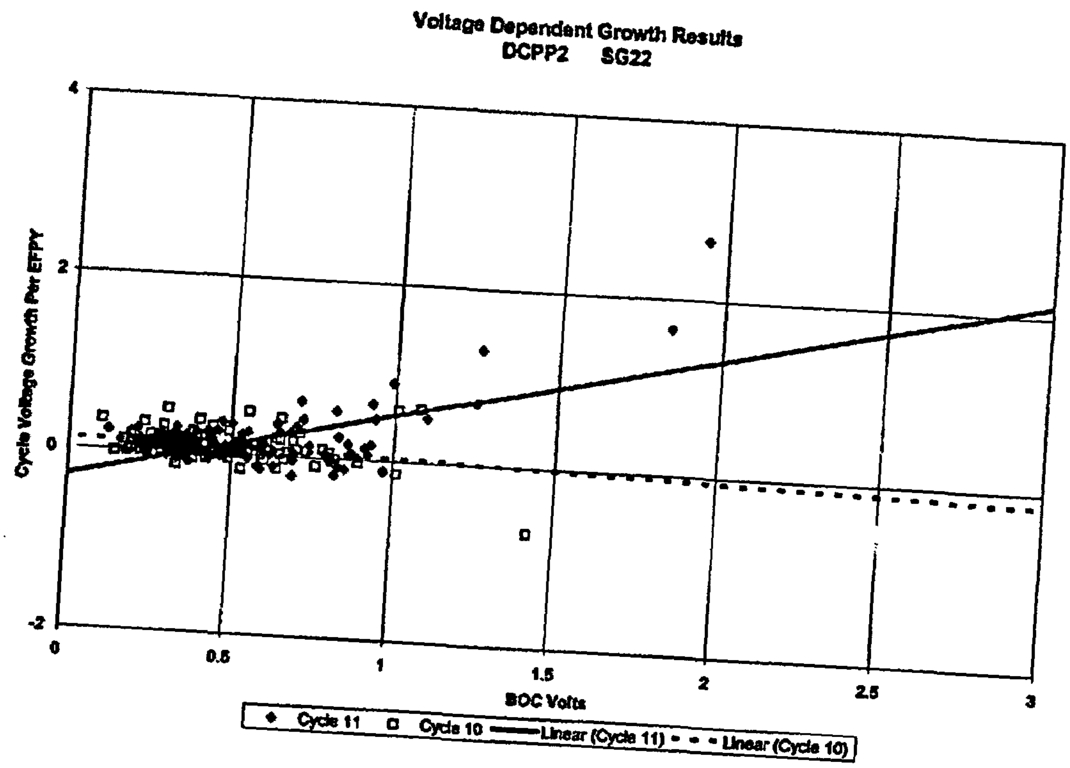


Figure 3-17: SG 2-3 Cycles 10 and 11 Growth vs. BOC Voltage

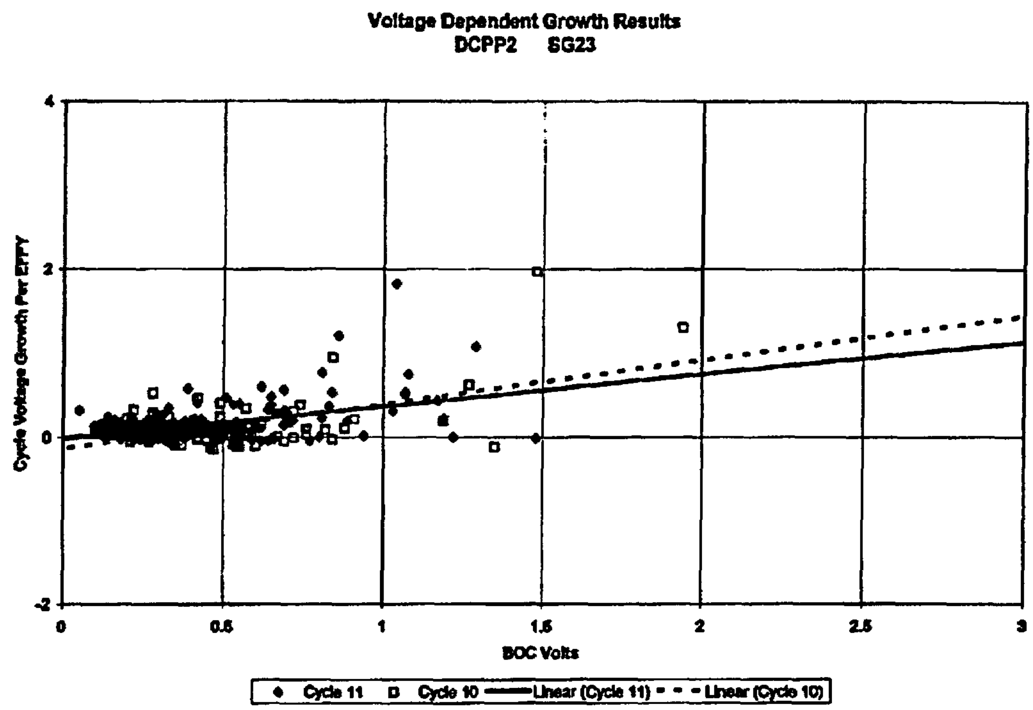


Figure 3-18: SG 2-4 Cycles 10 and 11 Growth vs. BOC Voltage

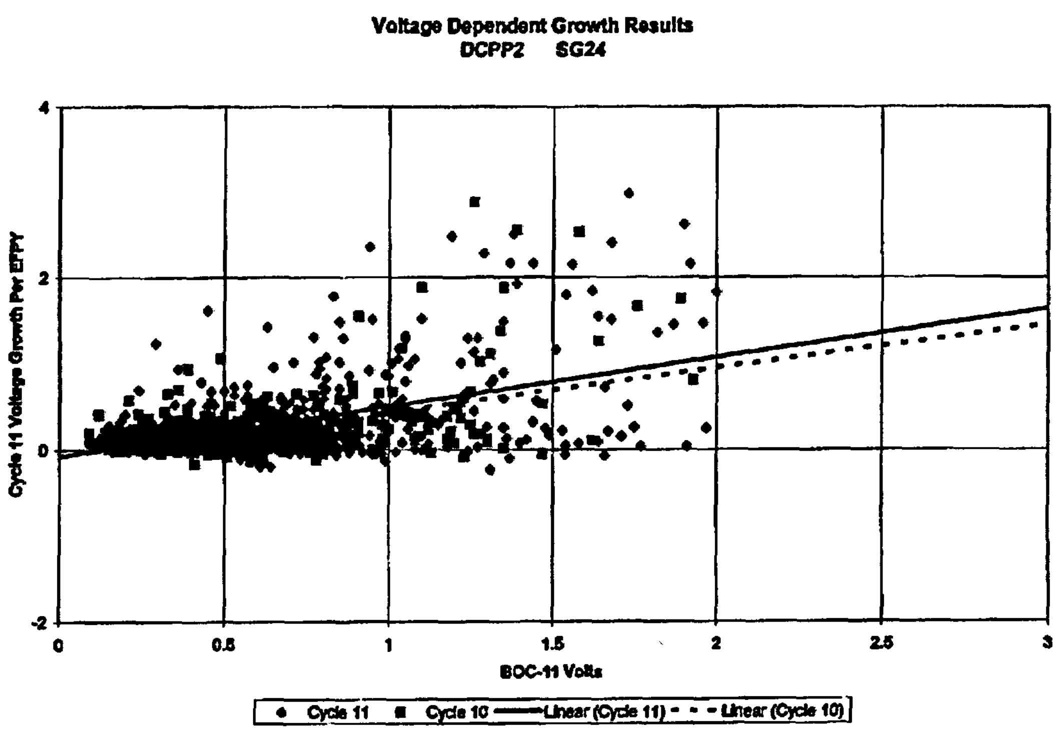


Figure 3-19: Cycle 11 VDG Breakpoint Analysis Results

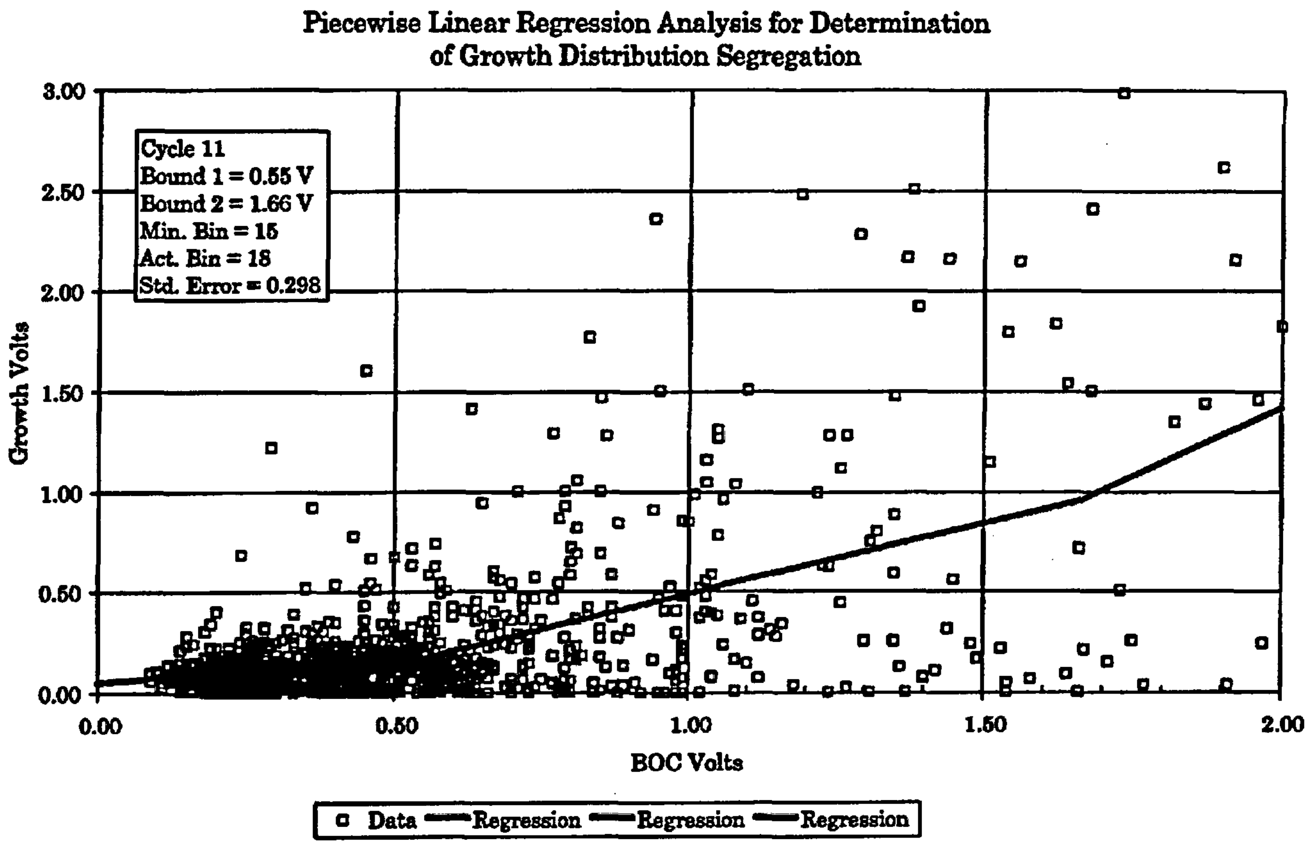


Figure 3-20: Cycle 10 VDG Breakpoint Analysis Results

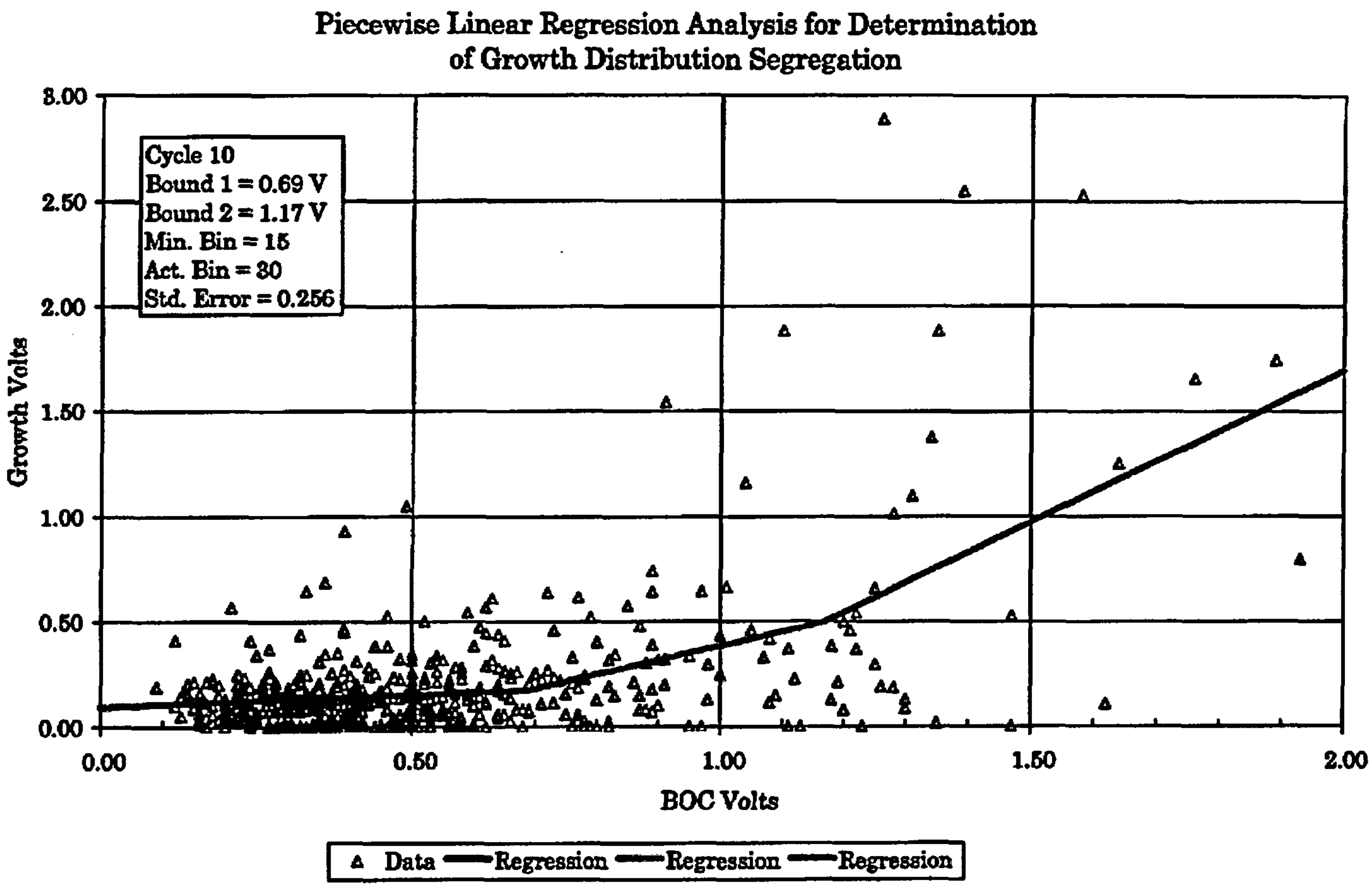


Figure 3-21: Final VDG Breakpoint Analysis Determination

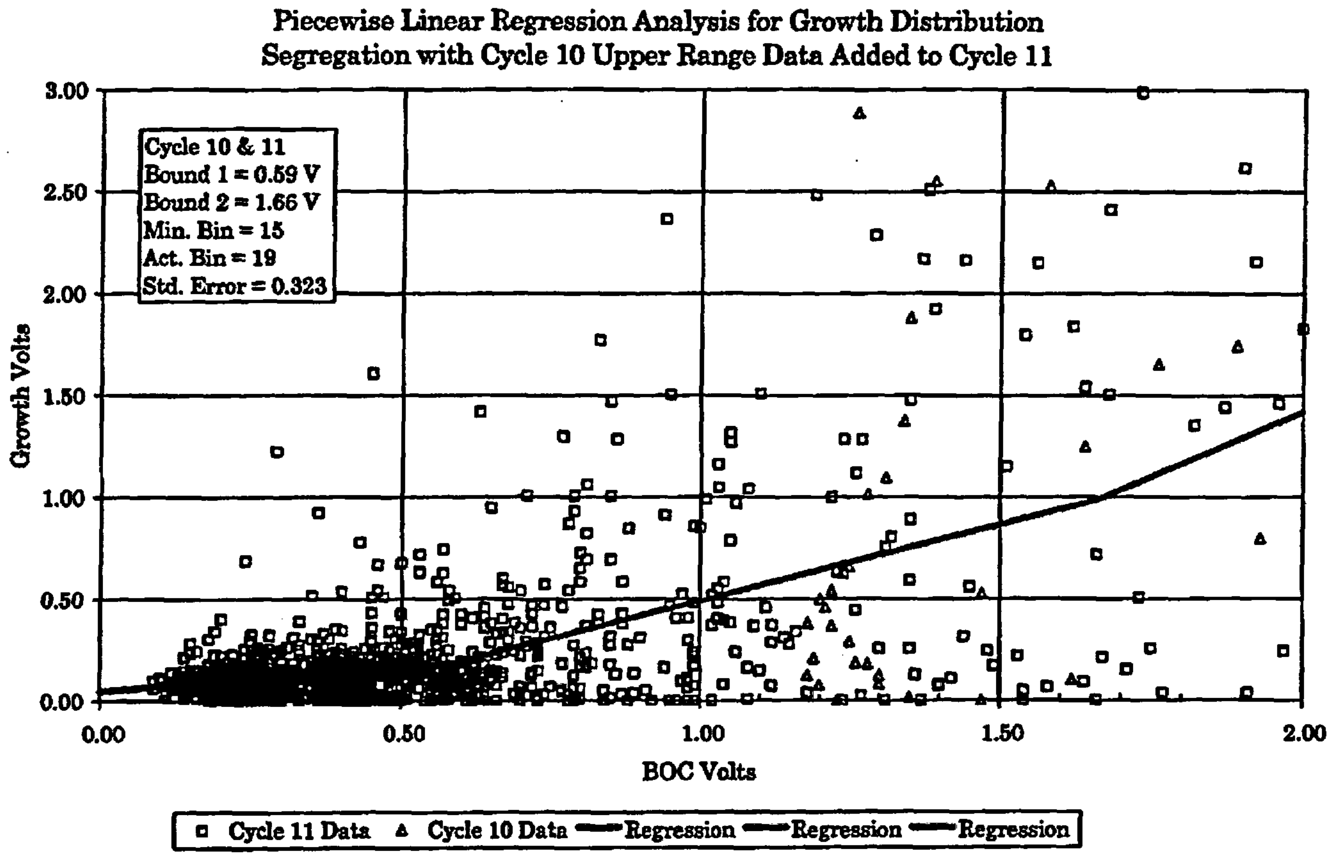


Figure 3-22: Cycle 11 VDG Curves All SGs

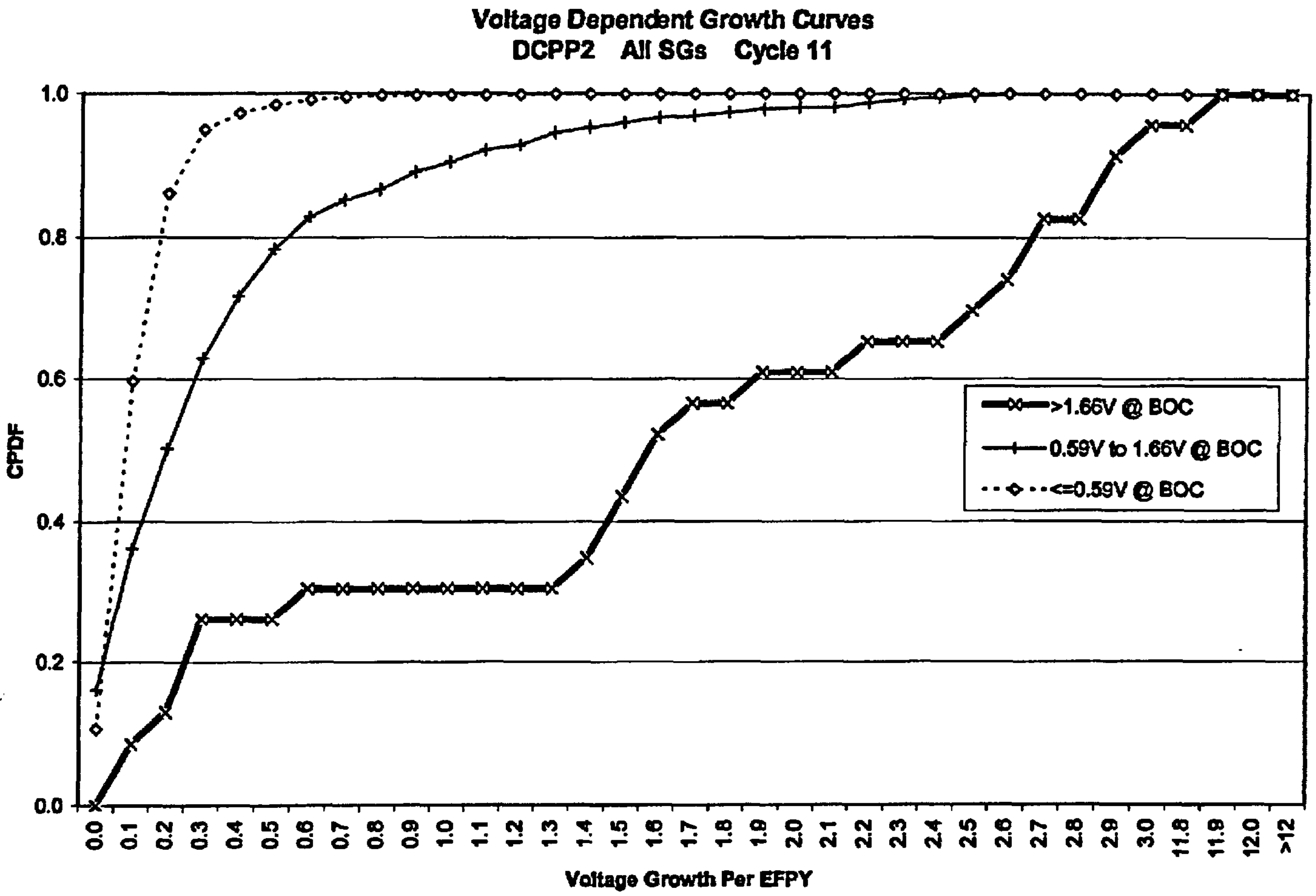


Figure 3-23: SG 2-1 Cycle 11 VDG Curves

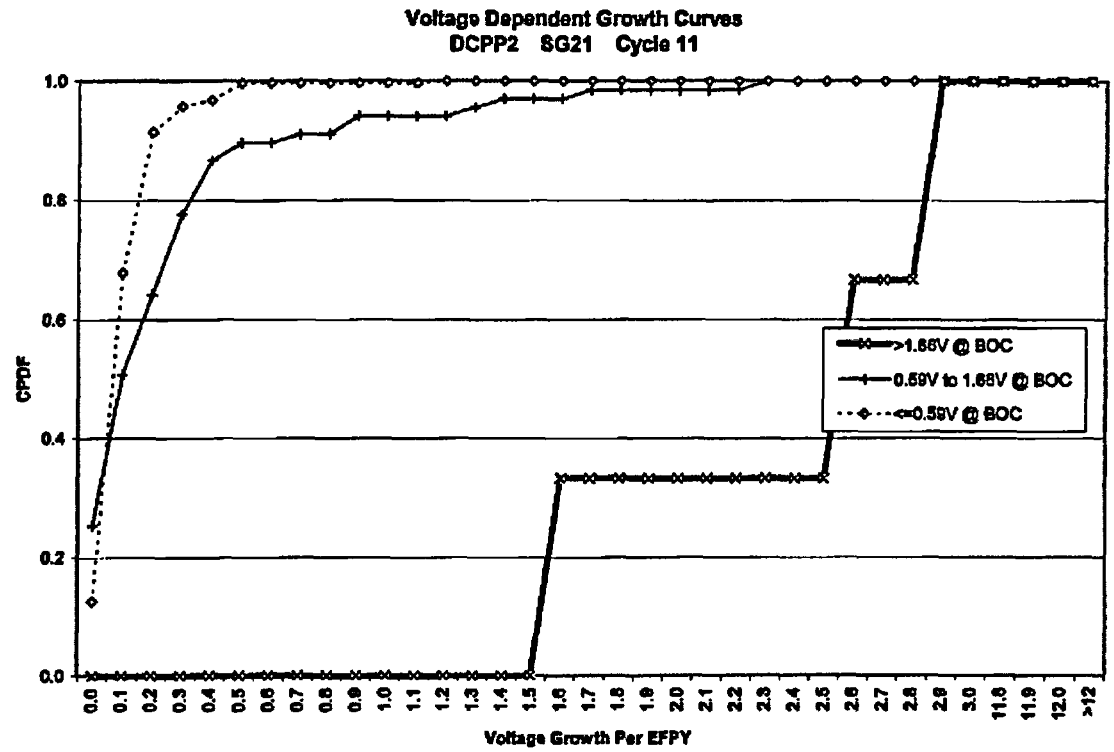


Figure 3-24: SG 2-2 Cycle 11 VDG Curves

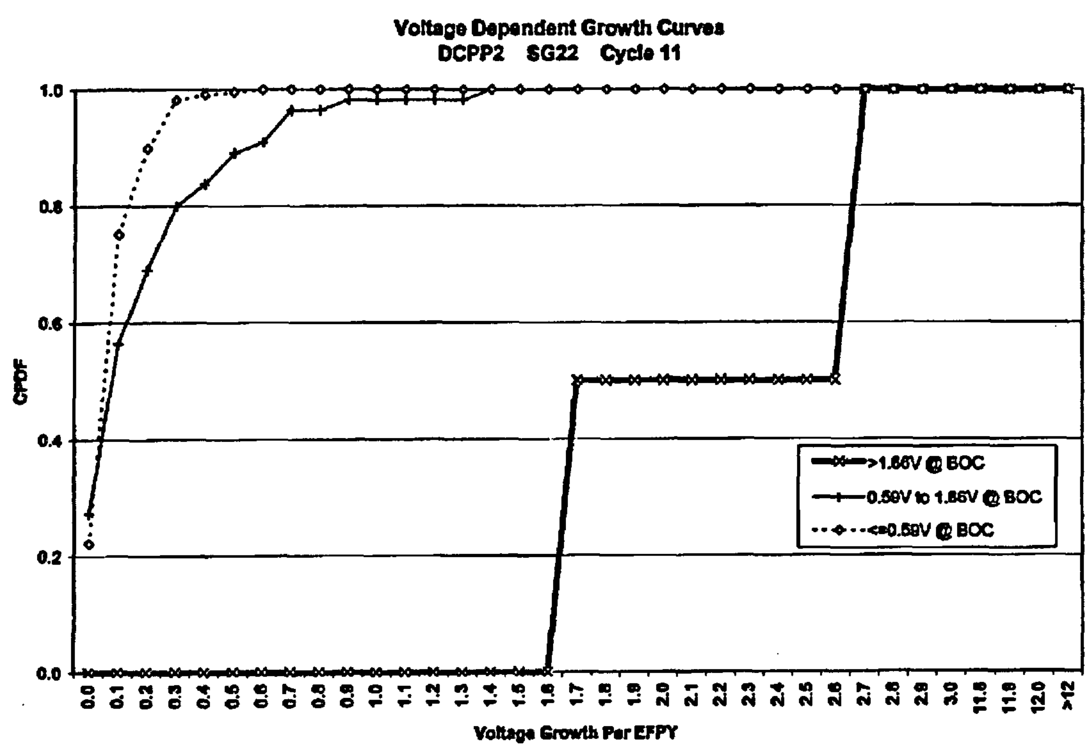


Figure 3-25: SG 2-3 Cycle 11 VDG Curves

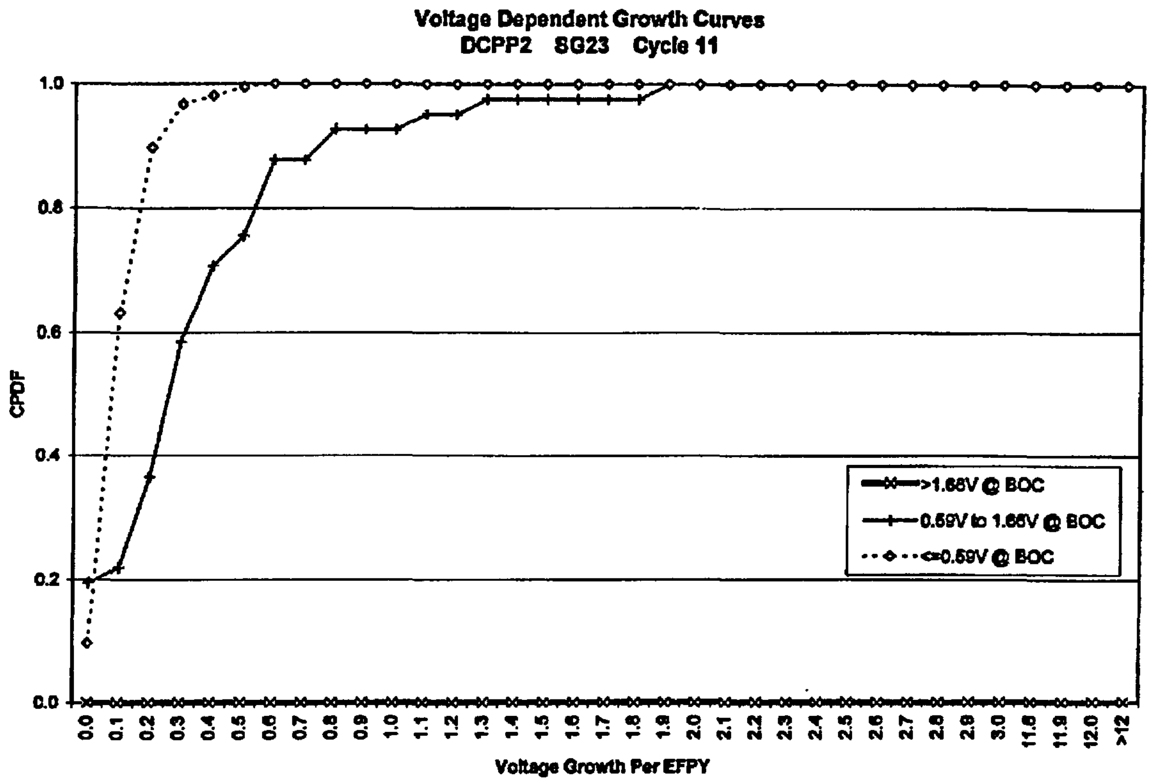


Figure 3-26: SG 2-4 Cycle 11 VDG Curves

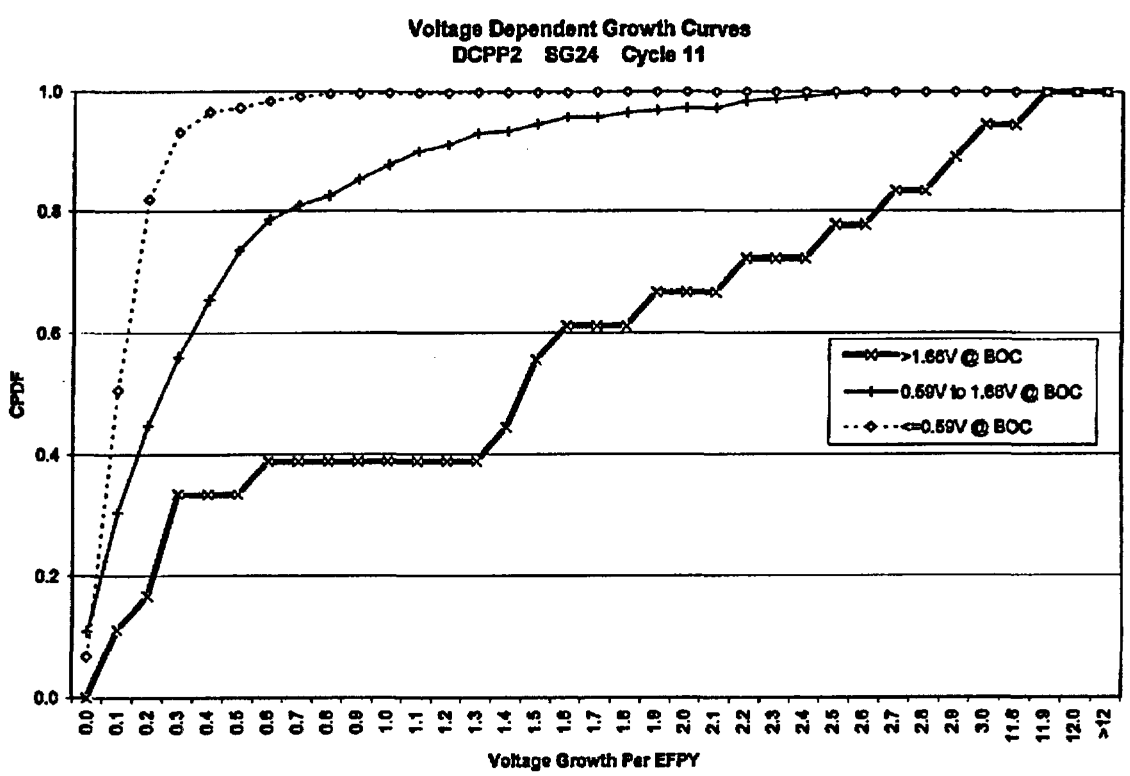


Figure 3-27 SG 2-4 Cycle 11 VDG vs. Independent Growth

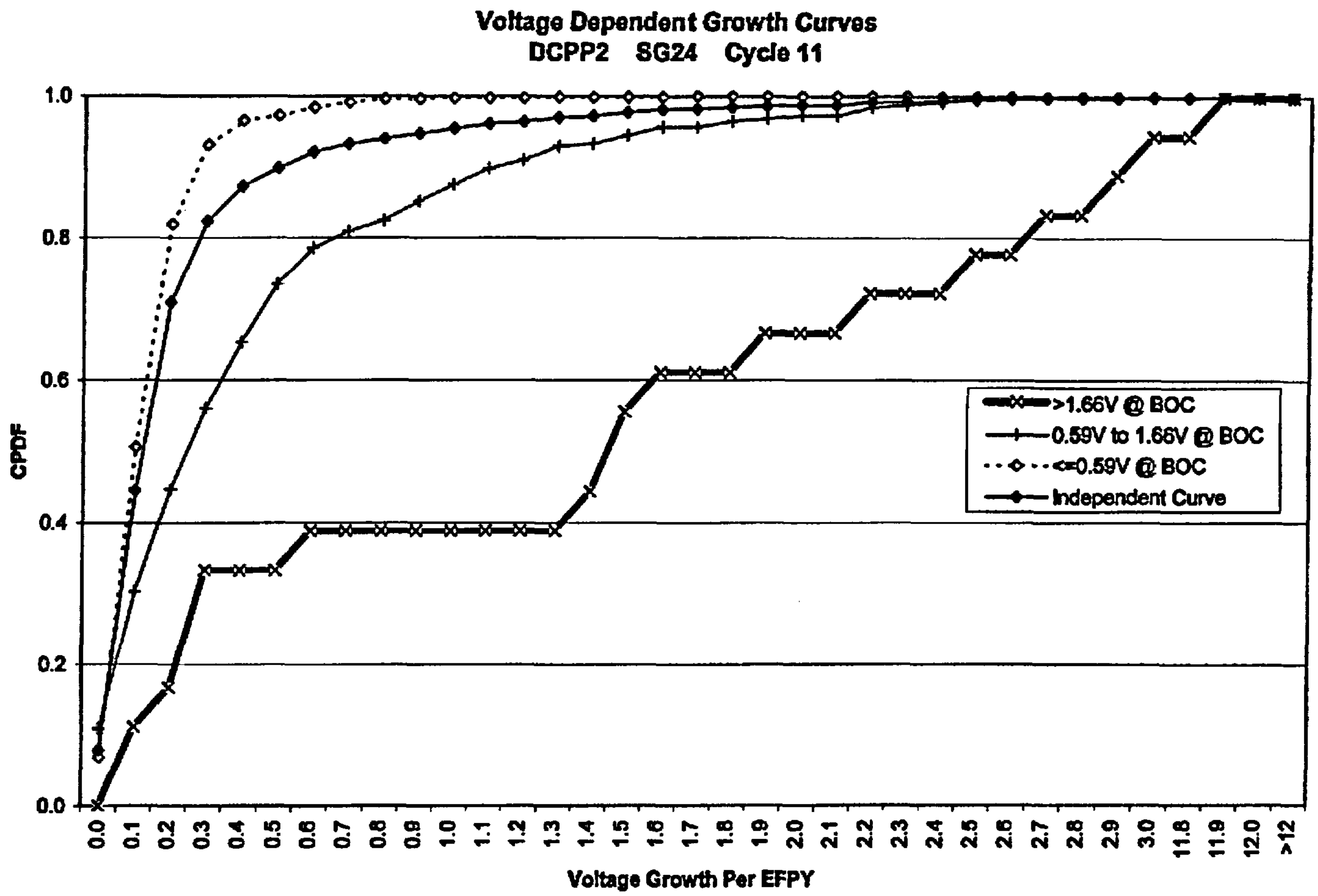


Figure 3-28: Cycle 10 VDG Curves All SGs

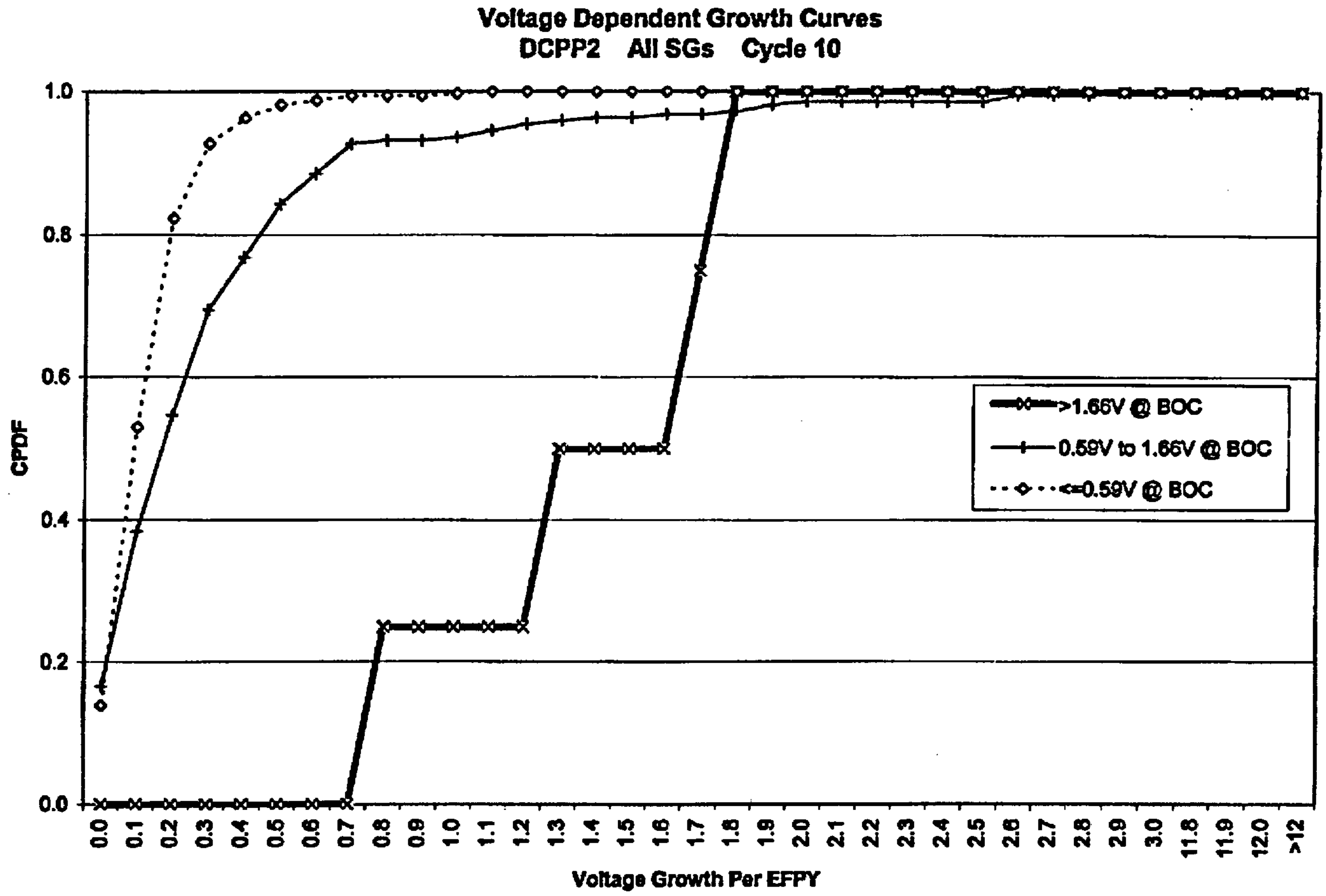


Figure 3-29: Historical Change in Growth and BOC Voltage All SGs

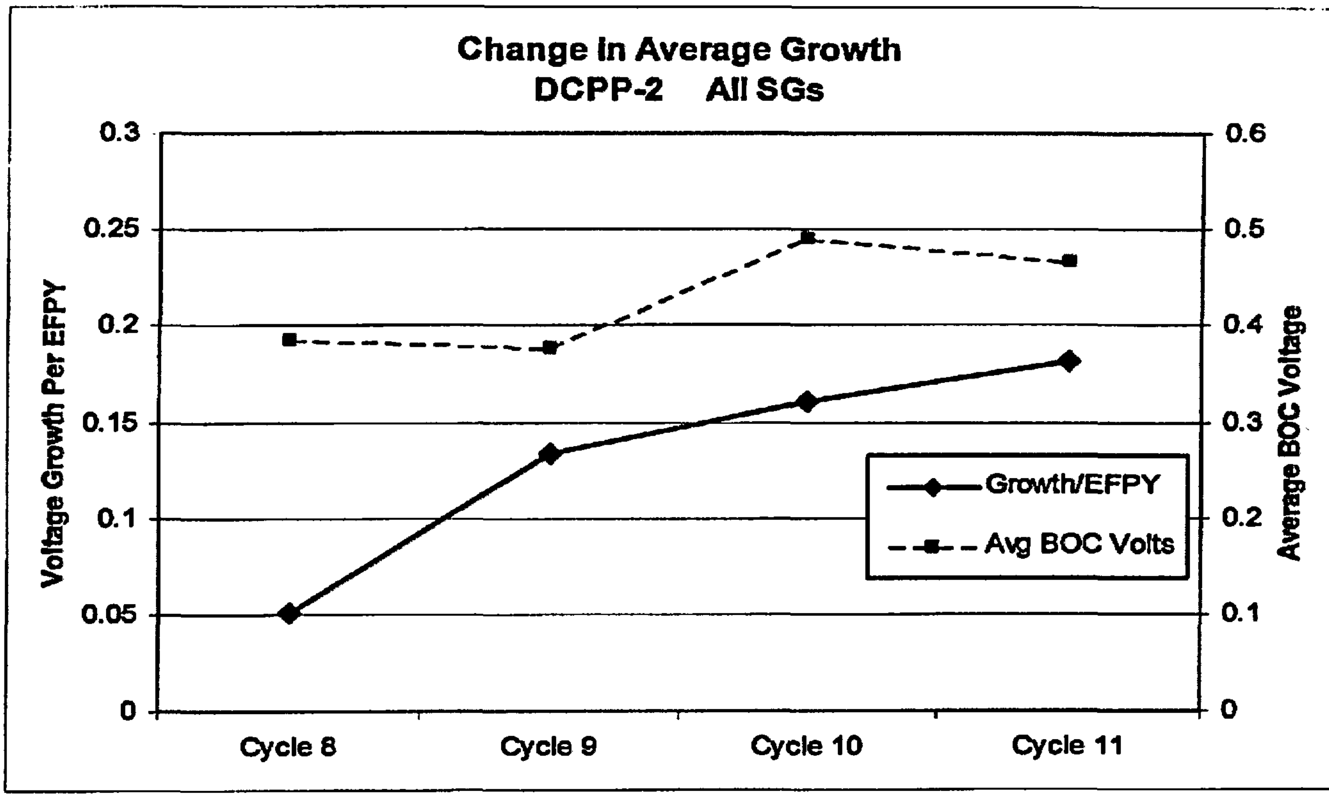


Figure 3-30: Cycle 10 Independent Growth Curves All SGs

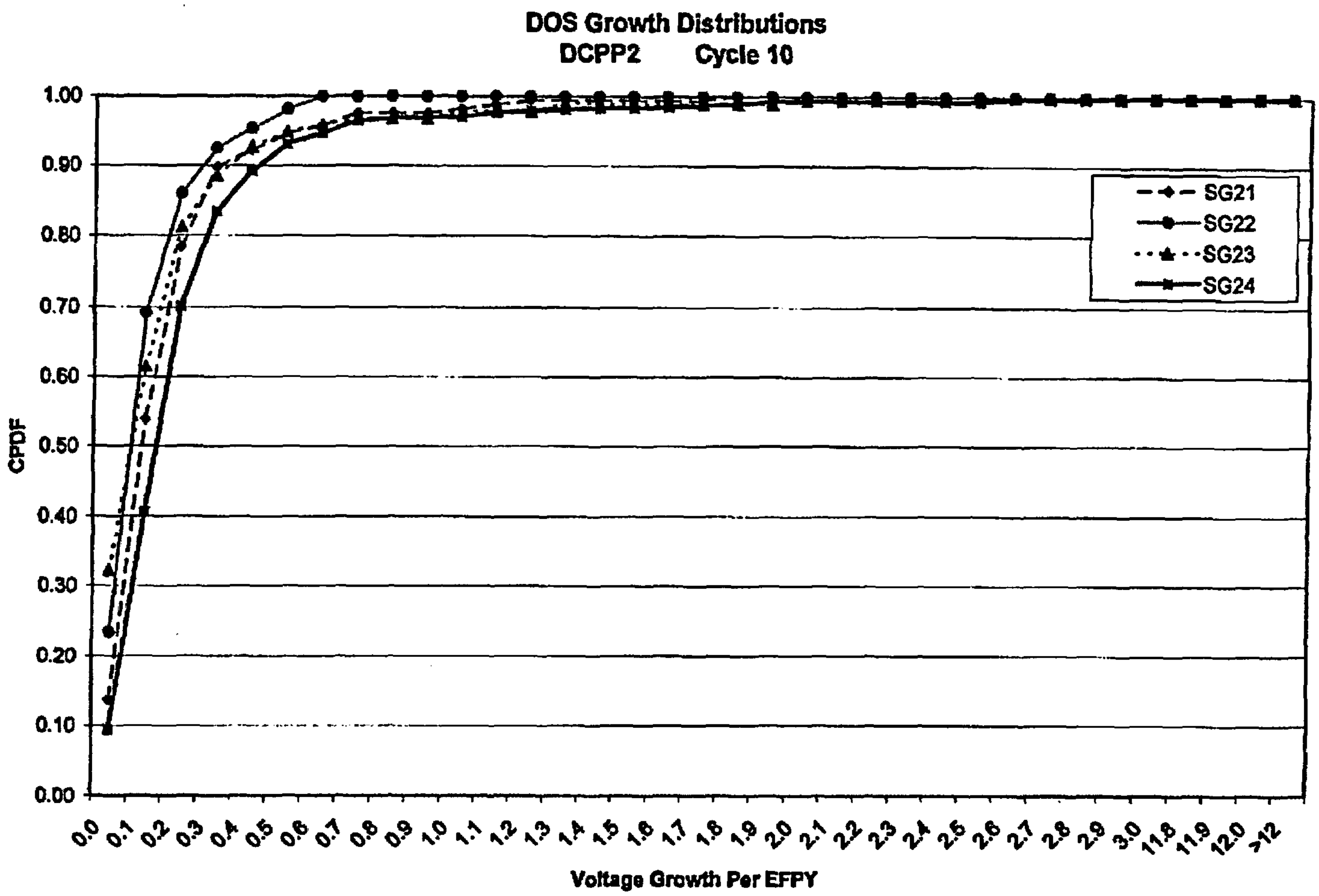


Figure 3-31: Cycle 11 Independent Growth Curves All SGs

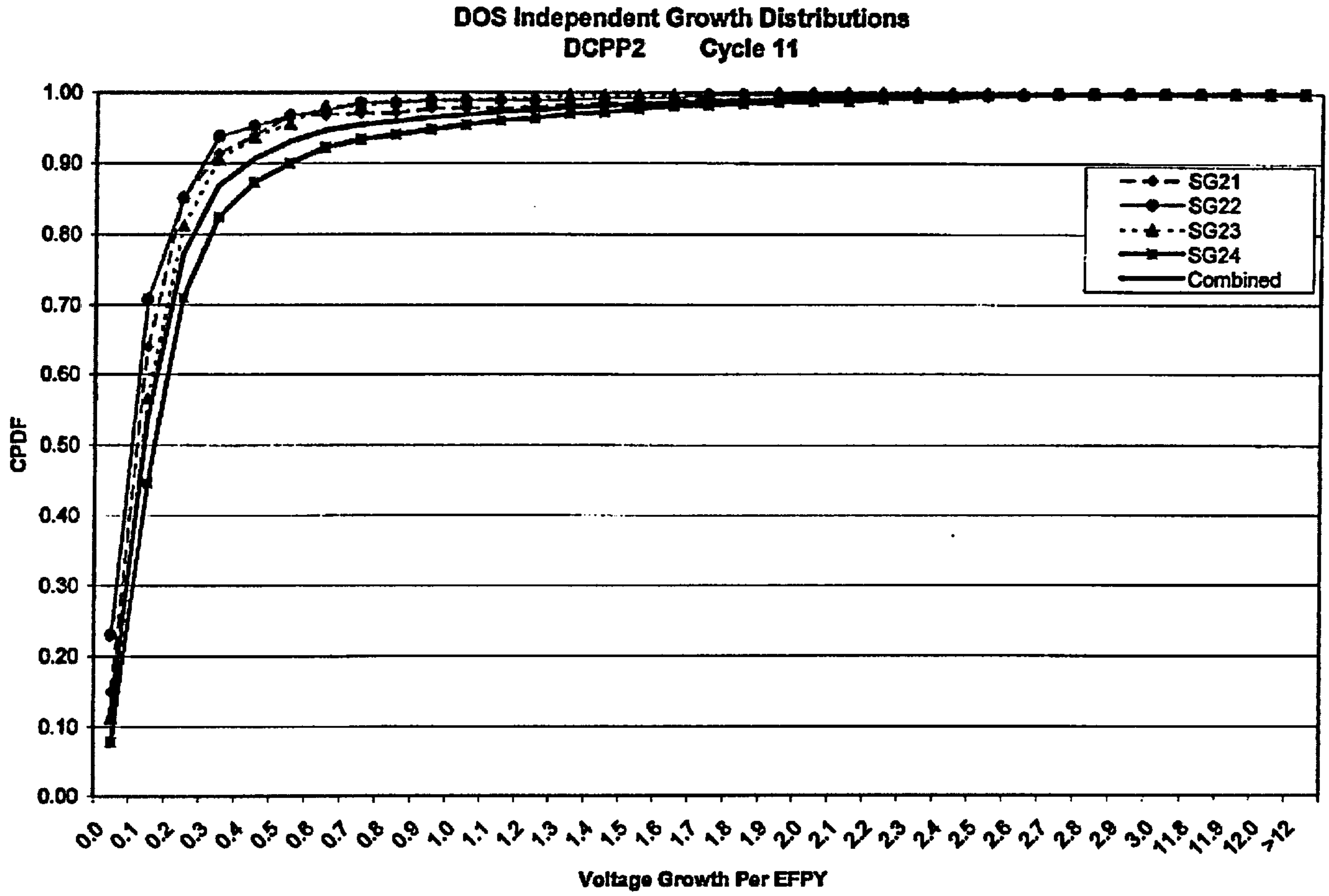


Figure 3-32: 2R11 Probe Wear Voltage Comparison

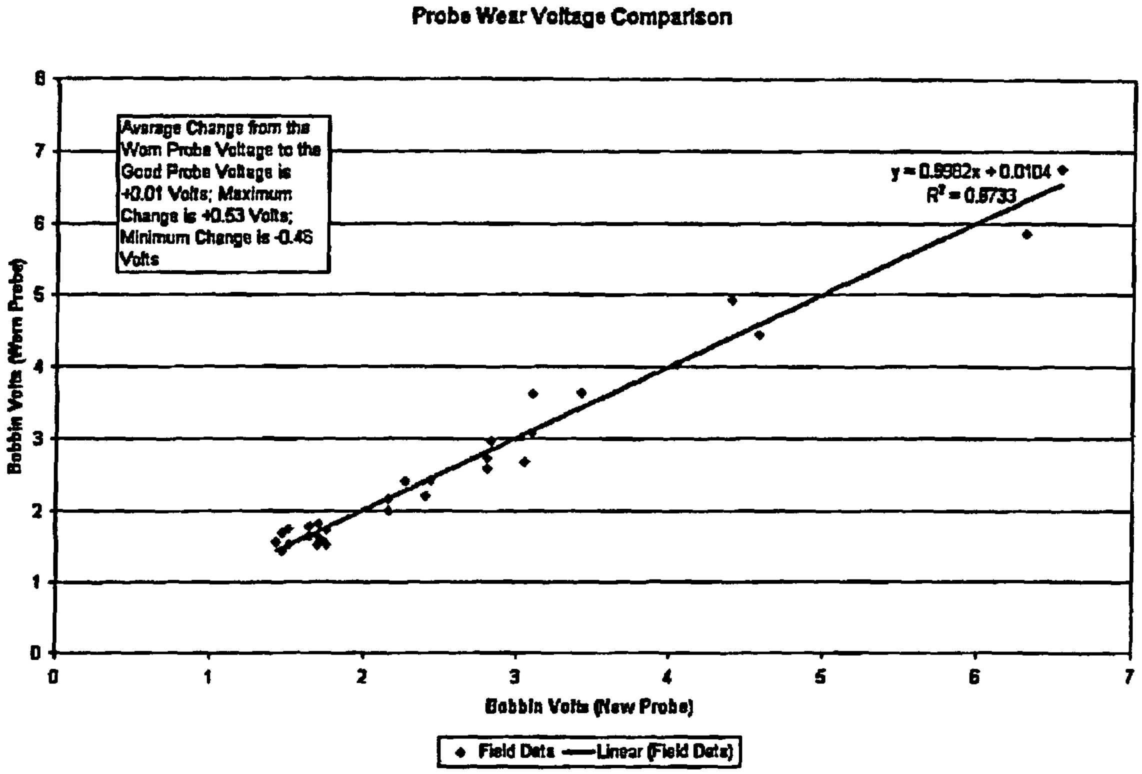
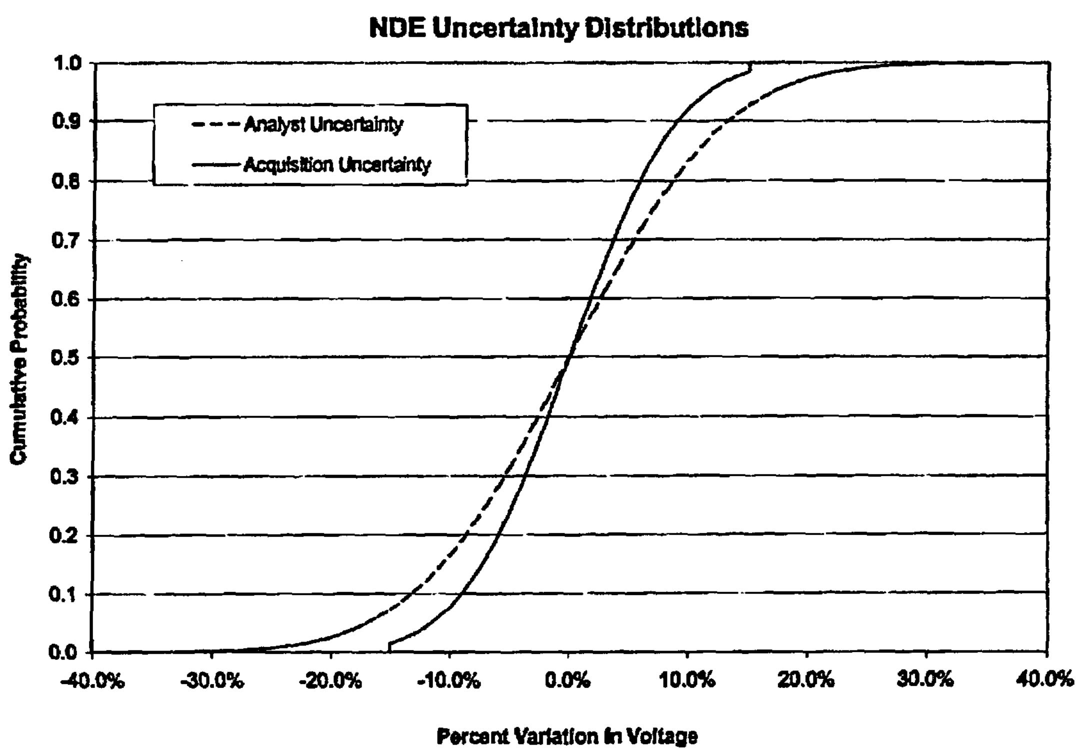


Figure 3-33: Bobbin Voltage Uncertainty Distributions



4.0 Cause Assessment of Growth Rate Experienced by R44C45-2H

Tube R44C45 in SG 2-4 was found to have a bobbin voltage indication at 2H of 21.5 volts at 2R11. The bobbin voltage for this indication was 2.0 volts at 2R10, which permitted the indication to be left in service under the voltage based ARC. The corresponding Plus Point volts for the indication are 12.2 volts at 2R11 and 2.97 volts at 2R10. The intent of this section is to assess the causative factors for the large voltage growth rate found for R44C45. In particular, this section assesses whether the causative factor is associated with a large increase in the corrosion rate as associated with growth in depth or due to a characteristic of voltage response to a throughwall indication with a modest growth in depth.

4.1 Voltage Dependence on Depth and Length for Axial ODSCC

Crack voltages increase exponentially with crack depth as based on theoretical models representing the diffusion of the electro-magnetic wave into the metal or empirical assessments of NDE data. Figure 4-1 shows the increase in bobbin voltage as a function of destructive examination maximum depth for the ARC database. An exponential provides a good fit to the data. There is significant scatter in the data as the bobbin coil responds to multiple indications around the tube as well as the dominant or maximum depth indication. Parallel macrocracks, multiple initial sites and cellular corrosion increase the bobbin voltage over that of the dominant single crack and contribute to the scatter in Figure 4-1. The principal conclusion for this assessment is that bobbin voltage increases rapidly as the crack depth approaches a throughwall indication.

A theoretical model for the dependence of bobbin voltage on throughwall length is not available. It may be expected to have a dependence approximating length squared with an asymptotic limit at a multiple of the coil field length. Data for throughwall EDM notches in the ARC database report, NP-7480-L, indicate saturation of bobbin voltage responses at about the TSP thickness. Thus, for throughwall lengths less than the TSP thickness, it is reasonable to assess the voltage dependence on length as either a length squared or an exponential dependence. Figure 4-2 shows an exponential fit to the ARC database data for bobbin voltage as a function of throughwall length. The exponential fit provides a reasonable fit for the throughwall length dependence. The principal conclusion for this assessment is that bobbin voltage increases approximately exponentially with throughwall length. Throughwall lengths for ⅞-inch tubing in the range of 0.40 to 0.45 inch can be expected to have bobbin voltages near 20 volts as found for R44C45. Bobbin voltages for corresponding throughwall lengths in ¾-inch tube would be slightly lower as indicated by Figure 4-2.

4.2 Crack Depth Profiles for R45C45 at 2R10 and 2R11

For this assessment, it is necessary to estimate the R44C45 crack sizes at 2R10 and 2R11 as well as to develop crack growth rates as a function of depth for the DCPP SGs during Cycle 11. This assessment requires reasonable confidence in the NDE sizing methods. For the DCPP data, NDE sizing is based on an amplitude sizing correlation developed from axial ODSCC corrosion data and applying Plus Point voltages as a function of depth. The acceptability of the sizing methods are demonstrated by comparing the NDE sizing results with the 2R11 DCPP-2 pulled tube destructive exam profiles for R44C45 and R35C57.

4.2.1 NDE Sizing Methods

The Plus Point amplitude sizing correlation applied is based on an exponential dependence approximating zero volts near zero percent depth and 2.75 Plus Point volts for 100% depth. This correlation is applied to the Plus Point sizing analyses for voltage versus axial position performed during the 2R11 outage.

4.2.2 Crack Depth Profiles for R45C45 at 2R10 and 2R11

Plus Point data are available for R44C45 at the 2R10 and 2R11 inspections. The results of the sizing analyses are shown in Figure 4-3. At 2R10, the indication was near throughwall or just throughwall. The indication then grew to a throughwall length near 0.4 inch based on the NDE sizing results. Based on the exponential dependence of bobbin voltage on depth and throughwall length described in Section 4.1, the bobbin voltage would have been expected to increase from the 2 volts at 2R10 to near 20 volts based on the estimated throughwall length shown in Figure 4-3. This estimate for voltage growth based on the NDE throughwall length of Figure 4-3 and voltage dependence on length of Figure 4-2 is consistent with the actual bobbin voltage growth from 2.0 to 21.5 bobbin volts.

4.2.3 Comparisons of NDE and Destructive Exam Depth Profiles

Comparisons of the NDE sizing and pulled tube destructive exam (DE) depth profiles are shown in Figures 4-4 to 4-6. Figure 4-4 shows the comparison of NDE with DE for the partial depth second crack in R44C45. The DE data are shown for the as-measured depth profile and for the profile obtained as a running average over a 0.1-inch length. The running average is recommended in Appendix H of the EPRI inspection guidelines for correlating NDE with maximum crack depth. The NDE results are in good agreement with the DE maximum depth and moderately overestimate the total crack length average depth (54% vs 47% by DE). This good agreement for a partial depth crack provides support to sizing R44C45 at 2R10 and for developing growth rates in depth from the NDE profiles.

Figures 4-5 and 4-6 compare the NDE and DE sizing results for the throughwall indications in R44C45 and R35C57. The NDE results provide a very good estimate of the DE throughwall length for R44C45. The throughwall length from the R44C45 destructive exam is comprised of the macrocrack throughwall length of 0.374 inch and a second microcrack of 0.056 inch length that was throughwall on the ID of the tube. The second crack was offset from the main macrocrack by an uncorroded ligament about 0.025 inch wide that did not tear up to SLB conditions as shown by oxidation of the crack after the SLB leak testing and the presence of a non-oxidized torn ligament after the burst test. Thus the second crack did not contribute to leakage at SLB conditions, but did contribute to the burst pressure determination as indicated by its presence on the burst crack face. Very few uncorroded ligaments were found within the throughwall length of R44C45. The throughwall length of R44C45 is consistent with the 21.5 bobbin volts reported for this indication.

Based on the NDE based depth at 2R10, as supported by the NDE versus DE comparisons above, it can be concluded that the R44C45 indication grew from a near or short throughwall indication at 2R10 to a relatively long throughwall length of about 0.43 inch (0.374 plus 0.056 inch) at 2R11. The end of cycle 21.5 volts for the indication is consistent with that expected for this throughwall length based on Figure 4-2.

The R35C57 indication was found to have bobbin and Plus Point responses of 5.09 and 4.08 volts at 2R11. The NDE and destructive exam profiles for this indication are shown in Figure 4-6. The DE throughwall length of 0.217 inch is in reasonable agreement with the NDE length of 0.11 inch. The results of Figure 4-6 further support the adequacy of the NDE sizing methods for the evaluations of this report.

4.3 DCPP-2 Crack Growth in Depth

4.3.1 Analysis Methods for Depth Growth Analyses

Growth rates in depth were obtained from 73 indications having Plus Point inspections at both 2R10 and 2R11. The amplitude sizing methods described above were applied to the Plus Point indications to obtain depth profiles for each cycle. Growth rates in average depth were obtained using the profiles for the burst effective lengths and for the total crack length. The burst effective lengths and average depths were obtained using the Westinghouse burst pressure correlation from the PG&E PWSCC ARC to search the profile for the partial length having the lowest burst pressure.

4.3.2 DCPP-2 Cycle 11 Crack Growth Rates

The Cycle 11 burst effective and total length average depth growth rates are shown as a cumulative probability distribution in Figure 4-7. The DCPP-2 growth distributions are compared in the figure with data from other plants for axial ODSCC growth at TSP intersections and at freespan locations. Although the largest average depth growth rate of 12% was obtained for R44C45, the DCPP-2 Cycle 11 growth rates are small compared to other plants that had large growth in depth. It is concluded that R44C45 and other Cycle 11 indications did not have high corrosion rates such as associated with a large growth rate in depth. A large corrosion rate was not the causative factor for the large voltage increase found for R44C45.

4.4 Causative Factor Conclusions

The amplitude sizing methods applied for the DCPP-2 axial ODSCC indications yield reasonable sizing results as shown by the comparisons with the R44C45 and R35C57 pulled tube depth profiles. The sizing methods yield good agreement on maximum depth and throughwall length although moderately overestimating average depths. Consequently, the amplitude sizing methods can be used to adequately assess the depth profiles for R44C45 at the 2R10 and at 2R11 inspections as well as to develop growth rates in depth for Cycle 11. The Cycle 11 average depth growth rate for R44C45 was about 12% per EFPY, which is much less than the 25% to 35% growth rate found for plants with large corrosion growth rates. Based on these evaluations, it is concluded that a large corrosion growth rate in depth was not the contributing factor to the large R44C45 voltage increase over Cycle 11 from 2.0 to 21.5 volts. The R44C45 indication was near throughwall or slightly throughwall at 2R10 and grew to a throughwall length at 2R11 of 0.39 inch by NDE sizing and 0.43 inch by destructive examination. As shown by the ODSCC ARC database, voltage increases exponentially with depth to a throughwall indication and again exponentially with throughwall length. A bobbin voltage of about 20 volts is typical of the voltage expected for a throughwall length in the range of 0.40 to 0.45 inch.

It is therefore concluded that the large R44C45 bobbin voltage growth over Cycle 11 from 2.0 to 21.5 volts is dominated by the exponential dependence of voltage on throughwall length, while associated with modest corrosion induced growth in depth that contributes to the increase in throughwall length from incipient throughwall to about a 0.43 inch throughwall indication at 2R11.

Figure 4-1: Bobbin Voltage vs. DE Max Depth

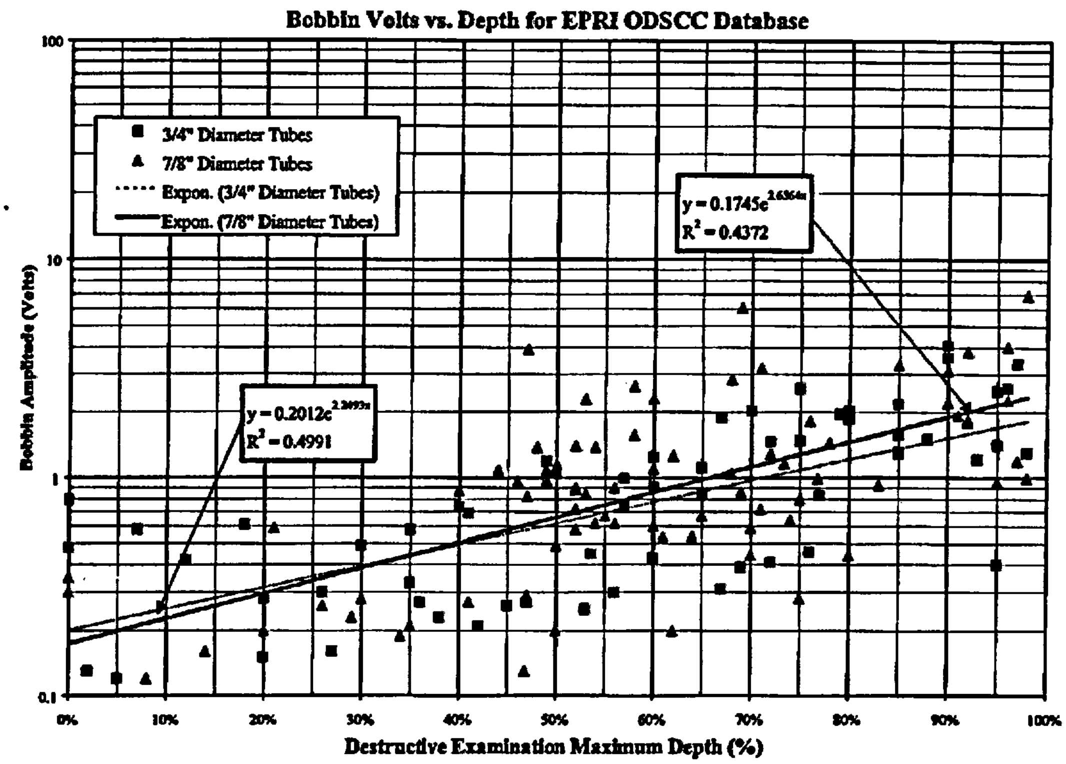


Figure 4-2: Bobbin Voltage vs. DE Length for 100%TW

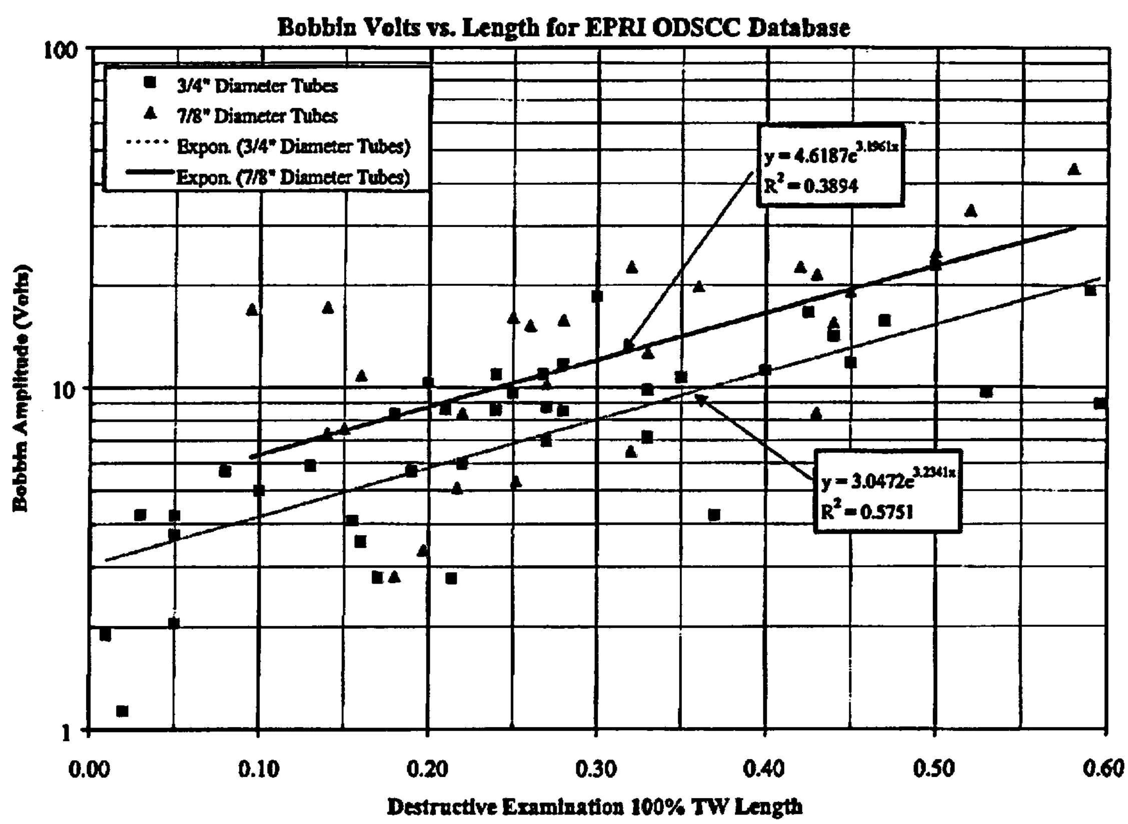


Figure 4-3: 2R10 vs. 2R11 Plus Point Amplitude Sizing of R44C45 Crack 1

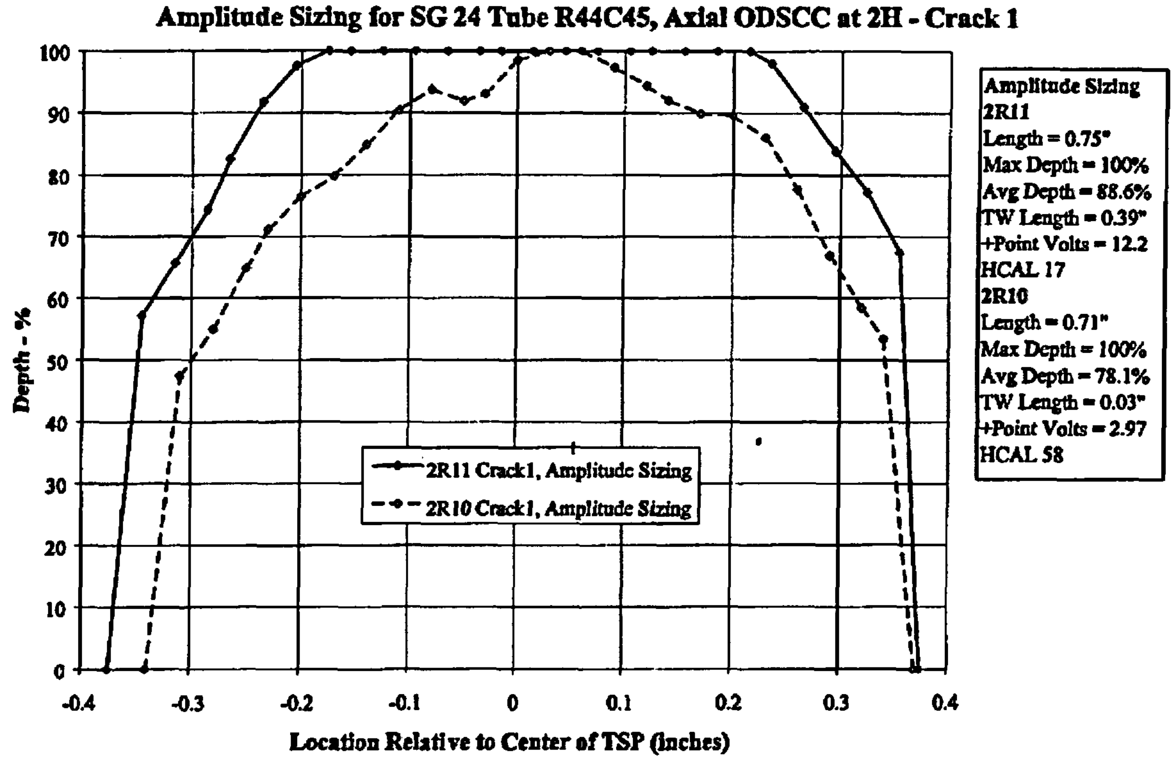


Figure 4-4: 2R11 Plus Point Amplitude Sizing of R44C45 Crack 2 vs. DE Profile

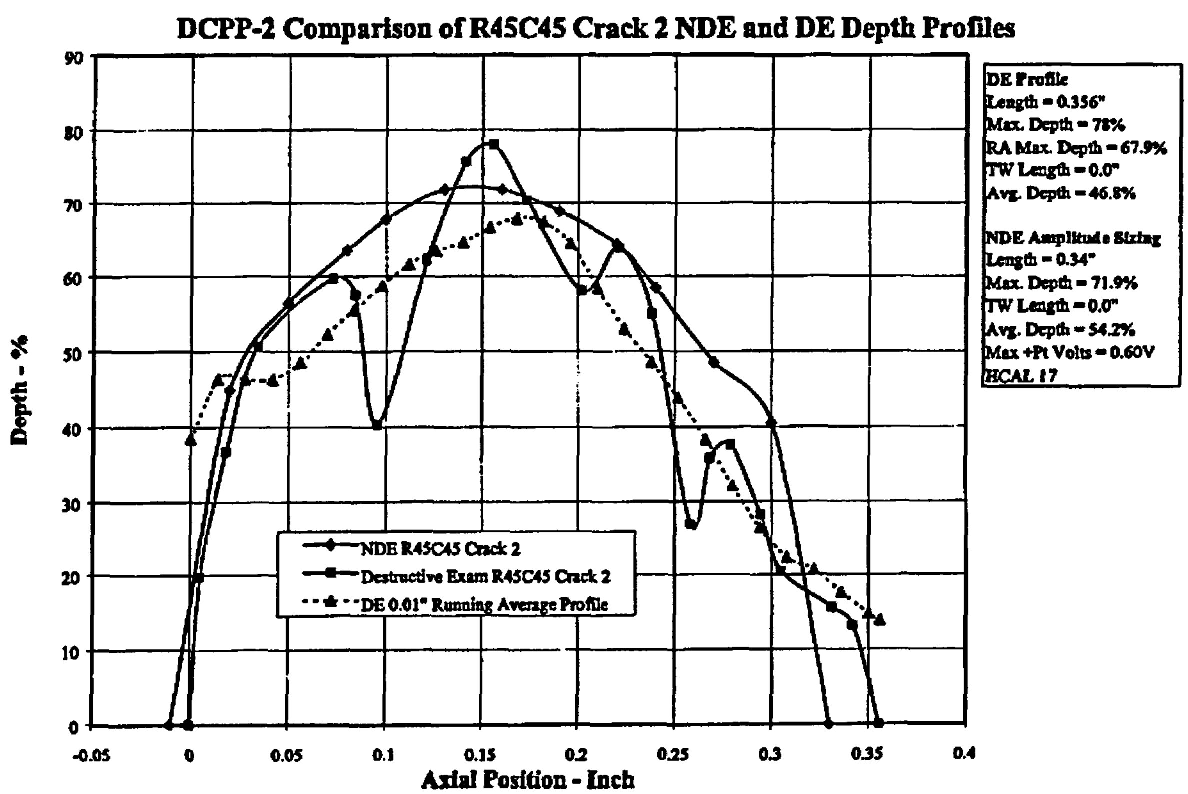


Figure 4-5: 2R11 Plus Point Sizing of R44C45 Crack 1 vs. DE Profile

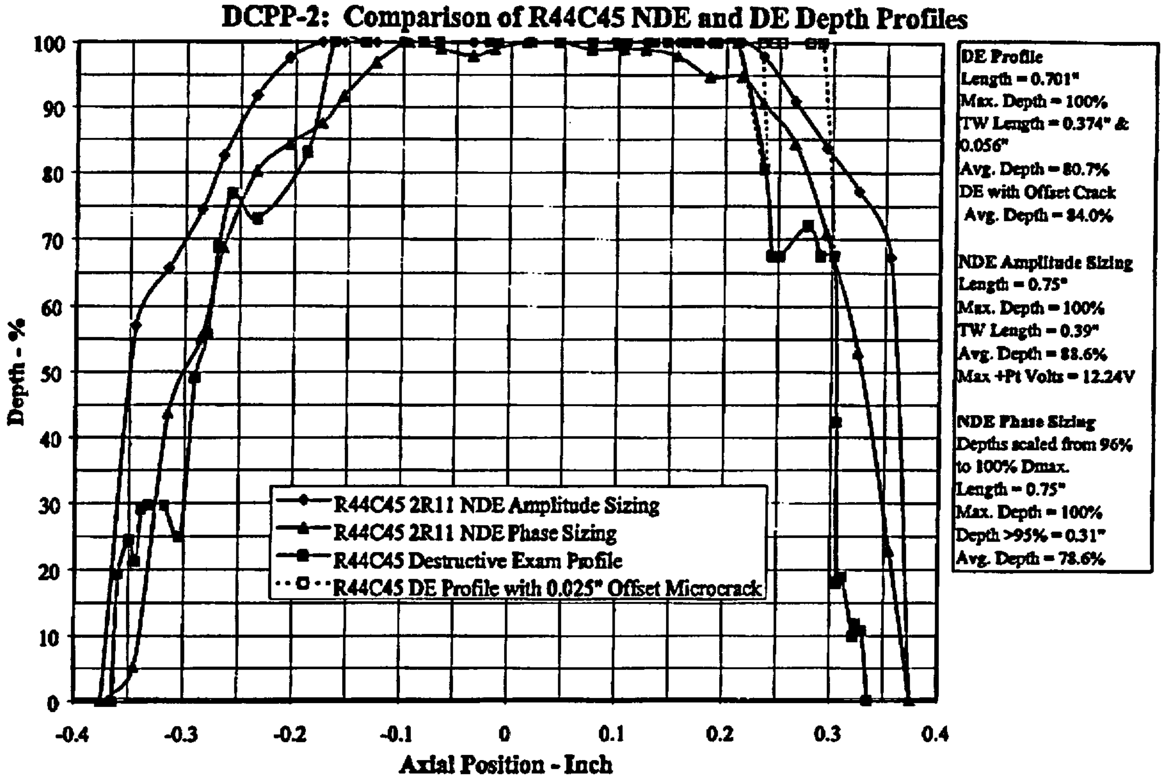


Figure 4-6: 2R11 Plus Point Sizing of R35C57 vs. DE Profile

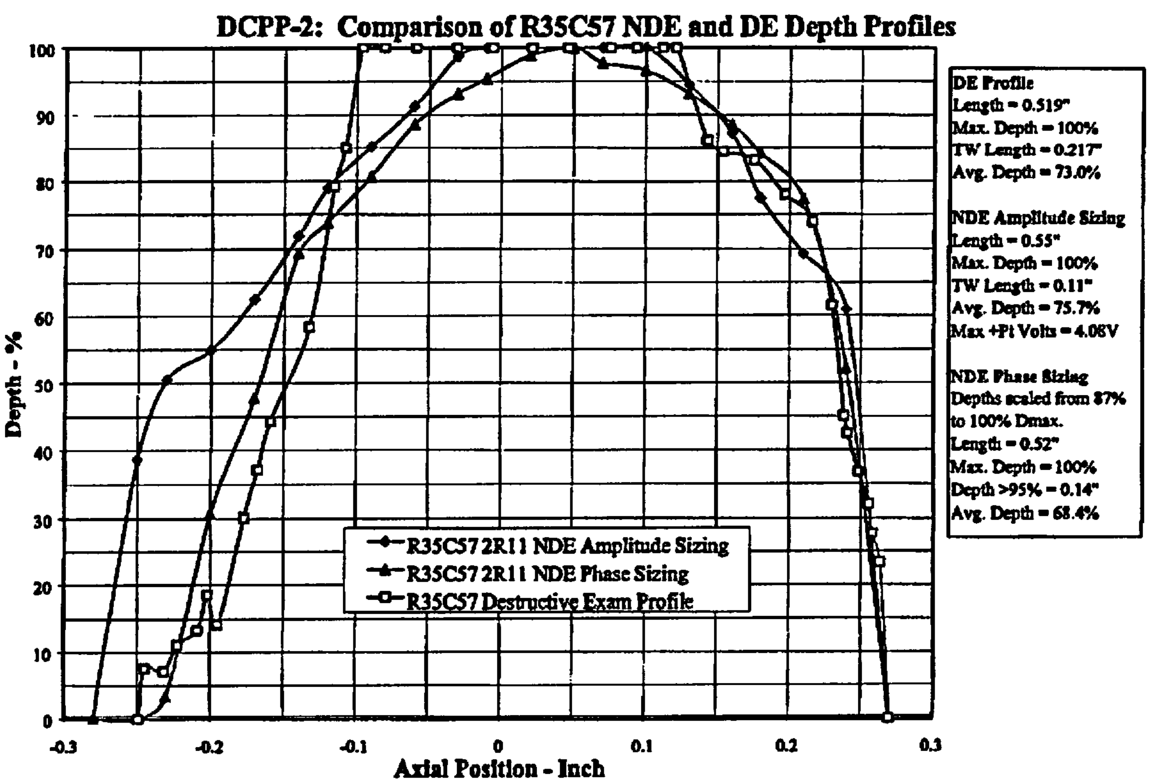
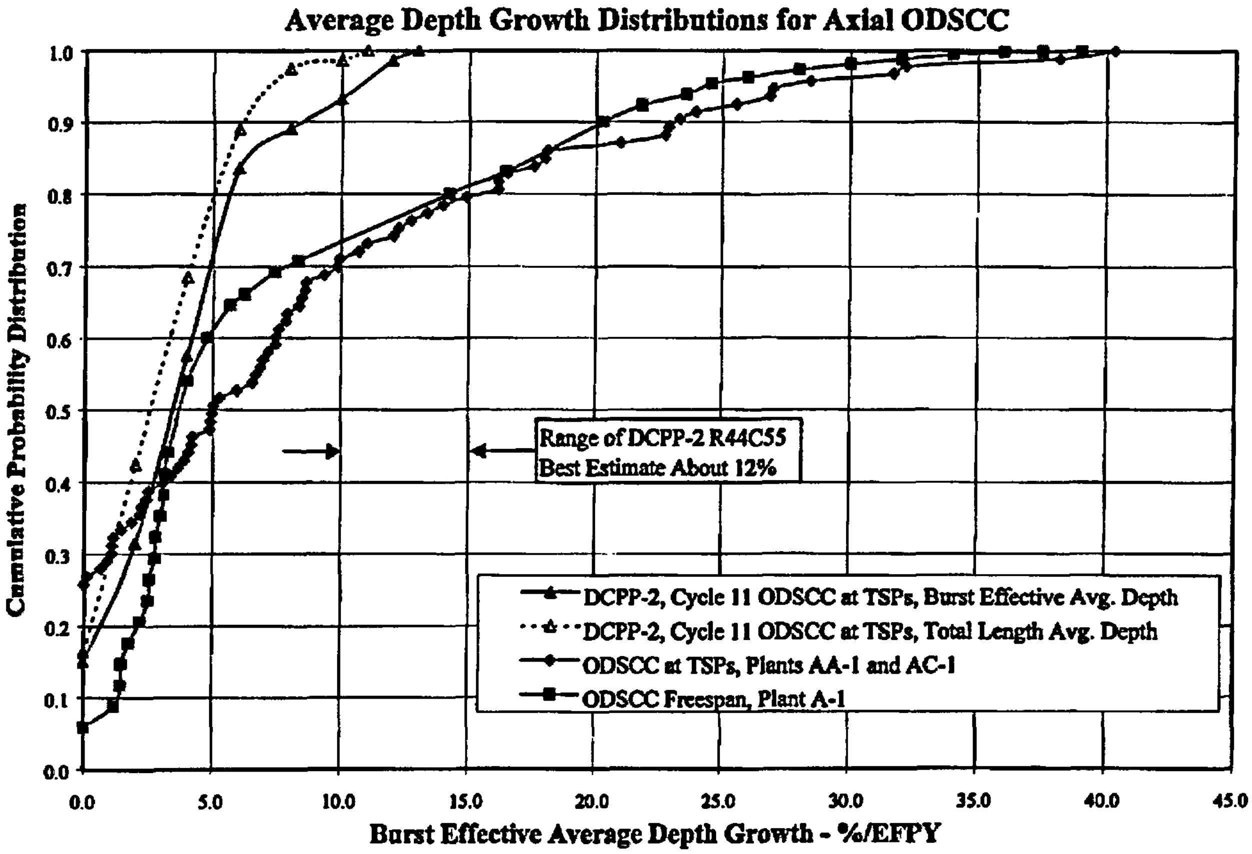


Figure 4-7: Cycle 11 DCPP-2 Average Depth Growth of TSP Axial ODSCC vs. Other Plant Data



5.0 Database and Methods Applied for Leak and Burst Correlations

Per GL 95-05, the databases used to perform the tube integrity evaluations should be the latest NRC approved industry database. For the as-found Diablo Canyon 2R11 analysis, the updated database coefficients from Ref. 8 were used. These contain the latest industry databases for ODSCC ARC Applications (GL 95-05).

During 2R11, sections of two tubes were removed from SG 2-4 (R44C45 and R35C57). These two tubes contained confirmed ODSCC indications at 2H that were selected to be leak and burst tested in order to be added to the Ref. 8 databases. Detailed results of the DE testing and results are documented in Ref. 21 and will also be submitted to the NRC. For the operational assessments performed for Cycle 12, the modified database parameters that were transmitted to DCPP via Ref. 20 were utilized in the Monte Carlo simulations.

5.1 Summary of Destructive Examination Results for Database Correlations

The two tubes removed from DCPP-2 were sent to Lynchburg for destructive examination and laboratory testing. Room temperature leak rate tests were performed on both flawed intersections with FANP in-situ pressure testing equipment. Room temperature testing was performed because of the relative potential for large leak rates from tube R44C45, 21.5-volt flaw to exceed the hot leak temperature system capacity. In order to evaluate ligament tearing at SLB conditions, the leak test was terminated at SLB differential pressure, the crack faces were then oxidized, and then the test was resumed for room temperature burst testing. Free span areas were also burst to obtain material properties for both tubes. Ref. 21 contains the detailed results of all tests performed on the samples.

Table 5-1 summarizes the results of the NDE performed on the two areas of interest in the pulled tube specimens. Tables 5-3, 5-4 and 5-5 provide the updated correlation data tables for burst, probability of leak, and leak rate. The other TSP intersections (1H) from these tubes were NDD in both field and lab NDE tests performed. The detailed results of the testing performed on these intersections are contained in Ref. 21.

Table 5-1: Bobbin and Plus Point Eddy Current Inspection Results Summary

Bobbin Data										
Tube Sample No.	Location in SG	Initial Exam			Post Tube Pull			In Lab		
		Call	Volts	Phase	Call	Volts	Phase	Call	Volts	Phase
R44C45	02H + 0.14"	DOS	21.5	54	DOS	32.31	53	93%	35.73	51
R35C57	02H + 0.07"	DOS	5.09	60	DOS DNT	7.18 8.76	56 188	91% DNT	7.75 9.40	55 188
Plus Point Data										
R44C45	02H + 0.04"	SAI	12.12	38	SAI	17.37	36	SAI 98% TW @ 73°	15.58	39
	02H – 0.09"	SAI	0.29	98	SAI	0.27	95	SAI 57% TW @ 25°	0.28	98
R35C57	02H + 0.03"	SAI	4.01	53	SAI	5.08	53	SAI 91% TW @ 202°	5.00	54

The results of the leak and burst testing are listed in Table 5-2 below. Based on the evaluation of the leak and burst results and their ultimate inclusion in the Ref. 8 database (see comparisons in Table 5-3, 5-4, 5-5), the pulled tubes from 2R11 were prototypical of those contained in the database and justify the use of the voltage-based ARC for DCPP Unit 2. The detailed evaluation of the pulled tubes on the ODSCC ARC database is submitted by PG&E as a separate attachment to the 90 day report.

Table 5-2: Analysis Properties of the DCPP 2 Pulled Tube Sections for Inclusion in the ODSCC ARC Database Correlation

Tube Section	Bobbin Amplitude (Volts)[1]	Yield + Ultimate (ksi)[2]	Burst Pressure (ksi)	Probability of Leak at SLB	Leak Rate at 2405 psi (lph)[3]	Leak Rate at 2560 psi (lph)[3]
R35C57 (freespan)	NDD	163.546	12.724	N/A	N/A	N/A
R44C45 (freespan)	NDD	154.186	12.235	N/A	N/A	N/A
R35C57-2H	5.09	163.546	5.950	1	0.54	1.59
R44C45-2H	21.50	154.186	4.212	1	62.9	91.4

Notes:
1. Locations with amplitude of NDD are included for information only.
2. The value of S_y+S_u is rounded to one decimal place for use in the regression analyses. The mill test reported (CMTR) values were 152 and 150 ksi respectively.
3. Leak rates were measured at room temperature and adjusted to accident conditions.

5.2 *Conditional Probability of Burst*

For the case of the burst pressure versus voltage correlation, the Addendum 5 database contained in Ref. 8, as modified by the addition of the DCPP pulled tubes meets all GL 95-05 requirements and was used in the calculations for EOC-12 projections. As-found calculations were performed utilizing only the Addendum 5 database. Material properties were also considered as part of the calculations and were obtained from Ref. 6. FANP computer simulation was utilized to compute as-found POB at the end of Cycle 11, as well as project EOC-12 POB. These simulations follow the statistical methods presented in Ref. 6. The Addendum 5 database and updated Addendum 5+ database tube burst correlations are shown in Table 5-3. As identified in Note 1 of this table, the values do not exactly match those published in Addendum 5. The exact values listed in Addendum 5 were utilized in the FANP CM analyses.

Table 5-3: Effect of Diablo Canyon 2 Data on the 7/8" Tube Burst Pressure vs. Bobbin Amplitude Correlation

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

Parameter	Addendum 5 Database [(1)]	Addendum 5+ Database	New / Old Ratio
Intercept, a_0	7.49325	7.48475	0.999
Slope, a_1	-2.37741	-2.39502	1.007
r^2	79.2 %	79.6 %	1.005
Std. Dev., σ_{Error}	0.88616	0.88248	0.996
Mean Log(V)	0.291958	0.306657	
SS of Log(V)	50.2333	51.4665	
N (data pairs)	97	99	
Structural Limit (2560 psi) [(2)]	7.67 V	7.54 V	0.982
Structural Limit (2405 psi) [(2)]	9.62 V	9.45 V	0.984
p Value for a_1 [(3)]	$1.9 \cdot 10^{-34}$	$1.4 \cdot 10^{-35}$	0.074
Reference σ_f	68.78 ksi [(4)]		

Notes: The number of significant figures reported simply corresponds to the output from the calculation code and does not represent true engineering significance.

(1) Slight departures from the published values in Reference 8 are due to a refinement in the analysis to apply consistent rounding of the strength values to a single decimal place prior to performing the regression analysis.

(2) Values reported correspond applying a safety factor of 1.4 on the differential pressure associated with a postulated SLB event.

(3) Numerical values are reported only to compare the calculated result to a criterion value of 0.05. For such small values the relative change is statistically meaningless.

(4) This is the flow stress value to which all data was normalized prior to performing the regression analysis.

5.3 *Probability of Leak and Conditional Leak Rate*

Ref. 8 presents the results of the regression analysis for the voltage-dependent leak rate correlation using the Addendum 5 leak rate database for 7/8" tubes. It should be noted that, for the 2405 psi delta pressure, the one-sided p-value for the slope parameter in the Addendum 5 voltage dependent leak rate correlation is 2.3% which meets the 5% threshold for an acceptable correlation specified in Generic Letter 95-05. Additionally, when adding the DCPP-2 data to the database, the Addendum 5+ correlation is actually improved with the new p-value at 1.0%. FANP computer simulations included the slope sampling method for the leak rate correlation agreed upon by the NRC and Industry that is presented in Ref. 8.

The methodology used in the calculation of these parameters is consistent with NRC criteria in Ref. 2. The Addendum 5 and Addendum 5+ POL and leak rate correlation parameters used in the CM and OA, respectively, are shown in Tables 5-4 and 5-5, obtained from Ref. 20.

Table 5-4: Effect of Diablo Canyon 2 Data on the Probability of Leak Correlation

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

Parameter	Addendum 5 Database	Addendum 5+ Database	New / Old Ratio
Intercept, β_1	-5.1017	-5.0503	0.990
Slope, β_2	7.3483	7.4342	1.012
V_{11} (1)	1.3742	1.3299	0.968
V_{12}	-1.7365	-1.7253	0.994
V_{22}	2.6428	2.6861	1.016
DoF (2)	113	115	
Deviance	30.21	31.47	1.042
Pearson SD	0.579	0.594	1.026
MSE	0.267	0.274	1.024

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

(2) Degrees of freedom.

Table 5-5: Effect of Diablo Canyon 2 Data on the 7/8" Tubes Leak Rate vs. Bobbin Amplitude Correlation (2405 psi)

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

Parameter	Addendum 5 Database Value	Addendum 5+ Database	Effect Ratio
Intercept, b_3	-0.534841	-0.664317	1.24
Slope, b_4	0.969885	1.106101	1.14
Index of Deter., r^2	14.0%	17.5%	1.25
Std. Error, σ_{Error} (b_5)	0.772839	0.772757	1.00
Mean of Log(Q)	0.53539	0.55024	1.03
Std. Dev. of Log(Q)	0.81822	0.83625	1.02
p Value for b_4	2.3%	1.0%	0.42
Data Pairs, N	29	31	
Mean of Log(V)	1.10347	1.09805	
SS of Log(V)	2.78407	2.99300	

Note: The number of significant figures reported simply corresponds to the output from the calculation code and does not represent true engineering significance.

6.0 Bobbin Voltage Distributions

The bobbin voltage distributions are listed in Tables 6-3 through 6-6. For operational assessments, the number of bobbin voltage indications used to predict tube leak rate and burst probability is obtained by adjusting the number of reported indications to account for non-detected cracks that could contribute to leak or rupture under MSLB conditions during the next cycle.

6.1 Probability of Detection

The number of bobbin indications used to predict the tube leak rate and burst probability at EOC-12 is obtained by adjusting the number of reported indications to account for the detection capability of the bobbin coil. This is accomplished by using a POD factor. The calculation of the bobbin voltage distribution is a net total number of indications returned to service, defined as:

$$N_{BOC12} = \frac{N_{EOC11}}{POD} - N_{repaired}$$

where:

N_{BOC12}	-	Number of bobbin indications being returned to service for the next operating cycle
N_{EOC11}	-	Number of bobbin indications reported in the current inspection
POD	-	Probability of Detection
$N_{repaired}$	-	Number of bobbin indications repaired after the last cycle

The NRC generic letter (Ref. 2) requires the application of a constant POD equal to 0.6 to define the BOC distribution for the EOC voltage projections. As mentioned previously, a probability of detection of 0.6 was applied to all indications, except the 21.5-volt indication in SG 2-4. A probability of detection of 1.0 was applied to this indication based on Ref. 22. A DCPP-specific POPCD was also used in Cycle 12 OA analyses, as discussed below.

A probability of detection was not applied for the condition monitoring analysis since it addresses the as-found conditions of the SGs.

6.2 Probability of Prior Cycle Detection

Per the Generic Letter, the beginning-of-cycle voltage distribution must be developed using a constant POD of 0.6 as mentioned above. In reality, however, the POD has been demonstrated to be a function of the bobbin voltage, and increases as the bobbin voltage increases. EPRI has developed a voltage-dependent POD based on data from 27 inspections at plants with ⅞" diameter tubing and 10 inspections at plants with ¾" tubing. The latest update of the probability of prior cycle detection (POPCD) is documented in Ref. 8. The POPCD method is described in Electric Power Research Institute (EPRI) Topical Report NP 7480-L, Addenda 1 and 5, "Steam Generator Tubing Outside Diameter Stress Corrosion Cracking at Tube Support Plates Database for Alternate Repair Limits," dated November, 1996 and January, 2003, respectively, and the industry has previously requested that the NRC review and approve the use of the POPCD method.

During 2R11, it was determined that a POPCD approach would be required for DCPP-2 Cycle 12 operation to maintain EOC-12 POB results below the GL reporting threshold of 1.0×10^{-2}. The DCPP plant-specific POPCD data was provided to the NRC in Ref. 10. Based on meetings with NRC after 2R11, the format for presenting DCPP POPCD data was slightly revised from Ref. 10 to provide a more detailed understanding of the data that contributes to its calculation. Table 6-1 contains the data obtained during 2R11 (EOC_{n+1}) to develop the POPCD evaluation for only the 2R10 (EOC_n) inspection. Table 6-2 provides the final format of the DCPP Units 1 and 2 Composite POPCD that contains data from 5 inspections evaluated in the same manner. The resulting log-logistic parameters for the composite POPCD are data are also provided as a footnote to Table 6-2. Figure 6-9 contains a graph of the fitted log-logistic curve to the DCPP composite data. The following is a summary of each type of indication that is, or is not included in the DCPP POPCD determination that was used in the Cycle 12 calculations.

The following indications are considered to be false bobbin coil calls and are not included in the POPCD analyses:

- **Bobbin indications reported at EOC_n but found to be NDD by RPC/+Pt inspection at EOC_n or EOC_{n+1}.** EOC_n bobbin indications confirmed by RPC/+Pt at EOC_n and found to be RPC/+Pt NDD at EOC_{n+1} are not expected to occur, but are excluded from the POPCD analyses if they did, since the $Cycle_{n+1}$ inspection would expect to find a larger indication if the indication was not a false call.
- **Bobbin indications reported at EOC_n but not found by the bobbin inspection at EOC_{n+1}.** These indications are classified as INRs and require resolution analysis to confirm that an indication is not present at EOC_{n+1}. Again, at the $Cycle_{n+1}$ inspection it is expected that the indication would be larger, if it was not a false call at EOC_n.
- **New bobbin indications reported at EOC_{n+1} but found to be NDD by RPC/+Pt inspection at EOC_{n+1}.** RPC/+Pt NDD indications are assumed to be false bobbin calls for POPCD applications.

When new EOC_{n+1} indications are found by RPC/+Pt inspection but not reported as EOC_{n+1} bobbin indications (AONDB), the indications are included as new indications in the POPCD analysis for EOC_n, even though they may have been identified as AONDB in the previous inspection. The bobbin voltage for EOC_n may be obtained by look-up analyses or by subtracting the average growth rate from the EOC_{n+1} voltage obtained by identifying the flaw based on a review of the 200 kHz data, or by applying a site-specific bobbin voltage to RPC/+Pt voltage correlation. These indications would continue to be included as new indications in subsequent cycles unless the indication is reported in the normal bobbin coil inspection at a cycle following EOC_{n+1}. Thus, the indications would be considered as undetected at a minimum of two cycles, the EOC_n and EOC_{n+1} inspections. For the DCPP POPCD analysis, the voltages at EOC_n for EOC_{n+1} AONDB indications were determined by calculating the bobbin voltage at EOC_{n+1} using the DCPP bobbin-to-Plus-point correlation and then by subtracting the average voltage growth for the specific cycle.

If the RPC/+Pt inspection identifies more than one AONDB indication at the same TSP intersection, the total bobbin voltage assigned to the TSP is estimated as the square root of the sum of squares (SRSS) of the calculated/inferred bobbin voltages from the RPC/+Pt indications. This is the standard practice for addressing these indications at DCPP. It is an approximation to the effect on bobbin voltage of multiple indications around the tube circumference. Once the total bobbin voltage is determined, the EOC_n bobbin voltage is determined by subtracting the

average cycle bobbin voltage growth rate. If a negative voltage results, 0.01 volts is assigned to this indication.

Bobbin and AONDB indications found in deplugged tubes and subsequently replugged in the same outage do not count as "Confirmed and Plugged" for EOC_n. These indications are not in the active tube population and therefore are not utilized in POPCD evaluations until returned to service. AONDB indications detected in deplugged tubes that are returned to service are evaluated as new indications at $EOC_{n+1}$when they are detected either by bobbin and/or RPC/+Pt at the EOC_{n+1} inspection. Noting that no tubes were deplugged in 2R10 at DCPP, this criteria is not applicable to the 2R10 POPCD evaluation in Table 6-1. However, this criterion was utilized in the Composite Table 6-2 for the EOCn inspections that included deplugging activities.

For new indications detected at EOC_{n+1} but found to be NDD upon look-up in the EOC_n data, the EOC_n volts were estimated by subtracting the average SG voltage growth rate from the EOC_{n+1} volts for the applicable cycle. If the resultant voltage was less than zero, the EOC_n voltage was assigned as 0.01 volts. This rationale was used for the DCPP POPCD evaluations presented in this report.

As previously stated, the 2R10 POPCD evaluation based on the 2R11 inspection data is summarized in Table 6-1. The DCPP Units 1 and 2 composite POPCD data is summarized in Table 6-2. This included data from five inspections at DCPP, two at Unit 2 and 3 at Unit 1. The fitted log-logistic statistical parameters to the data in Table 6-2 were provided to DCPP via Ref. 16 and were utilized in the Monte Carlo simulations for EOC-12 projections, as well as EOC-11 benchmarks.

6.3 *Calculation of BOC-12 Voltage Distributions*

The first step in performing the leak rate and probability of burst calculations is to determine the number and voltages of the indications being returned to service for the next operating cycle. The BOC-12 distribution is calculated by dividing the as-found condition of the SG by the probability of detection (POD), and subtracting the number of repaired tubes, as discussed in Section 6.1. For the required analyses, the BOC-12 distributions for each SG were calculated using the constant POD of 0.6 as required per the Generic Letter, except for the 21.5-volt flaw in SG 2-4, which has a POD of 1.0. Tables 6-3 through 6-6 and Figures 6-1 through 6-4 summarize the as-found distribution, repaired tubes, and the calculated BOC-12 (POD 0.6 and 1.0 for R44C45) distributions for SG 2-1, SG 2-2, SG 2-3, and SG 2-4 respectively. One important point of note is that the typical 2.0-volt lower voltage repair limit was not utilized during 2R11. A preventive plugging was undertaken that repaired all bobbin indications >1.2 volts. The 1.2-volt criterion was utilized to ensure that adequate measures were enacted during the outage to maintain tube integrity at EOC-12 relative to the voltage-based ARC requirements.

6.4 *Predicted EOC-12 Voltage Distributions*

The EOC-12 voltage distributions are obtained by applying a Monte Carlo sampling process to the BOC-12 voltages. This process randomly assigns NDE uncertainty values and a growth value to each of the BOC-12 indications. In the cases where DCPP POPCD was utilized, the POD was also randomly determined to calculate the BOC-12 distribution, prior to the application of growth and uncertainty. The EOC-12 voltage distributions are then used to calculate a leak rate and probability of tube burst. Section 3.2 provides information on the growth distributions that were used in the analyses. Section 7 contains the details of the calculations performed for EOC-12, as well as the populations and results.

6.5 *Comparison of Predicted and Actual EOC-11 Conditions*

6.5.1 Benchmark of Prior 90 Day Report Predicted Distributions

The as-found EOC-11 bobbin voltage distributions and the predicted distributions from the previous 90-day report using a POD of 0.6 and a voltage independent growth for all SGs are compared in Table 6-7. Figures 6-5 through 6-8 depict the projected population at EOC-11 using a POD of 0.6 and independent growth from Ref. 7, versus the as-found EOC-11 conditions. As shown in Table 6-7, the number of indications was under-predicted using the 0.6 POD for all steam generators. Figures 6-5 through 6-8 show that the under predictions generally occurred in voltage bins less than about 0.8 volts. For bins exceeding 0.8 volts, the predictions generally exceed the as-found voltages except for the tail of the distribution for all four SGs. SG 2-1 and 2-2 had several indications over 6 volts that were not projected at 2R10. The EOC-11 results for SG 2-4 projected there would be 8 indications at 4.6 volts. There were fourteen indications found during 2R11 that exceeded 4.6 volts. The results of these comparisons demonstrate that the voltage independent growth rate method in conjunction with the 0.6 POD was not adequate to predict EOC-11 conditions. VDG calculations were also performed at EOC-10 for SGs 2-3 and 2-4, using both POD of 0.6 and EPRI Addendum 4 POPCD. Table 6-8 compares both of the projected distributions to the EOC-11 as-found conditions for these SGs. The projections both under predicted the number of indications compared to the as-found conditions. The POD of 0.6 did predict a higher number of large voltage indications, however, this is expected since a much larger fraction of the repaired indications are returned to service, compared to application of POPCD which has a much higher POD in the high voltage ranges. The shortcoming of the 2R10 90-day report VDG+POPCD projections are attributed to the growth rate differences between the cycles and the bins that were chosen in the analysis (one breakpoint at 1 volt based on Addendum 4 recommendations for 50 indications in the upper voltage bin).

6.5.2 Revised Benchmarking Comparison

DCPP benchmarking analyses were performed to show the adequacy of using a DCPP POPCD distribution. As part of this benchmarking evaluation, the EOC-11 leak and burst projections were calculated using the Addendum 5 values, the revised leak rate method referred to in Section 9.5 of Addendum 5, and the lower 2405 psi SLB delta pressure. The projected EOC-11 leak rate and POB in the 2R10 90 day report (Ref. 7) used a SLB dP of 2560 psi and the database correlations of Addendum 4, as well as the leak rate method of Ref. 6.

The benchmarking projections were performed for DCPP EOC-11 using the DCPP POPCD and a POD of 0.6. Two comparisons of as-found versus projections were performed to assess the POPCD methods. The first method uses the Cycle 11 voltage dependent growth distribution to separate POPCD issues from growth issues for the EOC-11 projections. The second method uses the DCPP Cycle 10 voltage dependent growth distributions but excludes the 21.5-volt indication from the EOC-11 condition monitoring assessment. Since pulled tube R44C45-2H was found to have a burst pressure exceeding steam line break (SLB) accident pressure differentials, the updated condition monitoring assessment for EOC-11 excludes this indication from the burst probability analysis. The 21.5-volt indication in DCPP 2R11 is clearly a growth rate issue and assessments of POPCD must either include the growth rate or exclude the indication to isolate potential POD issues from the growth rate issue. The projected SLB leak rate and burst probability can be compared with the results obtained using the DCPP 2R11 as-found voltage distributions. Tables 6-9 through 6-12 contain the voltage distributions from each benchmark compared to the as-found conditions. Table 6-13 provides the POB and leak rate analysis results. The differences between the projected (OA analysis) and as-found (CM analysis) probability and leak rate are included in the table and compared with the magnitude for significant differences. Significant differences are defined as differences greater than 10% of the reporting thresholds for burst and leakage.

The results in Table 6-13 show that the use of the DCPP POPCD results in insignificant differences between the OA projections and the CM results, except for SG 2-4. The use of 0.6 POD results in excessively conservative projections that are about a factor of two higher than the CM results, as shown in Table 6-13 for SG 2-4. The fact that the 0.6 POD predictions are so conservative would have entirely masked the increased growth rate issues for Unit 2 Cycle 11 if the 21.5-volt indication had not occurred (predicted POB of 6.46E-03 using Cycle 10 growth compared to CM result of 3.84E-03). For SG 2-4 using the Cycle 10 growth rates, the differences between the OA and CM results are due to a combination of increases in growth rates between Cycle 10 and Cycle 11, as well as the conservative treatment for NDE uncertainties in the CM analyses for indications above two volts. As discussed in Section 3, DCPP-2 Cycle 11 growth rates are about 10 percent larger than Cycle 10 data between 0.6 and 1.6 volts with somewhat larger increases above 1.6 volts, thus showing increased voltage-dependent growth in the upper bin. For SG 2-4, using the Cycle 11 voltage dependent growth rates including the 21.5-volt indication in both the OA and CM analyses, there is a difference of 2.0E-03 between the calculated POPCD POB (2.38E-02), and the condition monitoring POB (2.18E-02). This difference exceeds 10 percent of the GL POB reporting threshold of 1.0E-02 and requires further evaluation. The difference is principally accounted for by the application of percentage based non-destructive examination uncertainties to indications above two volts and particularly to the 21.5-volt indication in the condition monitoring calculation. The influence of NDE uncertainties in the CM analysis is much greater than for the OA analysis due to the larger voltage indications in the CM analysis and to the fact that growth rates are much larger than the NDE uncertainties in the OA analysis. It is shown in Table 6-12 that the EOC voltage distribution is conservatively predicted using POPCD above 1 volt, including the prediction of a 21.5 volts indication. As seen from the two SG 2-4 CM results, the 21.5-volt indication increases the POB by a factor of 6.2. As noted in Note 5 of Table 6-13, a reduction of the NDE analyst variability standard deviation from 10% to 5% for indications >2 volts, leads to a reduction in CM POB from 2.38E-02 to 2.23E-02, for which the difference of 1.5E-03 by itself exceeds 10% of the reporting threshold. By comparing the reduced as-found calculation, 2.23E-02, to the projected value of 2.18E-02, the difference of 5.0E-04 between the CM and OA results is then insignificant.

Assessments were also performed for the ability of the POPCD method to conservatively project the EOC-11 voltage distribution using Cycles 11 and 10 growth rates. Tables 6-10 and 6-12 provide a comparison of the projected and actual EOC-11 distributions for all four DCPP SGs, based on POPCD and Cycle 11 voltage dependent growth with breakpoints at 0.59 and 1.66 BOC volts. All calculations used SG-specific Cycle 11 voltage dependent growth, except for the upper bin (>1.66v) in SG 2-3, where no indications existed. The SG 2-3 calculation used a composite growth rate from all SGs, excluding the 11.9 v/EFPY growth point from R44C45. Table 6-12 also provides 0.6 POD EOC-11 projections for SG 2-4 for comparison. The results show conservative projections of indications above 1 volt, and project the 21.5-volt indication. Indications less than 1 volt can be slightly under predicted with POPCD and POD=0.6, however, these indications do not contribute significantly to tube integrity calculations. For SG 2-4, the under prediction by about 25 percent of the indications less than 1 volt is compensated for tube integrity analyses by the over prediction by about 23 percent of the number of indications greater than 1 volt. It is seen from the 0.6 POD calculation for SG 2-4 in Table 6-11 and 6-12 that the number of indications less than 1 volt is close to a factor of 2 too low while the indications above 1 volt are over predicted by close to a factor of 2. This comparison demonstrates that POPCD provides a more accurate voltage distribution prediction than 0.6 POD.

Similar to Tables 6-10 and 6-12, Tables 6-9 and 6-11 provide the comparison of projected and actual EOC-11 voltage distributions, but apply the DCPP Unit 2 Cycle 10 voltage dependent growth distributions with break points at 0.69 and 1.17 volts. Table 6-11 also provides 0.6 POD EOC-11 projections for SG 2-4 for comparison. All calculations used composite SG Cycle 10 growth in each bin because of the small number of flaws that existed in the upper and middle bins in Cycle 10. R44C45 in SG 2-4 was excluded from the as-found and projected distribution since the benchmark was performed to evaluate the methods for projections and as-found analyses, excluding the limitations on predicting the large flaw. The slight over predictions using POPCD for SGs 2-1, 2-2 and 2-3 are very reasonable above 1 volt. The indications above 2 volts in SG 2-4 are slightly under predicted. This difference is due to the increase in Cycle 11 growth rates above about 0.6 volt for SG 2-4.

It is seen from the 0.6 POD calculation for SG 2-4 in Table 6-11 and 6-12 that the number of indications less than 1 volt is under predicted by about a factor of 2, while the indications above 1 volt are over predicted by about a factor of 2 (thus masking the growth rate issue). This comparison demonstrates that POPCD provides a more accurate voltage distribution prediction than 0.6 POD.

Under predictions when applying POPCD are more likely to be due to growth rate uncertainties than POPCD uncertainties as shown by the differences in projected > 2 volt EOC voltage indications for SG 2-4 between use of 2R10 and 2R11 voltage dependent growth rates. The above benchmarking results support the adequacy of the DCPP POPCD distribution for ARC applications. In summary, when utilizing a known growth rate (Cycle 11 with VDG at 0.59 and 1.66 v breakpoints) combined with a realistic POD (DCPP POPCD), the projected results, both in population distribution and in POB/leak rate result, provide a realistic estimation of the conditions of the DCPP SGs at EOC-11. Therefore it is reasonable to assume that this approach will produce similar results for EOC-12 projections. As discussed in Sections 3 and 7, for additional conservatism, the Cycle 11 growth rates in the middle VDG bin were increased by 10% when performing EOC-12 projections.

Table 6-1: Diablo Canyon Unit 2 2R10 POPCD from the 2R11 Inspection Results

A	B	C	D	E	F	G	H	I	J	K	L	M
Data Reporting Requirements for POPCD Analyses[1, 6]												
	EOCn Bobbin Detected for POPCD Analysis IND[2]			EOCn Bobbin Detected Ind. Excluded from POPCD		New EOCn+1 (Undetected at EOCn) Ind. for POPCD Analysis			New EOCn+1 Excluded from POPCD	POPCD Calculation[1]		
Voltage Bin[3]	EOCn Bobbin Ind. RPC Confirmed at EOCn+1	EOCn Bobbin Ind. Not RPC Inspected at EOCn+1	EOCn Bobbin Ind. Detected & Repaired at EOCn	EOCn Bobbin Ind. RPC NDD at EOCn+1	EOCn Bobbin Ind. INR[4] at EOCn+1	New EOCn+1 Bobbin Ind. RPC Confirmed at EOCn+1	New EOCn+1 Bobbin Ind. Not RPC Inspected at EOCn+1	New EOCn+1 Ind. Found Only[5] by RPC Inspection	New EOCn+1 Bobbin Ind. RPC NDD at EOCn+1	EOCn Bobbin Detected Ind.	New EOCn+1 ODSCC Ind.	POPCD for Voltage Bin
0.1	0	0	0	0	0	10	14	0	2	0	24	
0.2	1	10	0	3	0	64	184	5	11	11	253	0.04
0.3	26	52	0	11	0	80	218	3	18	78	301	0.21
0.4	35	76	2	6	0	60	134	1	13	113	195	0.37
0.5	50	78	1	8	1	23	68	0	4	129	91	0.59
0.6	64	60	2	4	0	16	30	0	5	126	46	0.73
0.7	62	32	0	7	0	10	17	0	3	94	27	0.78
0.8	40	15	0	3	0	6	6	0	1	55	12	0.82
0.9	48	5	0	1	0	2	3	0	0	53	5	0.91
1	30	5	1	0	0	3	0	0	0	36	3	0.92
1.1	31	1	0	0	0	0	0	0	1	32	0	1.00
1.2	11	0	0	0	0	3	0	0	1	11	3	0.79
1.3	18	0	0	1	0	0	0	0	0	18	0	1.00
1.4	16	1	0	1	0	0	0	0	0	17	0	1.00
1.5	9	0	0	0	0	0	0	0	0	9	0	1.00
1.6	7	0	0	0	0	0	0	0	0	7	0	1.00
1.7	8	0	0	0	0	0	0	0	0	8	0	1.00
1.8	5	0	0	0	0	0	0	0	0	5	0	1.00
1.9	6	0	0	0	0	0	0	0	0	6	0	1.00
2	8	0	0	0	0	0	0	0	0	8	0	1.00
2.1	0	0	0	0	0	0	0	0	0	0	0	
2.2	0	0	3	0	0	0	0	0	0	3	0	1.00
2.3	0	0	1	0	0	0	0	0	0	1	0	1.00

Table 6-1: Diablo Canyon Unit 2 2R10 POPCD from the 2R11 Inspection Results

A	B	C	D	E	F	G	H	I	J	K	L	M
Data Reporting Requirements for POPCD Analyses(1, 6)												
	EOCn Bobbin Detected for POPCD Analysis IND(2)			EOCn Bobbin Detected Ind. Excluded from POPCD		New EOCn+1 (Undetected at EOCn) Ind. for POPCD Analysis			New EOCn+1 Excluded from POPCD	POPCD Calculation(1)		
Voltage Bin(3)	EOCn Bobbin Ind. RPC Confirmed at EOCn+1	EOCn Bobbin Ind. Not RPC Inspected at EOCn+1	EOCn Bobbin Ind. Detected & Repaired at EOCn	EOCn Bobbin Ind. RPC NDD at EOCn+1	EOCn Bobbin Ind. INR(4) at EOCn+1	New EOCn+1 Bobbin Ind. RPC Confirmed at EOCn+1	New EOCn+1 Bobbin Ind. Not RPC Inspected at EOCn+1	New EOCn+1 Ind. Found Only(5) by RPC Inspection	New EOCn+1 Bobbin Ind. RPC NDD at EOCn+1	EOCn Bobbin Detected Ind.	New EOCn+1 ODSCC Ind.	POPCD for Voltage Bin
2.4	0	0	0	0	0	0	0	0	0	0	0	
2.5	0	0	0	0	0	0	0	0	0	0	0	
2.6	0	0	1	0	0	0	0	0	0	1	0	1.00
2.7	0	0	0	0	0	0	0	0	0	0	0	
2.8	0	0	2	0	0	0	0	0	0	2	0	1.00
2.9	0	0	1	0	0	0	0	0	0	1	0	1.00
3.0	0	0	0	0	0	0	0	0	0	0	0	
3.1	0	0	1	0	0	0	0	0	0	1	0	1.00
3.2	0	0	1	0	0	0	0	0	0	1	0	1.00
3.3	0	0	0	0	0	0	0	0	0	0	0	
3.4	0	0	2	0	0	0	0	0	0	2	0	1.00
3.5	0	0	1	0	0	0	0	0	0	1	0	1.00
3.6	0	0	0	0	0	0	0	0	0	0	0	
3.7	0	0	0	0	0	0	0	0	0	0	0	
3.8	0	0	0	0	0	0	0	0	0	0	0	
3.9	0	0	2	0	0	0	0	0	0	2	0	1.00
4.0	0	0	0	0	0	0	0	0	0	0	0	
4.1	0	0	1	0	0	0	0	0	0	1	0	1.00
4.2	0	0	1	0	0	0	0	0	0	1	0	1.00
4.3	0	0	0	0	0	0	0	0	0	0	0	
4.4	0	0	2	0	0	0	0	0	0	2	0	1.00
4.5	0	0	0	0	0	0	0	0	0	0	0	
4.6	0	0	0	0	0	0	0	0	0	0	0	
4.7	0	0	0	0	0	0	0	0	0	0	0	

Table 6-1: Diablo Canyon Unit 2 2R10 POPCD from the 2R11 Inspection Results

A	B	C	D	E	F	G	H	I	J	K	L	M
Data Reporting Requirements for POPCD Analyses(1, 6)												
	EOCn Bobbin Detected for POPCD Analysis IND(2)			EOCn Bobbin Detected Ind. Excluded from POPCD		New EOCn+1 (Undetected at EOCn) Ind. for POPCD Analysis			New EOCn+1 Excluded from POPCD	POPCD Calculation(1)		
Voltage Bin(3)	EOCn Bobbin Ind. RPC Confirmed at EOCn+1	EOCn Bobbin Ind. Not RPC Inspected at EOCn+1	EOCn Bobbin Ind. Detected & Repaired at EOCn	EOCn Bobbin Ind. RPC NDD at EOCn+1	EOCn Bobbin Ind. INR(4) at EOCn+1	New EOCn+1 Bobbin Ind. RPC Confirmed at EOCn+1	New EOCn+1 Bobbin Ind. Not RPC Inspected at EOCn+1	New EOCn+1 Ind. Found Only(5) by RPC Inspection	New EOCn+1 Bobbin Ind. RPC NDD at EOCn+1	EOCn Bobbin Detected Ind.	New EOCn+1 ODSCC Ind.	POPCD for Voltage Bin
4.8	0	0	0	0	0	0	0	0	0	0	0	
4.9	0	0	0	0	0	0	0	0	0	0	0	
5.0	0	0	0	0	0	0	0	0	0	0	0	
5.1	0	0	1	0	0	0	0	0	0	1	0	1.00
5.2	0	0	0	0	0	0	0	0	0	0	0	
5.3	0	0	1	0	0	0	0	0	0	1	0	1.00
5.4	0	0	0	0	0	0	0	0	0	0	0	
5.5	0	0	1	0	0	0	0	0	0	1	0	1.00
TOTALS	475	335	28	45	1	277	674	9	57	838	960	

Notes:

1. POPCD for each voltage bin calculated as (EOCn Bobbin Detected for POPCD Analysis)/(EOCn Bobbin Detected for POPCD Analysis + New EOCn+1 Ind. for POPCD Analysis). By column, POPCD = (B+C+D)/[(B+C+D)+(G+H+I)].
2. EOCn detection based on inspection records for EOCn. Voltages obtained from EOCn inspection records.
3. Plant specific POPCD to be based upon voltage bins of 0.10 volt. Industry POPCD database may use 0.20 volt bins due to difficulty of adjusting existing database to smaller bins.
4. INR = bobbin indication found at EOCn but not reported at EOCn+1 including resolution analyst review to assign indication as INR. Bobbin indications found to be RPC NDD or INR are considered to be false calls and not included in the POPCD analysis.
5. Includes new indications at EOCn+1, not reported in the bobbin inspection, and found by RPC inspection of dents, mixed residuals or other reasons for the RPC inspection. These indications are included as new indications at each EOCn+1 found only by RPC inspection even if included as a new indication in previous POPCD evaluations. If the RPC inspection identifies more than one ODSCC indication at the same TSP intersection, the bobbin voltage assigned to the TSP is estimated as the square root of the sum of squares for the bobbin voltages inferred from the RPC indications.
6. The sum of all EOCn bobbin indications = sum of columns B through F. The sum of all EOCn+1 bobbin indications = sum of columns B+C+E+ columns G through J.

Table 6-2: Diablo Canyon Composite POPCD Data

A	B	C	D	E	F	G	H	I	J	K	L	M
Data Reporting Requirements for POPCD Analyses[1, 6]												
	EOCn Bobbin Detected for POPCD Analysis IND[2]			EOCn Bobbin Detected Ind. Excluded from POPCD		New EOCn+1 (Undetected at EOCn) Ind. for POPCD Analysis			New EOCn+1 Excluded from POPCD	POPCD Calculation[1]		
Voltage Bin[3]	EOCn Bobbin Ind. RPC Confirmed at EOCn+1	EOCn Bobbin Ind. Not RPC Inspected at EOCn+1	EOCn Bobbin Ind. Detected & Repaired at EOCn	EOCn Bobbin Ind. RPC NDD at EOCn+1	EOCn Bobbin Ind. INR[4] at EOCn+1	New EOCn+1 Bobbin Ind. RPC Confirmed at EOCn+1	New EOCn+1 Bobbin Ind. Not RPC Inspected at EOCn+1	New EOCn+1 Ind. Found Only[5] by RPC Inspection	New EOCn+1 Bobbin Ind. RPC NDD at EOCn+1	EOCn Bobbin Detected Ind.	New EOCn+1 ODSCC Ind.	POPCD for Voltage Bin
0.1	3	1	0	0	0	19	47	0	4	4	66	0.06
0.2	13	42	2	3	4	100	394	6	15	57	500	0.10
0.3	50	191	5	20	10	135	511	55	26	246	701	0.26
0.4	70	283	13	9	15	107	386	70	20	366	563	0.39
0.5	73	261	6	14	13	66	197	18	6	340	281	0.55
0.6	87	195	6	10	5	40	114	12	8	288	166	0.63
0.7	77	146	3	7	6	29	58	0	8	226	87	0.72
0.8	54	89	4	5	2	20	36	1	2	147	57	0.72
0.9	58	68	2	2	0	16	14	0	1	128	30	0.81
1	39	38	1	0	2	4	5	0	1	78	9	0.90
1.1	35	16	2	0	0	6	6	0	2	53	12	0.82
1.2	18	22	1	1	0	3	3	0	2	41	6	0.87
1.3	24	18	0	1	0	2	4	0	0	42	6	0.88
1.4	27	9	0	1	1	2	1	0	0	36	3	0.92
1.5	14	7	0	0	0	1	0	0	0	21	1	0.95
1.6	8	4	1	0	0	0	0	0	0	13	0	1.00
1.7	11	1	0	0	0	0	0	0	0	12	0	1.00
1.8	8	1	0	0	0	0	0	0	0	9	0	1.00
1.9	7	0	0	0	0	0	0	0	0	7	0	1.00
2	11	1	0	0	0	0	0	0	0	12	0	1.00
2.1	0	0	0	0	0	0	0	0	0	0	0	
2.2	0	0	5	0	0	0	0	0	0	5	0	1.00

Table 6-2: Diablo Canyon Composite POPCD Data

A	B	C	D	E	F	G	H	I	J	K	L	M
Data Reporting Requirements for POPCD Analyses[1, 6]												
	EOCn Bobbin Detected for POPCD Analysis IND[2]			EOCn Bobbin Detected Ind. Excluded from POPCD		New EOCn+1 (Undetected at EOCn) Ind. for POPCD Analysis			New EOCn+1 Excluded from POPCD	POPCD Calculation[7]		
Voltage Bin[3]	EOCn Bobbin Ind. RPC Confirmed at EOCn+1	EOCn Bobbin Ind. Not RPC Inspected at EOCn+1	EOCn Bobbin Ind. Detected & Repaired at EOCn	EOCn Bobbin Ind. RPC NDD at EOCn+1	EOCn Bobbin Ind. INR[4] at EOCn+1	New EOCn+1 Bobbin Ind. RPC Confirmed at EOCn+1	New EOCn+1 Bobbin Ind. Not RPC Inspected at EOCn+1	New EOCn+1 Ind. Found Only[5] by RPC Inspection	New EOCn+1 Bobbin Ind. RPC NDD at EOCn+1	EOCn Bobbin Detected Ind.	New EOCn+1 ODSCC Ind.	POPCD for Voltage Bin
2.3	0	0	3	0	0	0	0	0	0	3	0	1.00
2.4	0	0	2	0	0	0	0	0	0	2	0	1.00
2.5	0	0	0	0	0	0	0	0	0	0	0	
2.6	0	0	2	0	0	0	0	0	0	2	0	1.00
2.7	0	0	0	0	0	0	0	0	0	0	0	
2.8	0	0	3	0	0	0	0	0	0	3	0	1.00
2.9	0	0	3	0	0	0	0	0	0	3	0	1.00
3.0	0	0	0	0	0	0	0	0	0	0	0	
3.1	0	0	1	0	0	0	0	0	0	1	0	1.00
3.2	0	0	1	0	0	0	0	0	0	1	0	1.00
3.3	0	0	0	0	0	0	0	0	0	0	0	
3.4	0	0	2	0	0	0	0	0	0	2	0	1.00
3.5	0	0	1	0	0	0	0	0	0	1	0	1.00
3.6	0	0	0	0	0	0	0	0	0	0	0	
3.7	0	0	0	0	0	0	0	0	0	0	0	
3.8	0	0	0	0	0	0	0	0	0	0	0	
3.9	0	0	2	0	0	0	0	0	0	2	0	1.00
4.0	0	0	0	0	0	0	0	0	0	0	0	
4.1	0	0	1	0	0	0	0	0	0	1	0	1.00
4.2	0	0	1	0	0	0	0	0	0	1	0	1.00
4.3	0	0	0	0	0	0	0	0	0	0	0	
4.4	0	0	2	0	0	0	0	0	0	2	0	1.00
4.5	0	0	0	0	0	0	0	0	0	0	0	

Table 6-2: Diablo Canyon Composite POPCD Data

A	B	C	D	E	F	G	H	I	J	K	L	M
Data Reporting Requirements for POPCD Analyses(1, 6)												
	EOCn Bobbin Detected for POPCD Analysis IND(2)			EOCn Bobbin Detected Ind. Excluded from POPCD		New EOCn+1 (Undetected at EOCn) Ind. for POPCD Analysis			New EOCn+1 Excluded from POPCD	POPCD Calculation(1)		
Voltage Bin(3)	EOCn Bobbin Ind. RPC Confirmed at EOCn+1	EOCn Bobbin Ind. Not RPC Inspected at EOCn+1	EOCn Bobbin Ind. Detected & Repaired at EOCn	EOCn Bobbin Ind. RPC NDD at EOCn+1	EOCn Bobbin Ind. INR(4) at EOCn+1	New EOCn+1 Bobbin Ind. RPC Confirmed at EOCn+1	New EOCn+1 Bobbin Ind. Not RPC Inspected at EOCn+1	New EOCn+1 Ind. Found Only(5) by RPC Inspection	New EOCn+1 Bobbin Ind. RPC NDD at EOCn+1	EOCn Bobbin Detected Ind.	New EOCn+1 ODSCC Ind.	POPCD for Voltage Bin
4.6	0	0	0	0	0	0	0	0	0	0	0	
4.7	0	0	0	0	0	0	0	0	0	0	0	
4.8	0	0	0	0	0	0	0	0	0	0	0	
4.9	0	0	0	0	0	0	0	0	0	0	0	
5.0	0	0	0	0	0	0	0	0	0	0	0	
5.1	0	0	1	0	0	0	0	0	0	1	0	1.00
5.2	0	0	0	0	0	0	0	0	0	0	0	
5.3	0	0	1	0	0	0	0	0	0	1	0	1.00
5.4	0	0	0	0	0	0	0	0	0	0	0	
5.5	0	0	1	0	0	0	0	0	0	1	0	1.00
TOTALS	687	1393	78	73	58	550	1776	162	95	2158	2488	

Notes: (Same as previous Table 6-1)

Log-logistic Fit Parameters of DCPP Composite POPCD Used in Monte Carlo Analyses

# of Data	4646
a.0	1.7673
a.1	4.7049
V11	0.00546
V12	0.01078
V22	0.02687
Deviance	5188.56
MSE	0.1895
Binary	TRUE
Chi Sqr	879.82
DoF	4644
p-Value	< 2.9E-07

Table 6-3: SG 2-1 As-Found and BOC-12 Voltage Distribution (POD 0.6)

Voltage Bin	As-Found EOC-11	POD (0.6)	Repaired Tubes	Calculated BOC-12	DOSs/AONDBs Returned to Service: Conf. OD-SCC or Not Insp w/+Pt	DOSs/AONDBs Returned to Service: Total
0.1	0		0		0	0
0.2	21	35	0	35	11	21
0.3	66	110	3	107	52	63
0.4	59	98.33	2	96.33	46	57
0.5	51	85	1	84	39	50
0.6	36	60	1	59	31	35
0.7	34	56.67	0	56.67	23	34
0.8	21	35	0	35	18	21
0.9	11	18.33	0	18.33	9	11
1	5	8.33	0	8.33	5	5
1.1	11	18.33	0	18.33	10	11
1.2	4	6.67	0	6.67	4	4
1.3	11	18.33	11	7.33	0	0
1.4	2	3.33	2	1.33	0	0
1.5	4	6.67	4	2.67	0	0
1.6	0		0		0	0
1.7	1	1.67	1	0.67	0	0
1.8	1	1.67	1	0.67	0	0
1.9	2	3.33	2	1.33	0	0
2	0		0		0	0
2.1	0		0		0	0
2.2	0		0		0	0
2.3	1	1.67	1	0.67	0	0
2.4	0		0		0	0
2.5	0		0		0	0
2.6	0		0		0	0
2.7	0		0		0	0
2.8	1	1.67	1	0.67	0	0
2.9	2	3.33	2	1.33	0	0
3	0		0		0	0
3.1	0		0		0	0
3.2	0		0		0	0
3.3	1	1.67	1	0.67	0	0
3.4	0		0		0	0
3.5	1	1.67	1	0.67	0	0
3.6	0		0		0	0
3.7	0		0		0	0
3.8	0		0		0	0
3.9	0		0		0	0
4	0		0		0	0
4.1	0		0		0	0
4.2	0		0		0	0
4.3	0		0		0	0
4.4	1	1.67	1	0.67	0	0
4.5	0		0		0	0
4.6	0		0		0	0
4.7	0		0		0	0
4.8	0		0		0	0
4.9	0		0		0	0
5	0		0		0	0
6	1	1.67	1	0.67	0	0
7	2	3.33	2	1.33	0	0
8	0		0		0	0
9	0		0		0	0
10	0		0		0	0
11	0		0		0	0
12	0		0		0	0
13	0		0		0	0
14	0		0		0	0
15	0		0		0	0
>20	0		0		0	0
Total	350	583.33	38	545.33	248	312

Table 6-4: SG 2-2 As-Found and BOC-12 Voltage Distribution (POD 0.6)

Voltage Bin	As-Found EOC-11	POD (0.6)	Repaired Tubes	Calculated BOC-12	DOSs/AONDBs Returned to Service	
					Conf. OD-SCC or Not Insp w/+Pt	Total
0.1	0		0		0	0
0.2	13	21.67	0	21.67	13	13
0.3	50	83.33	1	82.33	49	49
0.4	45	75	3	72	42	42
0.5	47	78.33	3	75.33	44	44
0.6	31	51.67	1	50.67	30	30
0.7	27	45	2	43	25	25
0.8	11	18.33	0	18.33	11	11
0.9	18	30	1	29	17	17
1	7	11.67	0	11.67	7	7
1.1	7	11.67	0	11.67	7	7
1.2	5	8.33	0	8.33	5	5
1.3	5	8.33	5	3.33	0	0
1.4	1	1.67	1	0.67	0	0
1.5	1	1.67	1	0.67	0	0
1.6	0		0		0	0
1.7	2	3.33	2	1.33	0	0
1.8	1	1.67	1	0.67	0	0
1.9	0		0		0	0
2	2	3.33	2	1.33	0	0
2.1	0		0		0	0
2.2	0		0		0	0
2.3	0		0		0	0
2.4	1	1.67	1	0.67	0	0
2.5	1	1.67	1	0.67	0	0
2.6	0		0		0	0
2.7	0		0		0	0
2.8	0		0		0	0
2.9	0		0		0	0
3	0		0		0	0
3.1	0		0		0	0
3.2	0		0		0	0
3.3	0		0		0	0
3.4	0		0		0	0
3.5	1	1.67	1	0.67	0	0
3.6	0		0		0	0
3.7	0		0		0	0
3.8	0		0		0	0
3.9	0		0		0	0
4	0		0		0	0
4.1	0		0		0	0
4.2	0		0		0	0
4.3	0		0		0	0
4.4	0		0		0	0
4.5	0		0		0	0
4.6	1	1.67	1	0.67	0	0
4.7	0		0		0	0
4.8	0		0		0	0
4.9	0		0		0	0
5	0		0		0	0
6	0		0		0	0
7	1	1.67	1	0.67	0	0
8	0		0		0	0
9	0		0		0	0
10	0		0		0	0
11	0		0		0	0
12	0		0		0	0
13	0		0		0	0
14	0		0		0	0
15	0		0		0	0
>20	0		0		0	0
Total	278	463.33	28	435.33	250	250

Table 6-5: SG 2-3 As-Found and BOC-12 Voltage Distribution (POD 0.6)

Voltage Bin	As-Found EOC-11	POD (0.6)	Repaired Tubes	Calculated BOC-12	DOSs/AONDBs Returned to Service: Conf. OD-SCC or Not Insp w/+Pt	DOSs/AONDBs Returned to Service: Total
0.1	0		0		0	0
0.2	17	28.33	0	28.33	15	17
0.3	42	70	3	67	38	39
0.4	58	96.67	3	93.67	50	55
0.5	39	65	0	65	38	39
0.6	28	46.67	1	45.67	26	27
0.7	19	31.67	1	30.67	17	18
0.8	19	31.67	1	30.67	18	18
0.9	3	5	0	5	3	3
1	4	6.67	0	6.67	4	4
1.1	4	6.67	0	6.67	4	4
1.2	7	11.67	0	11.67	7	7
1.3	6	10	6	4	0	0
1.4	1	1.67	1	0.67	0	0
1.5	3	5	3	2	0	0
1.6	3	5	3	2	0	0
1.7	1	1.67	1	0.67	0	0
1.8	1	1.67	1	0.67	0	0
1.9	2	3.33	2	1.33	0	0
2	1	1.67	1	0.67	0	0
2.1	1	1.67	1	0.67	0	0
2.2	0		0		0	0
2.3	1	1.67	1	0.67	0	0
2.4	0		0		0	0
2.5	0		0		0	0
2.6	0		0		0	0
2.7	0		0		0	0
2.8	0		0		0	0
2.9	1	1.67	1	0.67	0	0
3	0		0		0	0
3.1	1	1.67	1	0.67	0	0
3.2	0		0		0	0
3.3	0		0		0	0
3.4	0		0		0	0
3.5	0		0		0	0
3.6	0		0		0	0
3.7	0		0		0	0
3.8	0		0		0	0
3.9	0		0		0	0
4	0		0		0	0
4.1	1	1.67	1	0.67	0	0
4.2	0		0		0	0
4.3	0		0		0	0
4.4	0		0		0	0
4.5	0		0		0	0
4.6	0		0		0	0
4.7	0		0		0	0
4.8	0		0		0	0
4.9	0		0		0	0
5	0		0		0	0
6	0		0		0	0
7	0		0		0	0
8	0		0		0	0
9	0		0		0	0
10	0		0		0	0
11	0		0		0	0
12	0		0		0	0
13	0		0		0	0
14	0		0		0	0
15	0		0		0	0
>20	0		0		0	0
Total	263	438.33	32	406.33	220	231

Table 6-6: SG 2-4 As-Found and BOC-12 Voltage Distribution (POD 0.6 & 1.0 for R44C35)

					DOSs/AONDBs Returned to Service	
Voltage Bin	As-Found EOC-11	POD (0.6)	Repaired Tubes	Calculated BOC-12	Conf. OD-SCC or Not Insp w/+Pt	Total
0.1	0		0		0	0
0.2	14	23.33	1	22.33	12	13
0.3	91	151.67	8	143.67	82	83
0.4	135	225	13	212	119	122
0.5	139	231.67	15	216.67	122	124
0.6	106	176.67	11	165.67	95	95
0.7	94	156.67	13	143.67	79	81
0.8	81	135	6	129	74	75
0.9	60	100	7	93	53	53
1	33	55	5	50	28	28
1.1	22	36.67	2	34.67	20	20
1.2	26	43.33	3	40.33	23	23
1.3	20	33.33	20	13.33	0	0
1.4	18	30	18	12	0	0
1.5	12	20	12	8	0	0
1.6	16	26.67	16	10.67	0	0
1.7	16	26.67	16	10.67	0	0
1.8	12	20	12	8	0	0
1.9	10	16.67	10	6.67	0	0
2	9	15	9	6	0	0
2.1	1	1.67	1	0.67	0	0
2.2	2	3.33	2	1.33	0	0
2.3	6	10	6	4	0	0
2.4	8	13.33	8	5.33	0	0
2.5	3	5	3	2	0	0
2.6	3	5	3	2	0	0
2.7	3	5	3	2	0	0
2.8	2	3.33	2	1.33	0	0
2.9	4	6.67	4	2.67	0	0
3	3	5	3	2	0	0
3.1	2	3.33	2	1.33	0	0
3.2	1	1.67	1	0.67	0	0
3.3	2	3.33	2	1.33	0	0
3.4	3	5	3	2	0	0
3.5	1	1.67	1	0.67	0	0
3.6	1	1.67	1	0.67	0	0
3.7	0		0		0	0
3.8	2	3.33	2	1.33	0	0
3.9	0		0		0	0
4	0		0		0	0
4.1	1	1.67	1	0.67	0	0
4.2	2	3.33	2	1.33	0	0
4.3	1	1.67	1	0.67	0	0
4.4	1	1.67	1	0.67	0	0
4.5	1	1.67	1	0.67	0	0
4.6	1	1.67	1	0.67	0	0
4.7	1	1.67	1	0.67	0	0
4.8	0		0		0	0
4.9	1	1.67	1	0.67	0	0
5	3	5	3	2	0	0
6	6	10	6	4	0	0
7	2	3.33	2	1.33	0	0
8	0		0		0	0
9	0		0		0	0
10	0		0		0	0
11	0		0		0	0
12	0		0		0	0
13	0		0		0	0
14	0		0		0	0
15	0		0		0	0
>20	1	1	1	0	0	0
Total	982	1636	265	1371.03	707	717

Table 6-7: As-found EOC-11 vs. Projected EOC-11 Distributions with POD=0.6 and Independent Growth from 2R10 90 day Report

Voltage Bin	POD = 0.6 Normal Growth							
	SG 21 EOC-11		SG 22 EOC-11		SG 23 EOC-11		SG 24 EOC-11	
	As-Found	Projected	As-Found	Projected	As-Found	Projected	As-Found	Projected
0.1	0	0.04	0	0.04	0	0.04	0	0.05
0.2	21	1.21	13	0.88	17	1.07	14	1.29
0.3	66	6.16	50	3.63	42	4.66	91	6.40
0.4	59	12.85	45	8.79	58	8.65	135	17.16
0.5	51	21.86	47	15.22	39	13.38	139	34.71
0.6	36	29.82	31	20.31	28	16.68	106	55.12
0.7	34	31.92	27	22.24	19	16.55	94	70.79
0.8	21	32.11	11	20.76	19	16.63	81	78.40
0.9	11	27.41	18	18.05	3	14.36	60	77.33
1	5	22.33	7	14.88	4	12.28	33	70.03
1.1	11	17.47	7	12.08	4	10.28	22	60.83
1.2	4	13.28	5	9.64	7	8.25	26	51.39
1.3	11	10.50	5	7.30	6	6.76	20	42.95
1.4	2	8.62	1	5.44	1	5.51	18	35.98
1.5	4	7.10	1	4.00	3	4.28	12	30.12
1.6	0	5.80	0	2.83	3	3.20	16	25.25
1.7	1	4.55	2	2.00	1	2.29	16	21.10
1.8	1	3.48	1	1.43	1	1.62	12	17.47
1.9	2	2.71	0	1.11	2	1.20	10	14.36
2	0	2.18	2	1.01	1	0.90	9	11.82
2.1	0	1.88	0	0.95	1	0.75	1	9.84
2.2	0	1.62	0	0.88	0	0.63	2	8.15
2.3	1	1.39	0	0.76	1	0.56	6	6.64
2.4	0	1.18	1	0.65	0	0.51	8	5.33
2.5	0	0.95	1	0.54	0	0.43	3	4.22
2.6	0	0.76	0	0.43	0	0.36	3	3.34
2.7	0	0.58	0	0.33	0	0.28	3	2.65
2.8	1	0.46	0	0.25	0	0.23	2	2.13
2.9	2	0.39	0	0.20	1	0.20	4	1.78
3	0	0.34	0	0.17	0	0.17	3	1.57
3.1	0	0.33	0	0.16	1	0.16	2	1.47
3.2	0	0.36	0	0.17	0	0.18	1	1.44
3.3	1	0.37	0	0.19	0	0.18	2	1.46
3.4	0	0.39	0	0.20	0	0.19	3	1.50
3.5	1	0.39	1	0.20	0	0.19	1	1.48
3.6	0	0.34	0	0.18	0	0.17	1	1.36
3.7	0	0.29	0	0.14	0	0.16	0	1.19
3.8	0	0.22	0	0.10	0	0.14	2	0.99
3.9	0	0.17	0	0.08	0	0.13	0	0.83
4	0	0.12	0	0.05	0	0.12	0	0.70
4.1	0	0.09	0	0.04	1	0.12	1	0.61
4.2	0	0.07	0	0.02	0	0.11	2	0.53
4.3	0	0.06	0	0.02	0	0.11	1	0.48
4.4	1	0.08	0	0.03	0	0.12	1	0.50
4.5	0	0.13	0	0.06	0	0.16	1	0.63
4.6	0	0.13	1	0.09	0	0.14	1	0.74
4.7	0	0.13	0	0.08	0	0.12	1	0.77
4.8	0	0.11	0	0.06	0	0.11	0	0.73
4.9	0	0.10	0	0.05	0	0.11	1	0.67
5	0	0.10	0	0.06	0	0.11	3	0.64
6	1	0.37	0	0.23	0	0.43	6	3.80
7	2	0.03	1	0.01	0	0.04	2	0.82
8	0	0.00	0	0.00	0	0.01	0	0.14
9	0	0.00	0	0.00	0	0.00	0	0.04
10	0	0.00	0	0.00	0	0.00	0	0.01
>20	0	0.00	0	0.00	0	0.00	1	0.00
Total	350	275.34	278	179.01	263	156.00	982	791.71

Table 6-8: EOC-11 As-Found vs. Projected Voltage Distribution Cycle 10 VDG at 1.0 Volts for SGs 2-3 and 2-4, POD = 0.6 and EPRI POPCD (2R10 90 Day Report)

Voltage Bin	SG 2-3 EOC-11			SG 2-4 EOC-11		
	As-Found	POD = 0.6	EPRI POPCD	As-Found	POD = 0.6	EPRI POPCD
0.1	0	0.04	0.06	0	0.05	0.08
0.2	17	1.08	1.73	14	1.29	2.10
0.3	42	4.72	6.47	91	6.48	8.91
0.4	58	8.92	11.54	135	17.77	22.24
0.5	39	13.87	16.86	139	36.40	42.15
0.6	28	17.25	19.34	106	57.92	61.76
0.7	19	17.12	17.66	94	74.45	73.70
0.8	19	17.19	16.62	81	82.34	76.60
0.9	3	14.76	13.29	60	80.92	71.18
1	4	12.48	10.77	33	72.54	61.08
1.1	4	10.00	8.44	22	60.93	49.67
1.2	7	7.35	6.02	26	48.13	38.24
1.3	6	5.39	4.36	20	36.81	28.71
1.4	1	4.03	3.26	18	28.04	21.59
1.5	3	2.96	2.35	12	21.53	16.34
1.6	3	2.21	1.69	16	17.17	12.74
1.7	1	1.70	1.26	16	14.37	10.36
1.8	1	1.38	1.01	12	12.44	8.73
1.9	2	1.24	0.93	10	10.97	7.58
2	1	1.11	0.82	9	9.76	6.69
2.1	1	1.03	0.75	1	8.75	5.96
2.2	0	0.91	0.64	2	7.79	5.26
2.3	1	0.76	0.52	6	6.78	4.53
2.4	0	0.59	0.38	8	5.73	3.77
2.5	0	0.43	0.26	3	4.68	3.04
2.6	0	0.30	0.17	3	3.76	2.40
2.7	0	0.24	0.13	3	3.18	2.01
2.8	0	0.27	0.16	2	2.99	1.91
2.9	1	0.31	0.20	4	2.95	1.92
3	0	0.32	0.20	3	2.91	1.88
3.1	1	0.36	0.23	2	2.86	1.81
3.2	0	0.39	0.26	1	2.78	1.73
3.3	0	0.35	0.22	2	2.63	1.60
3.4	0	0.28	0.18	3	2.37	1.41
3.5	0	0.21	0.12	1	2.06	1.19
3.6	0	0.15	0.08	1	1.78	1.00
3.7	0	0.14	0.07	0	1.66	0.91
3.8	0	0.16	0.08	2	1.68	0.93
3.9	0	0.19	0.10	0	1.78	1.00
4	0	0.24	0.13	0	2.01	1.16
4.1	1	0.30	0.16	1	2.24	1.32
4.2	0	0.32	0.18	2	2.23	1.31
4.3	0	0.30	0.16	1	2.04	1.18
4.4	0	0.24	0.12	1	1.78	1.01
4.5	0	0.19	0.08	1	1.53	0.84
>4.5	0	2.23	0.78	15	20.44	9.81
Total	263	156.00	150.82	982	791.71	681.34

Table 6-9: EOC-11 As-Found vs. Recalculated Voltage Distribution Using DCPP POPCD and Cycle 10 VD Growth

Voltage Bin	DCPP POPCD with Cycle 10 VD Growth							
	SG 21 EOC-11		SG 22 EOC-11		SG 23 EOC-11		SG 24 EOC-11	
	As-Found	Projected	As-Found	Projected	As-Found	Projected	As-Found	Projected
0.1	0	0.20	0	0.20	0	0.20	0	0.40
0.2	21	4.86	13	4.09	17	4.53	14	8.73
0.3	66	16.19	50	10.20	42	13.01	91	25.14
0.4	59	29.44	45	20.40	58	22.09	135	50.41
0.5	51	44.10	47	29.85	39	30.46	139	78.68
0.6	36	49.85	31	33.54	28	30.88	106	95.99
0.7	34	46.20	27	32.63	19	26.21	94	101.33
0.8	21	40.95	11	26.60	19	22.16	81	93.92
0.9	11	30.00	18	20.09	3	15.72	60	76.77
1	5	21.71	7	14.16	4	11.81	33	58.19
1.1	11	14.89	7	9.77	4	8.58	22	42.37
1.2	4	10.11	5	7.07	7	6.15	26	32.37
1.3	11	7.67	5	5.28	6	4.86	20	26.50
1.4	2	6.04	1	4.24	1	3.90	18	22.55
1.5	4	4.85	1	3.31	3	3.13	12	19.06
1.6	0	3.64	0	2.45	3	2.33	16	15.69
1.7	1	2.78	2	1.73	1	1.77	16	12.68
1.8	1	2.17	1	1.30	1	1.39	12	10.43
1.9	2	1.94	0	1.11	2	1.23	10	9.15
2	0	1.76	2	1.09	1	1.08	9	8.05
2.1	0	1.60	0	0.97	1	0.92	1	6.85
2.2	0	1.27	0	0.77	0	0.66	2	5.62
2.3	1	1.02	0	0.53	1	0.48	6	4.53
2.4	0	0.83	1	0.38	0	0.36	8	3.70
2.5	0	0.66	1	0.28	0	0.26	3	2.97
2.6	0	0.50	0	0.22	0	0.18	3	2.41
2.7	0	0.42	0	0.20	0	0.16	3	2.24
2.8	1	0.39	0	0.22	0	0.16	2	2.03
2.9	2	0.34	0	0.22	1	0.14	4	1.71
3	0	0.30	0	0.18	0	0.13	3	1.46
3.1	0	0.27	0	0.13	1	0.11	2	1.25
3.2	0	0.25	0	0.09	0	0.09	1	1.07
3.3	1	0.25	0	0.09	0	0.10	2	1.09
3.4	0	0.30	0	0.11	0	0.13	3	1.30
3.5	1	0.31	1	0.13	0	0.13	1	1.37
3.6	0	0.29	0	0.12	0	0.12	1	1.35
3.7	0	0.26	0	0.11	0	0.11	0	1.36
3.8	0	0.25	0	0.13	0	0.12	2	1.34
3.9	0	0.25	0	0.15	0	0.13	0	1.31
4	0	0.24	0	0.16	0	0.12	0	1.21
4.1	0	0.23	0	0.13	1	0.11	1	1.09
4.2	0	0.22	0	0.10	0	0.10	2	0.98
4.3	0	0.22	0	0.07	0	0.09	1	0.91
4.4	1	0.21	0	0.06	0	0.08	1	0.88
4.5	0	0.20	0	0.05	0	0.07	1	0.86
4.6	0	0.18	1	0.05	0	0.05	1	0.82
4.7	0	0.14	0	0.04	0	0.04	1	0.73
4.8	0	0.11	0	0.03	0	0.02	0	0.61
4.9	0	0.08	0	0.03	0	0.01	1	0.49
5	0	0.06	0	0.03	0	0.01	3	0.38
6	1	0.87	0	0.27	0	0.30	6	3.70
7	2	0.43	1	0.17	0	0.09	2	2.21
8	0	0.01	0	0.01	0	0.00	0	0.05
9	0	0.00	0	0.00	0	0.00	0	0.01
10	0	0.00	0	0.00	0	0.00	0	0.00
>20	0	0.00	0	0.00	0	0.00	1	0.00
Total	350	352.30	278	235.35	263	217.10	982	848.28

Table 6-10: EOC-11 As-Found vs. Recalculated Voltage Distribution Using DCPP POPCD and Cycle 11 VD Growth

Voltage Bin	DCPP POPCD with Cycle 11 VD Growth							
	SG 21 EOC-11		SG 22 EOC-11		SG 23 EOC-11		SG 24 EOC-11	
	As-Found	Projected	As-Found	Projected	As-Found	Projected	As-Found	Projected
0.1	0	0.17	0	0.30	0	0.13	0	0.18
0.2	21	4.20	13	6.17	17	3.03	14	4.08
0.3	66	16.23	50	15.02	42	11.49	91	16.91
0.4	59	37.51	45	29.45	58	27.44	135	44.75
0.5	51	56.18	47	37.43	39	37.69	139	78.00
0.6	36	56.53	31	37.67	28	33.88	106	99.79
0.7	34	49.97	27	30.79	19	27.26	94	107.59
0.8	21	35.74	11	22.01	19	18.28	81	93.60
0.9	11	22.13	18	15.13	3	10.29	60	71.64
1	5	13.98	7	10.14	4	6.81	33	50.27
1.1	11	11.09	7	7.07	4	5.79	22	35.97
1.2	4	8.95	5	5.03	7	5.29	26	27.77
1.3	11	7.60	5	3.60	6	4.75	20	23.78
1.4	2	6.07	1	2.77	1	3.88	18	21.43
1.5	4	4.33	1	2.17	3	3.16	12	20.18
1.6	0	3.01	0	1.57	3	3.03	16	18.20
1.7	1	2.15	2	1.23	1	2.87	16	15.66
1.8	1	1.73	1	1.21	1	2.15	12	12.97
1.9	2	1.33	0	0.98	2	1.65	10	10.61
2	0	0.98	2	0.73	1	1.49	9	8.76
2.1	0	1.01	0	0.63	1	1.16	1	7.73
2.2	0	1.10	0	0.48	0	0.79	2	7.02
2.3	1	0.92	0	0.32	1	0.53	6	6.38
2.4	0	0.60	1	0.22	0	0.46	8	5.81
2.5	0	0.42	1	0.14	0	0.48	3	5.32
2.6	0	0.25	0	0.08	0	0.37	3	4.62
2.7	0	0.22	0	0.04	0	0.30	3	4.00
2.8	1	0.36	0	0.03	0	0.38	2	3.70
2.9	2	0.46	0	0.11	1	0.35	4	3.19
3	0	0.48	0	0.18	0	0.25	3	2.69
3.1	0	0.34	0	0.16	1	0.17	2	2.53
3.2	0	0.22	0	0.14	0	0.12	1	2.41
3.3	1	0.16	0	0.10	0	0.09	2	2.30
3.4	0	0.26	0	0.06	0	0.06	3	1.88
3.5	1	0.36	1	0.03	0	0.04	1	1.42
3.6	0	0.28	0	0.02	0	0.03	1	1.29
3.7	0	0.19	0	0.01	0	0.10	0	1.22
3.8	0	0.12	0	0.01	0	0.24	2	1.13
3.9	0	0.08	0	0.00	0	0.23	0	1.10
4	0	0.06	0	0.00	0	0.16	0	1.12
4.1	0	0.07	0	0.00	1	0.11	1	1.08
4.2	0	0.09	0	0.00	0	0.09	2	1.23
4.3	0	0.15	0	0.02	0	0.07	1	1.53
4.4	1	0.35	0	0.06	0	0.05	1	1.53
4.5	0	0.45	0	0.11	0	0.03	1	1.37
4.6	0	0.37	1	0.16	0	0.02	1	1.23
4.7	0	0.26	0	0.17	0	0.01	1	1.12
4.8	0	0.18	0	0.16	0	0.01	0	1.04
4.9	0	0.12	0	0.13	0	0.01	1	0.99
5	0	0.09	0	0.09	0	0.00	3	0.90
6	1	0.43	0	0.19	0	0.01	6	4.08
7	2	1.75	1	0.98	0	0.02	2	2.14
8	0	0.12	0	0.01	0	0.01	0	0.21
9	0	0.00	0	0.00	0	0.00	0	0.01
10	0	0.00	0	0.00	0	0.00	0	0.00
>10	0	0.00	0	0.00	0	0.00	1	1.00
Total	350	352.20	278	235.32	263	217.08	982	848.50

Table 6-11: EOC-11 Projected vs. As-Found Using Cycle 10 VD Growth Rates

Comparison of 2R11 As-Found and Projected Voltages Using 2R10 Growth Rates									
Voltage Category	SG 2-1		SG 2-2		SG 2-3		SG 2-4		
	As-Found	Projected	As-Found	Projected	As-Found	Projected	As-Found	POPCD Projected	0.6 POD Projected
≤1v	304	283.51	249	191.75	229	177.07	753	589.55	446.26
>1v	46	68.80	29	43.59	34	40.02	229	258.71	345.45
>2v	10	12.95	5	6.24	5	5.61	68	59.87	99.26
>5v	3	1.31	1	0.45	0	0.39	9	5.96	13.93
All	350	352.31	278	235.35	263	217.09	981[(4)]	848.27	791.71

Notes:
1. Projected voltages are based on a recalculation of the 2R10 OA using the DCPP-specific POPCD and Cycle 10 voltage-dependent growth with statistically based breakpoints at 0.69v and 1.17v.
2. All calculations used composite SG Cycle 10 growth in each bin because of the small number of flaws that existed in the upper and middle bins.
3. <1 volt flaws do not significantly contribute to POB and leak rate total.
4. R44C45 in SG 2-4 was excluded from the as-found and projected distribution since the benchmark was performed to evaluate the methods for projections and as-found analyses excluding the limitations on predicting the large flaw.

Table 6-12: EOC-11 Projected vs. As-Found Using Cycle 11 VD Growth Rates

Comparison of 2R11 As-Found and Projected Voltages Using 2R11 Growth Rates									
Voltage Category	SG 2-1		SG 2-2		SG 2-3		SG 2-4		
	As-Found	Projected	As-Found	Projected	As-Found	Projected	As-Found	POPCD Projected	0.6 POD Projected
≤1v	304	292.63	249	204.11	229	176.29	753	566.82	415.24
>1v	46	59.58	29	31.22	34	40.80	229	281.69	376.47
>2v	10	12.33	5	4.84	5	6.74	68	86.36	131.94
>5v	3	2.31	1	1.18	0	0.05	9	7.64	18.30
>20	0	0	0	0	0	0	1	1.00	2.20
All	350	352.21	278	235.32	263	217.09	982	848.50	791.71

Notes:
1. Projected voltages are based on a recalculation of the 2R10 OA using the DCPP-specific POPCD and Cycle 11 voltage-dependent growth with statistically based breakpoints at 0.59v and 1.66v.
2. All calculations used SG-specific Cycle 11 voltage dependent growth except for the upper bin (>1.66v) in SG 2-3, where no indications existed. The SG 2-3 calculation used a composite growth rate from all SGs, excluding the 11.9 v/EFPY growth point from R44C45.
3. <1 volt flaws do not significantly contribute to POB and Leak rate total.

Table 6-13: EOC-11 Benchmark Analysis Results POB & Leak Rate Comparisons for DCPP POPCD and POD = 0.6

2R10 OA Analyses vs. 2R11 As-Found CM								
DCPP POPCD							POD 0.6	
SG	Calc. Description	POB	Leak Rate (gpm)	Differences Between OA and CM Results (OA-CM)			OA POB	OA Leak Rate (gpm)
				ΔPOB	ΔLeak Rate	Significance of Differences[1]		
2-1	2R11 As-Found	1.18E-03	6.82E-01					
2-1	Calc. with Cycle 10 VD Growth[6]	5.80E-04	6.19E-01	-6.0E-04	-6.3E-02	Insignificant: Both ΔPOB and ΔLR differences < 10% of reporting thresholds		
2-1	Calc. with Cycle 11 VD Growth[7]	1.08E-03	7.36E-01	-1.0E-04	+5.4E-02			
2-2	2R11 As-Found	5.66E-04	3.62E-01					
2-2	Calc. with Cycle 10 VD Growth[6]	2.92E-04	2.96E-01	-2.74E-04	-6.6E-02	Insignificant: Both ΔPOB and ΔLR differences < 10% of reporting thresholds		
2-2	Calc. with Cycle 11 VD Growth[7]	4.67E-04	3.50E-01	-9.9E-05	-1.2E-02			
2-3	2R11 As-Found	1.58E-04	2.11E-01					
2-3	Calc. with Cycle 10 VD Growth[6]	2.53E-04	2.64E-01	+9.5E-05	+5.3E-02	Insignificant: Both ΔPOB and ΔLR differences < 10% of reporting thresholds		
2-3	Calc. with Cycle 11 VD Growth[7]	1.73E-04	2.45E-01	+1.5E-05	+3.4E-02			
2-4	2R11 As-Found	3.84E-03[2]	3.21[2]					
2-4		2.38E-02[3]	3.72[3]					
2-4	Calc. with Cycle 10 VD Growth[6]	2.75E-03[2]	2.58[2]	-1.09E-03	-0.63	ΔPOB slightly significant, ΔLR insignificant. Review required.[4]	6.46E-03[2]	4.51[2]
2-4	Calc. with Cycle 11 VD Growth[7]	3.47E-03[2]	3.24[2]	-3.7E-04	+0.03	Insignificant: Both ΔPOB and ΔLR differences < 10% of reporting thresholds	9.97E-03[2]	5.67[2]
2-4		2.18E-02[3]	3.76[3]	-2.0E-03	+0.04	ΔPOB significant, ΔLR insignificant. Review required.[5]	5.06E-02[3]	6.49[3]

Notes:

1. Significant differences are defined as 10% of reporting thresholds or -1.0E-03 for POB and -1.05 gpm for SLB leakage (allowable limit of 10.5 gpm). A review of the analysis methods is required when these criteria are exceeded.
2. CM and OA results obtained excluding R44C45 from both analyses including exclusion from growth rates for OA.
3. CM and OA results include R44C45 in both analyses including growth rates for OA.
4. The differences between the CM and OA results can be attributed to the assignment of 10% NDE analyst variability uncertainties to indications > 2 volts in the CM analysis and to about a 5% increase in growth rates above about 0.6 BOC volts for Cycle 11.
5. Differences in the CM as-found calculations and the projected calculations utilizing cycle 11 actual growth rates are partially attributable to the NDE analyst uncertainties that are applied to the higher voltage indications at EOC conditions. By recalculating the EOC-11 as found conditions with the analyst uncertainty for indications >2 volts reduced to 5%, the CM POB is reduced to 2.23E-02, which leads to an insignificant ΔPOB of -5.0E-04. This result demonstrates the sensitivity of the as-found calculation to the application of the uncertainties in the Monte Carlo codes. The NDE uncertainties in the OA analyses are assigned to indications predominantly below the ARC repair limit for which the 10% NDE uncertainty was developed. In the CM analyses, an assignment of 10% NDE analyst variability uncertainties to indications > 2 volts is excessively conservative (see Section 4.5 and NUREG/CR-6791)
6. The 2R10 OA calculations with Cycle 10 VDG used growth rate breakpoints at 0.69v and 1.17v. SG 2-4 primarily dominates the growth rates in Cycle 10, and as such the curves used in the calculations were composite in all bins.
7. The 2R10 OA calculations with Cycle 11 VDG used growth rate breakpoints at 0.59v and 1.66v. The upper bin (>1.66v) for the SG 2-3 calculation used a Cycle 11 growth rate including indications from all steam generators except for R44C45 in SG 2-4. The other 'Cycle 11 Growth' runs used SG-specific growth.

Figure 6-1: As-found SG 2-1 and BOC-12 Voltage Distributions (POD 0.6)

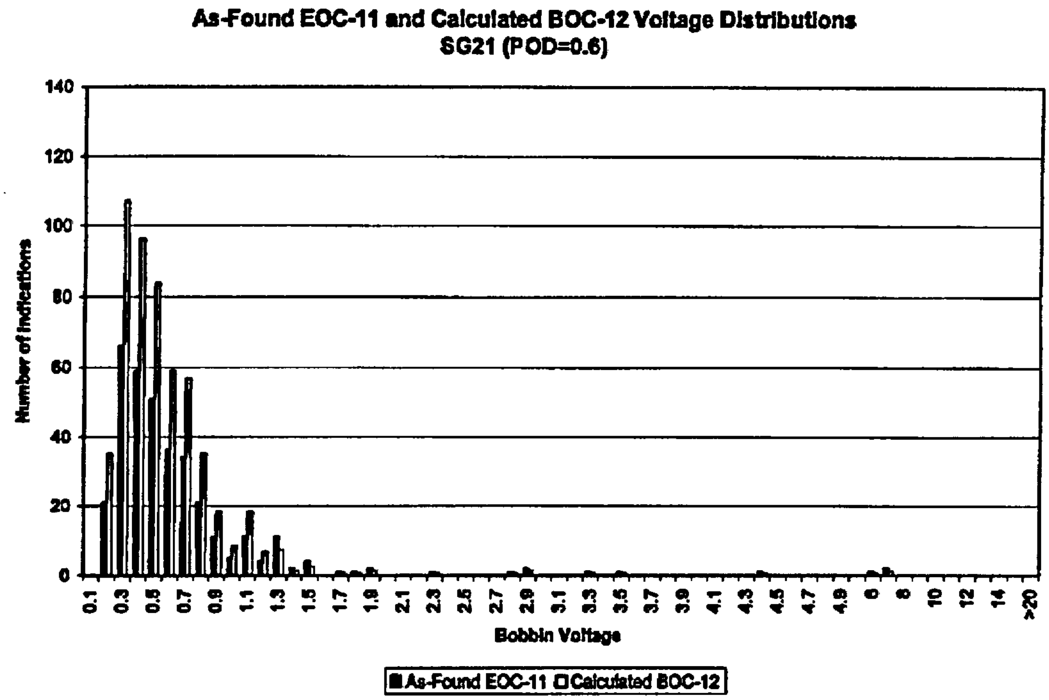


Figure 6-2: As-found SG 2-2 and BOC-12 Voltage Distributions (POD 0.6)

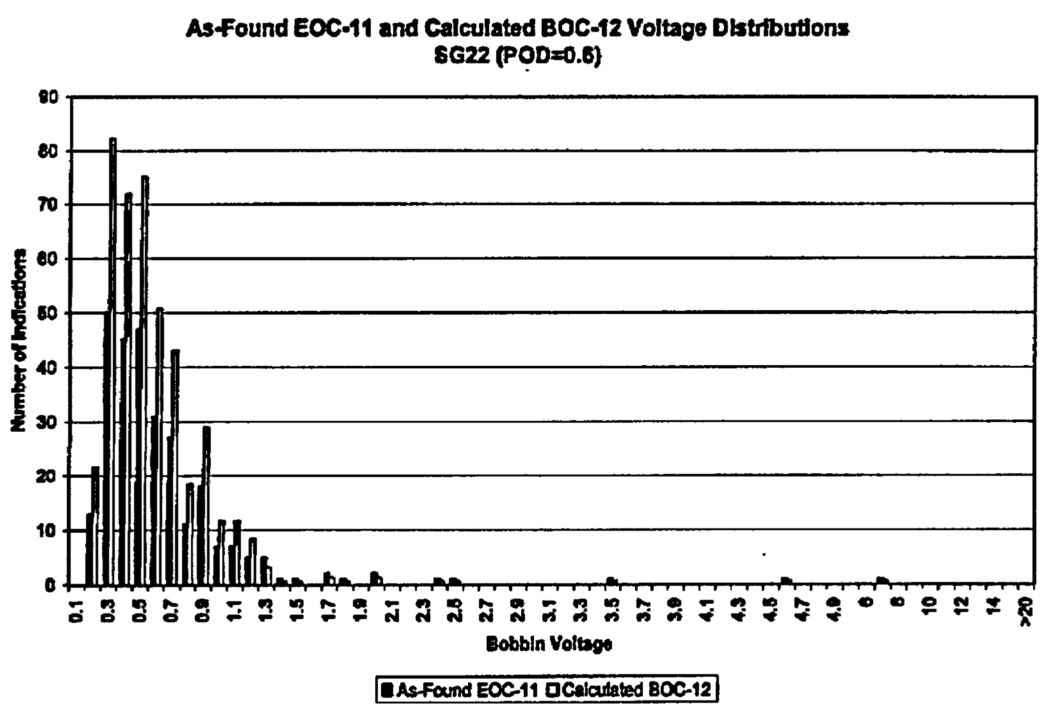


Figure 6-3: As-found SG 2-3 and BOC-12 Voltage Distributions (POD 0.6)

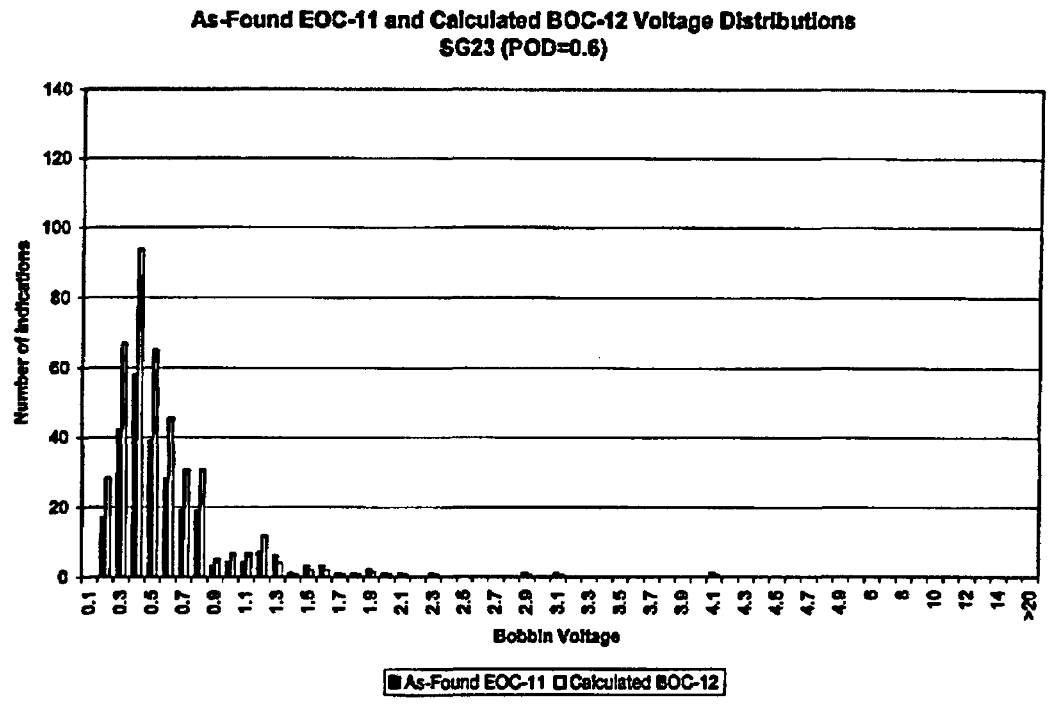


Figure 6-4: As-found SG 2-4 and BOC-12 Voltage Distributions (POD 0.6/1.0 for R44C45)

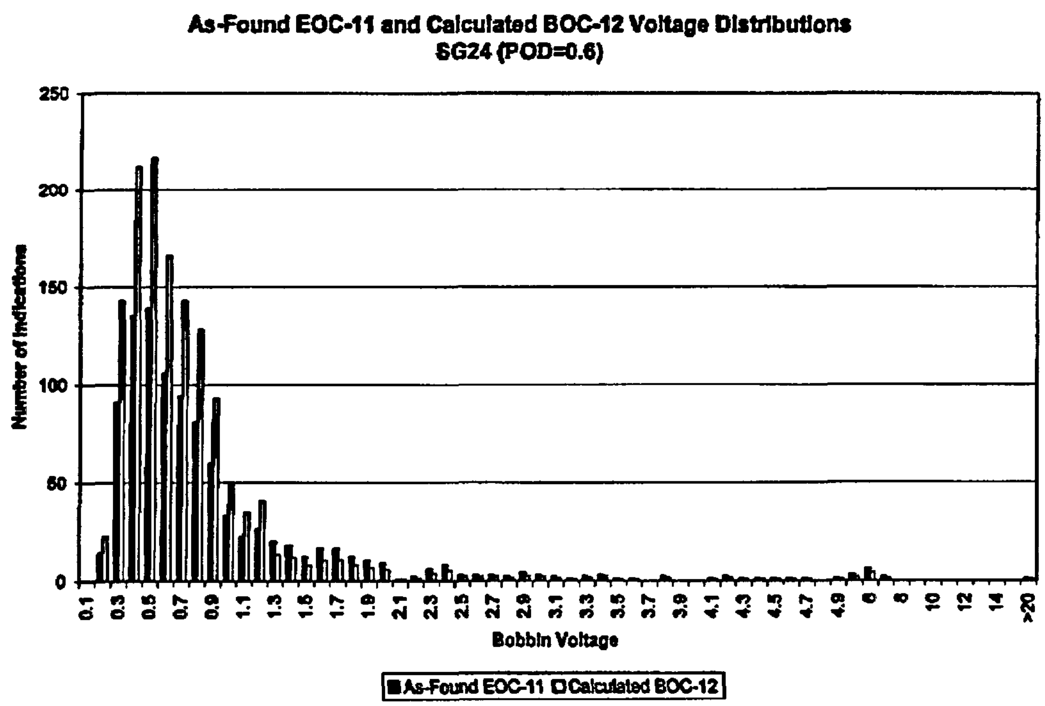


Figure 6-5: As-found SG 2-1 vs Projected Voltage Distributions from 2R10 OA

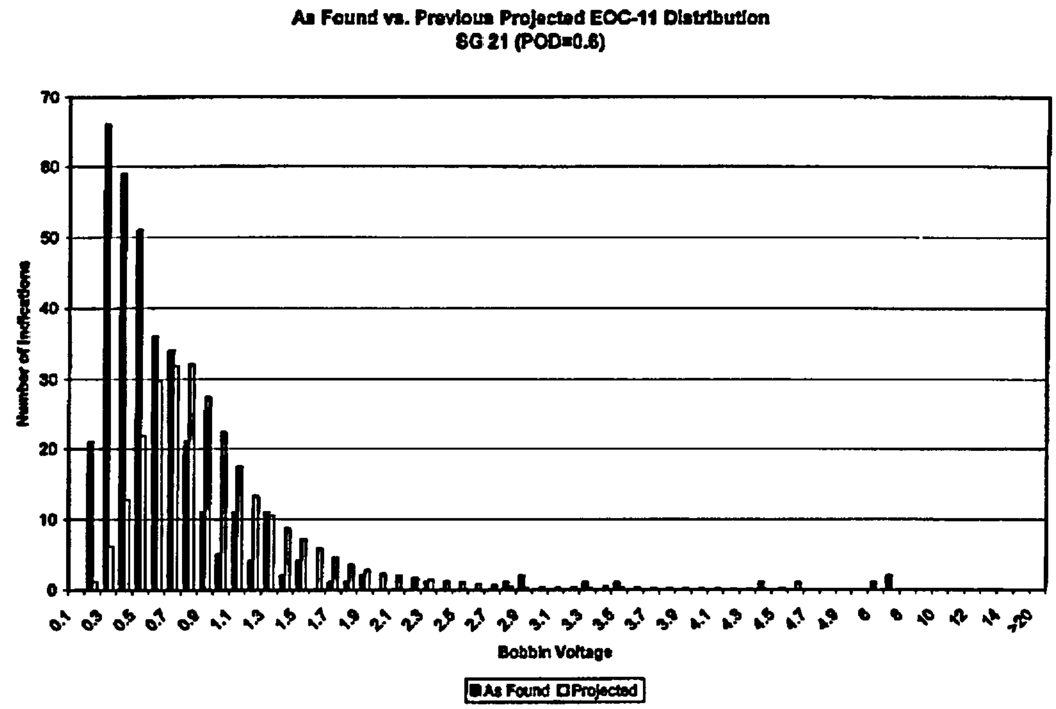


Figure 6-6: As-found SG 2-2 vs Projected Voltage Distributions from 2R10 OA

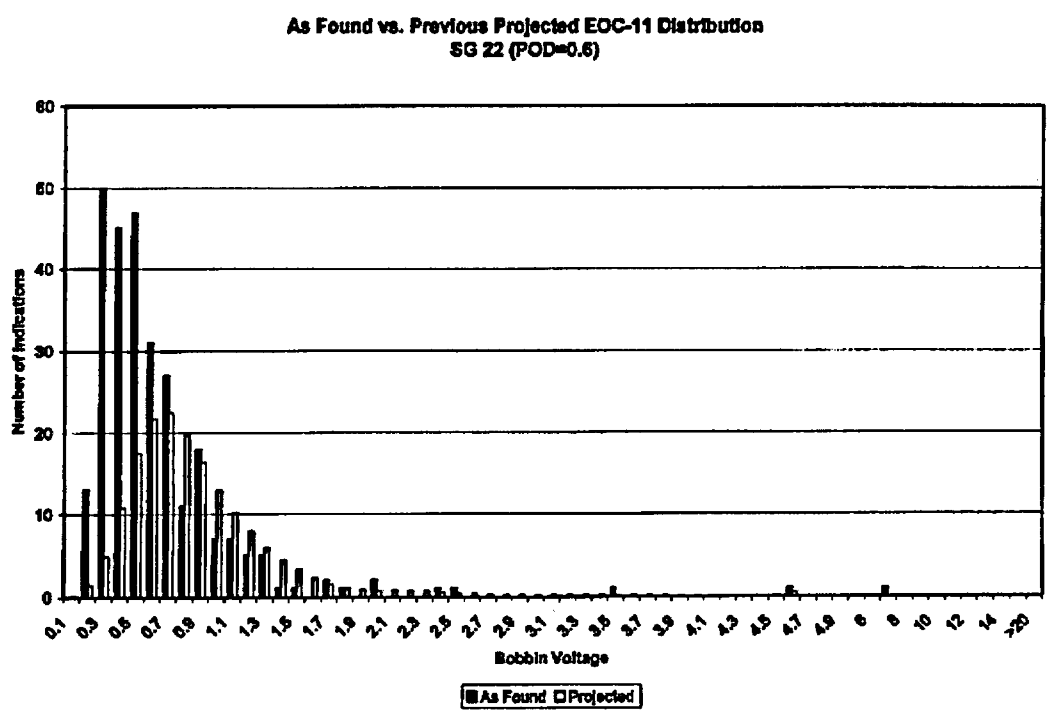


Figure 6-7: As-found SG 2-3 vs Projected Voltage Distributions from 2R10 OA

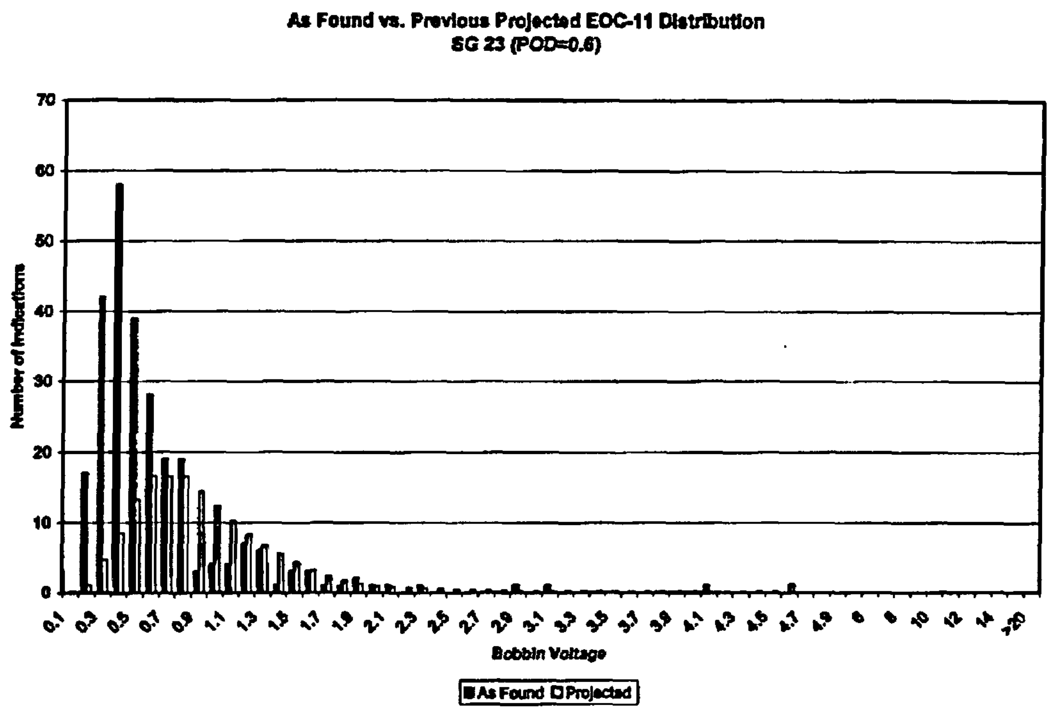


Figure 6-8: As-found SG 2-4 vs Projected Voltage Distributions from 2R10 OA

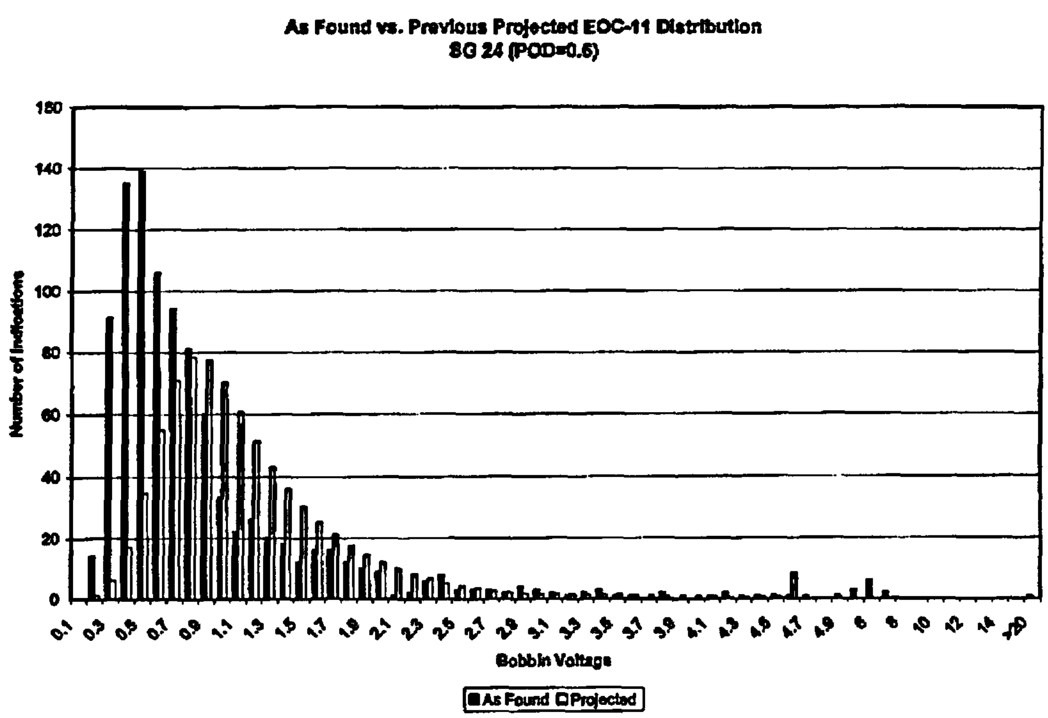
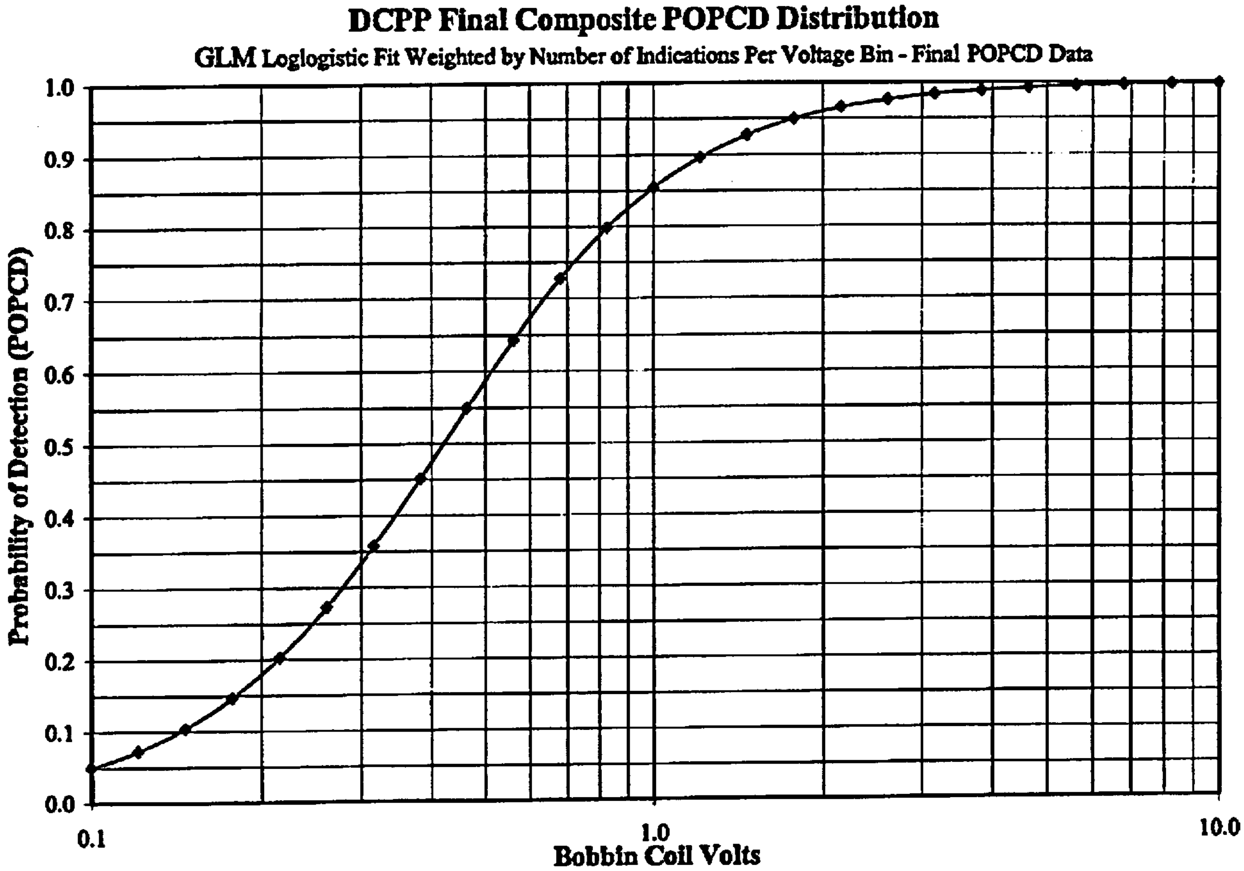


Figure 6-9: DCPP POPCD Log-logistic Fit of Composite Data



7.0 Tube Integrity Calculations for EOC-12

This section presents the results of analyses carried out to predict EOC-12 distributions at 1.54 EFPY, and EOC-12 leak rates and tube burst probabilities for postulated SLB conditions. Table 7-1 contains a matrix of calculations that were performed for DCPP-2 in support of this section. The results of each case are provided in subsequent Tables. Case 1 is the CM calculation, and the leak and burst results are reported in Table 7-2. Cases 2 through 5 vary the POD and growth rate method used in the calculations. Case 5 provides the results for full cycle operation, based on POPCD and VDG. Cases 6 to 8 provide sensitivity results to demonstrate the beneficial affects of preventive plugging at 1.2 volts that was performed in 2R11, as compared to the 2.0-volt GL 95-05 requirement. In all cases, SG 2-4 is the limiting SG, based on the population of indications that were detected at EOC-11. For all cases that used VDG, the distributions contained in Table 3-12 were utilized, and for all cases that used voltage independent growth the distributions in Table 3-11 were used. The middle bin VD growth contains a conservative assumption that the growth in it will increase by 10% for Cycle 12 operation.

7.1 Predicted EOC-12 Population Distributions

EOC-12 conditions were projected utilizing a POD of 0.6 and 1.0 for R44C45 with voltage independent growth (Case 2) and VD growth (Case 3), and these EOC-12 distributions are contained in Table 7-9. EOC-12 conditions were also projected utilizing the DCPP POPCD with voltage independent growth (Case 4) and VDG (Case 5), and these EOC-12 distributions are contained in Table 7-8. Figures 7-1 through 7-8 present the predicted EOC-12 distributions graphically for VDG and independent growth using both POD of 0.6 and 1.0 for R44C45 and DCPP POPCD. Table 7-10 provides a summary of indication populations for each of the eight projected EOC-12 voltage distributions. The differences between the projections will be evaluated in Section 7.3.

As expected, the EOC-12 populations differ considerably between using POD of 0.6 and 1.0 for R44C45 versus DCPP POPCD, as well as independent growth versus VD growth. The POD of 0.6 and 1.0 for R44C45 calculations predict a much higher number of high voltage indications than does the DCPP POPCD method, but the POPCD method predicts a much higher number of indications overall, due to the low POD in the lower voltage ranges. The VD growth projections show a larger number of high voltage indications at EOC-12 compared to the independent growth projections. The differences in total population at EOC-12 between the VDG and independent growth in the DCPP POPCD calculations are expected since the POD is a randomized term in the Monte Carlo simulations. A slightly different POD may occur for a given voltage bin between cases analyzed.

7.2 *Leak Rate and Tube Burst Probability Results for EOC-12*

7.2.1 POD of 0.6: Leak Rate and Tube Burst Probability for EOC-12

For POD of 0.6 and 1.0 for R44C45 calculations, both independent (Case 2) and VD growth (Case 3) were considered. As expected, the resulting POB and leak rate are much higher with voltage dependent growth (see Table 7-4) than with independent growth (see Table 7-3). Both calculated POB results exceed the reporting threshold of 1.0 E-2 during Cycle 12, and both leak rates meet the DCPP specific limit requirements. Utilizing a constant POD with a voltage dependent growth, although producing the most conservative results, is not a realistic way of assessing EOC-12 conditions. Further assessment of the differences projected at EOC-12 between VDG and voltage independent growth is provided in Section 7.3.

7.2.2 POPCD POD: Leak Rate and Tube Burst Probability for EOC-12

The results of the DCPP POPCD calculations in Cases 4 and 5 are provided in Tables 7-5 and 7-6 for voltage independent growth and VD growth, respectively. The independent voltage growth rate calculations produced more conservative POB and leak rate results than the VD calculations, with the voltage independent POB result exceeding the reporting threshold. Again, further assessment of these differences is provided in Section 7.3.

Sensitivity calculations for SG 2-4 were performed assuming that the normal 2.0-volt repair criterion was executed at EOC-11 in order to determine the benefit of the preventive plugging that was in fact performed (Cases 6, 7, 8). The leak rate and POB results of these three cases are provided in Table 7-7, and assessment of the results are provided in Section 7.3.

7.3 *Discussion of Voltage Dependent Growth and DCPP POPCD Results for Cycle 12 Operational Assessments of SG 2-4*

The intent of this evaluation is to assess the influence of DCPP POPCD and VDG on DCPP SG 2-4 EOC-12 SLB burst and leak rate projections. In particular, DCPP POPCD and VDG are applied to assess the benefits of preventive plugging below the 2.0-volt ARC repair limit. DCPP POPCD and VDG properly represent the voltage dependence of POD and growth and permit a true assessment of the benefits of preventive plugging to the 1.2-volt repair limit applied for Cycle 12.

The evaluation was performed for the limiting SG 2-4 at full cycle operation of 1.54 EFPY. For analyses applying POD of 0.6 and 1.0 for R44C45, the R44C45 growth rate is included in the analyses. The EOC-12 results for this assessment are given in Table 7-7 as pairs of results to facilitate comparisons and the following discussion. Some results are repeated between the different cases.

Cases 2 and 4 together with 6 and 7 compare POD 0.6 and 1.0 for R44C45 with DCPP POPCD for voltage growth independent of BOC volts. These Cases apply 1.2 and 2.0-volt repair limits to assess the influence of preventive plugging with voltage independent growth. The benefits of DCPP POPCD on POB are modest for these cases due to the low POPCD POD (less than 0.6) below about 0.5 volt in conjunction with the large voltage growth rate for R44C45 included in the analyses. About 40% of the SG 2-4 as-found indications are below 0.5 volt. The lower DCPP POPCD POD below 0.5 volt results in a larger number of low voltage indications than obtained with a POD of 0.6. Since voltage growth is postulated to be independent of BOC volts for these cases, the large growth is applied to the low voltage indications, which leads to significant contributions to burst and leakage that offset the benefits of POPCD at higher voltages. Due to these effects, very little benefit of preventive plugging is seen for these cases either with a POD of 0.6 and 1.0 for R44C45 or DCPP POPCD. Although POPCD provides the appropriate voltage dependence for POD, the assumption of voltage independent growth, in contrast to the actual voltage growth data, leads to fictitious conclusions on the benefits of preventive plugging.

Cases 7 and 8 compare voltage independent and VDG for DCPP POPCD analyses with an assumed 2.0-volt ARC repair limit. For the 2.0-volt repair limit, the use of VDG is seen to be more conservative than voltage independent growth. Similarly, Cases 2 and 3 compare voltage independent and VDG for POD of 0.6 and 1.0 for R44C45 analyses for the applied 1.2-volt ARC repair limit. Comparison of Case 3 with Case 2 shows that the use of VDG with POD of 0.6 and 1.0 for R44C45 is extremely conservative. Similar conservatism would be expected for applications of a POD of 0.6 with a 2.0-volt repair limit. In addition, Cases 6 and 8 compare the GL 95-05 reference analysis with POD of 0.6 and 1.0 for R44C45 and voltage independent growth with DCPP POPCD and VDG for a 2.0-volt repair limit. The POPCD analysis with VDG for this case is seen to be more conservative for POB (0.0383 versus 0.0280, while leakage is essentially no different). It is concluded that the use of VDG, including DCPP POPCD with VDG, is conservative for ARC analyses applied at the required 2.0-volt repair limit.

Cases 4 and 5 compare voltage independent and VDG for DCPP POPCD analyses with the DCPP-2 applied preventive repair limit at 1.2 bobbin volts. At the 1.2-volt repair limit, VDG is less conservative than voltage independent growth. This is due to the 1.2-volt repair limit being less than the lower voltage limit of 1.66 volts for the VDG upper growth bin. The largest growth rates occur in the upper voltage growth bin in which no detected indications were left in service at BOC-12 and the large growth rates are applied only to the small number of undetected indications based on DCPP POPCD above about 1.66 volt. Table 7-11 presents an "average" BOC-12 distribution for SG 2-4 estimated from DCPP POPCD from 100k trials compared to the calculated BOC-12 distribution using 0.6 and 1.0 for R44C45 POD. The differences between these BOC distributions above the 1.2-volt repair limit are significant, due to the POD differences. The number of flaws in the DCPP POPCD BOC-12 distribution >1.66 volts is less than about 4 indications, which also has a large affect on the EOC-12 results. The EOC-12 results for these cases is summarized in Table 7-10 for all SGs. Again, the differences between the use of VDG using a 1.2-volt repair limit versus the 2.0-volt repair limit can be seen by comparing the number of EOC-12 indications predicted >10 volts in SG 2-4. The intent of the preventive 1.2-volt repair limit was to plug the most probable indications having a potential for large voltage growth, and only the DCPP POPCD analyses with VDG properly reflect the benefits of preventive plugging.

Cases 8 and 5 shows the effects of the preventive repair at 1.2 volts based on DCPP POPCD and VDG. These two cases provide the best estimate of the true benefits of the 1.2-volt preventive repair limit. Preventive repair reduces the SLB burst probability from 0.0383 to 0.0055 and the SLB leak rate from 5.93 to 2.81 gpm at EOC-12.

The results of Table 7-7 show that VDG leads to more conservative operational assessment results than voltage independent growth when applied at the GL 95-05 repair limit of 2.0 volts with the POD of 0.6 and 1.0 for R44C45, or DCPP POPCD. For the required 2.0-volt repair limit, DCPP POPCD with VDG is more conservative than the GL 95-05 reference analysis for POD of 0.6 and 1.0 for R44C45 and voltage independent growth. Paragraph 2.b.2(2) of GL 95-05 implies that 'voltage independent growth should be applied when the conservatism of this approach continues to be supported by operating experience', which is not the case for DCPP-2 Cycles 10 and 11 operating experience. Therefore, VDG should be applied for DCPP-2 Cycle 12 analyses, even though less conservative results are calculated at EOC-12 compared to voltage independent growth, for the preventive repair limit of 1.2 volts. VDG and DCPP POPCD are essential to obtaining the best estimate of the true benefits of preventive plugging that occurred at 2R11.

Upon NRC approval of the use of POPCD for DCPP-2 Cycle 12, the operational assessments should be based on the application of POPCD with voltage dependent growth (i.e., Case 5 of Table 7-7).

7.4 Summary and Conclusions

Utilizing the methods described in this report, DCPP has estimated at EOC-12 the conditions in the Unit 2 SGs relative to axial ODSCC at TSP intersections. The results of the projections and calculations performed in this report demonstrate that this degradation mechanism can continue to be effectively managed and predicted during Cycle 12 using a voltage dependent POD (POPCD) and a voltage dependent growth rate strategy.

Table 7-1: DCPP Unit 2 2003 Outage (2R11) Summary of Tube Integrity Calculations Performed for Cycle 12

Case	POD	Growth	Cycle Length (EFPY)	Leak	POB	Repair limit
1	NA	NA	NA	All SGs	All SGs	CM Calc for As-found Conditions
2	0.6 + 1.0 for R44C45	Independent Growth	1.54	All SGs	All SGs	1.2 volts
3	0.6 + 1.0 for R44C45	VDG	1.54	All SGs	All SGs	1.2 volts
4	DCPP POPCD	Independent Growth	1.54	All SGs	All SGs	1.2 volts
5	DCPP POPCD	VDG	1.54	All SGs	All SGs	1.2 volts
6	0.6 + 1.0 for R44C45	Independent Growth	1.54	SG 2-4	SG 2-4	2.0 volt repair limit assumption
7	DCPP POPCD	Independent Growth	1.54	SG 2-4	SG 2-4	2.0 volt repair limit assumption
8	DCPP POPCD	VDG	1.54	SG 2-4	SG 2-4	2.0 volt repair limit assumption

Table 7-2: Case 1 - DCPP Unit 2 R11
Summary of Calculations of Leak Rate and Burst Probability at EOC-11
(As-found conditions appended by Lab Test Results)

	SG21	SG22	SG23	SG24
Number of DOS Plus AONDB (1)	350	278	263	981 (5)
Leak Rate (gpm) (2,3,4)	0.682	0.362	0.211	3.49 (5)
POB	1.18×10^{-3}	5.66×10^{-4}	1.58×10^{-4}	3.84×10^{-3} (5)
Reporting Threshold	1.0×10^{-2}		10.5 gpm	

Notes:
(1) Includes AONDB assigned bobbin voltages.
(2) The 95% Upper Confidence Limit (UCL) is based on the number of trials with one or more failures.
(3) Equivalent volumetric rate at room temperature.
(4) The calculated total leak rate reflects the upper 95% quantile value at an upper 95% confidence bound.
(5) For EOC-11 as-found conditions, the 21.5-volt flaw in R44C45 was removed from the distribution for Monte Carlo leak and burst calculations. The POB result reflects the fact that the indication did NOT burst at SLB conditions during lab testing. The 3.49 gpm leak rate result reflects the actual leak rate of the indication at SLB conditions (0.28 gpm) during the lab testing added to the calculation result of 3.21 gpm. R35C57 was conservatively retained in the EOC-11 distribution for leak and burst even though the indication did NOT burst at SLB conditions and leaked slightly during lab testing. .
(6) The reference leak limits (10.5 gpm for CM) considers contributions from other ARCs. Therefore other ARC Leak rates should be added to the results in this table to assess total leakage.

Table 7-3: Case 2 - Leak Rate and Burst Probability at EOC-12 for 500k Simulations Using 0.6 POD/1.0 for R44C45 and Independent Growth

Steam Generator	Number of Indications at EOC-12	Probability of Burst		SLB Leak Rate
		Best Estimate	95% UCL (1 or More Failures)	(gpm)
SG21	545	5.71×10^{-3}	5.89×10^{-3}	1.26
SG22	435	4.06×10^{-3}	4.21×10^{-3}	0.90
SG23	406	3.56×10^{-3}	3.70×10^{-3}	0.75
SG24	1371	2.50×10^{-2}	2.54×10^{-2}	5.15
Reporting Threshold			1.0×10^{-2}	10.5

(1) Exceeds 1.0×10^{-2} at ~1.00 EFPY into Cycle 12 (approximately April 2004).

Table 7-4: Case 3 - Leak Rate and Burst Probability at EOC-12 for 500k Simulations Using 0.6 POD/1.0 for R44C45 and VD Growth

Steam Generator	Number of Indications at EOC-12	Probability of Burst		SLB Leak Rate
		Best Estimate	95% UCL (1 or More Failures)	(gpm)
SG21	545	1.30×10^{-2}	1.33×10^{-2}	1.95
SG22	435	8.32×10^{-3}	8.53×10^{-3}	1.41
SG23	406	6.46×10^{-3}	6.65×10^{-3}	1.16
SG24	1371	7.91×10^{-2}	7.98×10^{-2} (1)	9.58
Reporting Threshold			1.0×10^{-2}	10.5

(1) Exceeds 1.0×10^{-2} at 0.53 EFPY into Cycle 12 (approximately October 2003).

Table 7-5: Case 4 - Leak Rate and Burst Probability at EOC-12 for 500k Simulations Using DCPP POPCD and Independent Growth

Steam Generator	Number of Indications at EOC-12	Probability of Burst		SLB Leak Rate
		Best Estimate	95% UCL (1 or More Failures)	(gpm)
SG21	857	6.82×10^{-3}	7.01×10^{-3}	1.11
SG22	650	5.21×10^{-3}	5.38×10^{-3}	0.88
SG23	647	5.11×10^{-3}	5.28×10^{-3}	0.85
SG24	1578	2.38×10^{-2}	2.42×10^{-2}	3.23
Reporting Threshold			1.0×10^{-2}	10.5

(1) Exceeds 1.0×10^{-2} at 1.13 EFPY into Cycle 12 (approximately May 2004).

Table 7-6: Case 5 - Leak Rate and Burst Probability at EOC-12 for 500k Simulations Using DCPP POPCD and VD Growth

Steam Generator	Number of Indications at EOC-12	Probability of Burst		SLB Leak Rate
		Best Estimate	95% UCL (1 or More Failures)	(gpm)
SG21	857	8.88×10^{-4}	9.60×10^{-4}	0.72
SG22	650	6.90×10^{-4}	7.54×10^{-4}	0.60
SG23	647	6.08×10^{-4}	6.69×10^{-4}	0.48
SG24	1578	5.35×10^{-3}	5.52×10^{-3}	2.81
Reporting Threshold			1.0×10^{-2}	10.5

Table 7-7: Comparisons of Leak Rate and Burst Probability at EOC-12 for SG 2-4

Case	POD	Growth	Repair Limit	SG 24 EOC-12	
				Leak	POB
2	0.6 +1.0 for R44C45	Voltage Independent	>1.2V	5.15	0.0254
4	DCPP POPCD	Voltage Independent	>1.2V	3.23	0.0242
6	0.6 +1.0 for R44C45	Voltage Independent	>2.0V	6.02	0.0280
7	DCPP POPCD	Voltage Independent	>2.0V	4.08	0.0267
7	DCPP POPCD	Voltage Independent	>2.0V	4.08	0.0267
8	DCPP POPCD	VDG	>2.0V	5.93	0.0383
2	0.6 +1.0 for R44C45	Voltage Independent	>1.2V	5.15	0.0254
3	0.6 +1.0 for R44C45	VDG	>1.2V	9.58	0.0798
6	0.6 +1.0 for R44C45	Voltage Independent	>2.0V	6.02	0.0280
8	DCPP POPCD	VDG	>2.0V	5.93	0.0383
4	DCPP POPCD	Voltage Independent	>1.2V	3.23	0.0242
5	DCPP POPCD	VDG	>1.2V	2.81	0.0055
8	DCPP POPCD	VDG	>2.0V	5.93	0.0383
5	DCPP POPCD	VDG	>1.2V	2.81	0.0055

Notes:

- Case 6 is referred to as the GL 95-05 reference case.
- Upon NRC approval of POPCD for DCPP-2 Cycle 12, the operational assessment should be based on Case 5.

Table 7-8: EOC-12 Projected Distributions (DCPP POPCD)

Voltage Bin	EOC-12 Projected Distributions with DCPP POPCD - Cycle 12 VDG vs. Independent Growth							
	SG 21		SG 22		SG 23		SG 24	
	VDG	Ind Growth	VDG	Ind Growth	VDG	Ind Growth	VDG	Ind Growth
0.1	1.01	1.12	0.63	0.69	0.82	0.90	0.43	0.48
0.2	20.58	22.66	13.12	14.45	16.19	17.84	9.83	11.19
0.3	68.85	65.13	45.90	43.93	52.40	49.06	47.92	46.87
0.4	125.52	111.48	88.47	78.83	92.41	82.59	122.55	109.33
0.5	155.41	136.83	112.90	99.56	119.29	105.15	201.58	174.29
0.6	134.93	119.81	104.06	92.25	104.40	92.61	238.96	204.16
0.7	103.43	95.14	81.38	74.46	82.68	75.36	219.77	190.75
0.8	70.84	74.63	57.02	59.01	54.78	56.27	173.17	167.69
0.9	43.55	54.46	35.47	43.08	33.18	40.15	121.07	138.54
1	27.67	40.13	22.71	32.24	20.14	28.78	79.97	110.45
1.1	19.24	30.09	15.91	24.91	13.34	20.90	55.01	87.37
1.2	14.32	22.01	12.02	18.72	9.69	15.17	41.64	68.02
1.3	11.74	16.16	9.83	13.80	7.89	11.44	34.76	51.63
1.4	9.74	11.71	8.16	10.01	6.50	8.41	31.57	38.57
1.5	7.91	8.22	6.69	6.95	5.27	6.08	28.27	28.02
1.6	6.37	6.24	5.43	5.11	4.22	4.71	23.83	20.56
1.7	5.19	4.77	4.42	3.87	3.43	3.57	19.62	15.80
1.8	4.18	3.57	3.58	2.88	2.75	2.73	16.12	12.49
1.9	3.14	3.07	2.73	2.42	2.09	2.38	12.62	10.38
2	2.39	2.53	2.10	2.02	1.62	1.90	9.49	8.86
2.1	2.00	1.98	1.72	1.57	1.34	1.54	7.29	7.20
2.2	1.93	2.16	1.60	1.63	1.31	1.68	6.48	6.42
2.3	1.76	2.03	1.43	1.58	1.18	1.49	6.37	6.07
2.4	1.50	1.68	1.24	1.30	1.00	1.31	6.24	5.17
2.5	1.36	1.67	1.15	1.28	0.88	1.29	6.12	4.74
2.6	1.18	1.58	0.99	1.23	0.76	1.17	5.59	4.74
2.7	0.95	1.51	0.82	1.15	0.61	1.15	4.69	4.56
2.8	0.80	1.42	0.77	1.09	0.60	1.07	3.84	4.21
2.9	0.78	1.16	0.79	0.92	0.60	0.88	3.65	3.46
3	0.85	0.97	0.78	0.76	0.63	0.74	3.83	2.92
3.1	0.75	0.95	0.68	0.72	0.54	0.71	3.42	2.69
3.2	0.67	0.86	0.61	0.66	0.45	0.62	3.05	2.50
3.3	0.70	0.69	0.60	0.54	0.44	0.52	3.18	2.18
3.4	0.57	0.48	0.48	0.40	0.37	0.36	2.77	1.79
3.5	0.38	0.37	0.35	0.30	0.25	0.28	1.98	1.39
3.6	0.30	0.64	0.28	0.46	0.19	0.48	1.31	1.61
3.7	0.30	0.75	0.26	0.56	0.19	0.53	1.19	2.08
3.8	0.32	0.64	0.26	0.49	0.21	0.50	1.29	1.96
3.9	0.33	0.56	0.27	0.44	0.21	0.43	1.28	1.73
4	0.30	0.52	0.25	0.40	0.19	0.39	1.20	1.60
4.1	0.25	0.52	0.22	0.39	0.16	0.38	1.08	1.62
4.2	0.18	0.59	0.17	0.43	0.12	0.45	0.88	1.65
4.3	0.22	0.58	0.19	0.44	0.13	0.43	1.05	1.53
4.4	0.31	0.56	0.24	0.43	0.19	0.42	1.42	1.36
4.5	0.29	0.43	0.24	0.34	0.19	0.32	1.31	1.16
4.6	0.28	0.31	0.24	0.24	0.17	0.24	1.20	0.87
4.7	0.29	0.29	0.24	0.23	0.18	0.21	1.29	0.62
4.8	0.23	0.31	0.20	0.24	0.15	0.23	1.12	0.54
4.9	0.20	0.27	0.18	0.21	0.12	0.20	1.03	0.61
5	0.23	0.18	0.19	0.15	0.14	0.14	1.16	0.53
6	0.55	0.33	0.49	0.28	0.39	0.23	3.27	1.25
7	0.06	0.01	0.05	0.00	0.05	0.00	0.43	0.04
8	0.02	0.00	0.01	0.00	0.01	0.00	0.11	0.01
9	0.01	0.00	0.00	0.00	0.00	0.00	0.03	0.00
10	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00
>10	0.02	0.46	0.02	0.35	0.01	0.35	0.16	1.62
Total	856.88	857.22	650.51	650.37	647.06	646.76	1578.46	1577.89

Table 7-9: EOC-12 Projected Distributions (POD 0.6/1.0 for R44C45)

Voltage Bin	EOC-12 Projected Distributions with POD 0.6 - Cycle 12 VDG vs. Independent Growth							
	SG 21		SG 22		SG 23		SG 24	
	VDG	Ind Growth	VDG	Ind Growth	VDG	Ind Growth	VDG	Ind Growth
0.1	0.18	0.20	0.11	0.12	0.15	0.16	0.07	0.08
0.2	4.34	4.78	2.86	3.15	3.30	3.64	2.26	2.57
0.3	18.48	18.43	12.95	13.07	13.60	13.43	14.20	14.83
0.4	43.94	40.14	32.47	29.77	31.92	29.57	48.66	45.04
0.5	67.71	60.30	51.28	45.84	53.16	47.35	99.56	87.75
0.6	78.05	68.65	62.03	54.62	61.64	54.22	148.36	126.90
0.7	72.20	64.75	58.48	52.35	57.82	51.25	164.19	141.51
0.8	56.09	58.32	46.08	47.16	43.22	43.43	144.81	141.60
0.9	38.69	48.27	32.08	38.76	28.97	34.89	112.58	131.54
1	26.45	37.69	22.26	31.24	18.72	26.24	82.29	114.73
1.1	19.44	29.04	16.57	25.11	13.12	19.50	61.33	95.46
1.2	15.60	22.45	13.36	19.81	10.28	14.97	48.81	77.18
1.3	13.56	17.34	11.50	15.21	8.92	11.85	42.34	61.03
1.4	11.86	13.36	9.91	11.40	7.85	9.38	39.70	47.81
1.5	10.16	10.05	8.43	8.24	6.79	7.30	37.11	37.19
1.6	8.67	7.50	7.16	5.92	5.83	5.65	33.04	29.16
1.7	7.28	5.67	5.98	4.38	4.96	4.40	28.69	23.57
1.8	5.97	4.27	4.91	3.30	4.13	3.50	24.53	19.64
1.9	4.68	3.35	3.88	2.63	3.32	2.86	20.23	16.74
2	3.65	2.73	3.04	2.20	2.65	2.40	16.29	14.57
2.1	3.01	2.21	2.47	1.81	2.21	2.01	13.33	12.56
2.2	2.75	1.90	2.19	1.59	2.03	1.75	11.79	10.84
2.3	2.49	1.75	1.97	1.49	1.86	1.56	11.10	9.72
2.4	2.18	1.52	1.76	1.31	1.62	1.38	10.65	8.65
2.5	1.99	1.39	1.64	1.21	1.43	1.21	10.27	7.69
2.6	1.74	1.32	1.44	1.13	1.25	1.08	9.43	7.12
2.7	1.44	1.26	1.23	1.03	1.03	1.00	8.15	6.68
2.8	1.26	1.22	1.07	0.96	0.89	0.93	6.76	6.29
2.9	1.27	1.13	1.03	0.86	0.86	0.84	6.17	5.67
3	1.32	1.03	1.04	0.74	0.90	0.74	6.32	5.04
3.1	1.19	0.96	0.93	0.66	0.82	0.67	5.87	4.56
3.2	1.06	0.90	0.85	0.60	0.70	0.61	5.36	4.19
3.3	1.06	0.81	0.83	0.52	0.68	0.55	5.41	3.78
3.4	0.89	0.69	0.68	0.45	0.59	0.46	4.83	3.35
3.5	0.65	0.58	0.53	0.37	0.43	0.38	3.74	2.90
3.6	0.54	0.56	0.43	0.35	0.35	0.36	2.82	2.63
3.7	0.54	0.61	0.40	0.40	0.35	0.40	2.59	2.70
3.8	0.55	0.58	0.41	0.39	0.36	0.41	2.75	2.68
3.9	0.57	0.53	0.44	0.38	0.38	0.38	2.83	2.52
4	0.54	0.49	0.44	0.36	0.37	0.35	2.84	2.35
4.1	0.48	0.47	0.42	0.34	0.35	0.33	2.77	2.26
4.2	0.41	0.47	0.37	0.33	0.32	0.33	2.57	2.24
4.3	0.44	0.46	0.40	0.35	0.34	0.33	2.79	2.16
4.4	0.54	0.45	0.45	0.34	0.41	0.33	3.28	2.02
4.5	0.52	0.43	0.44	0.33	0.40	0.30	3.21	1.89
4.6	0.49	0.36	0.44	0.28	0.36	0.26	3.08	1.72
4.7	0.49	0.32	0.43	0.25	0.36	0.21	3.14	1.51
4.8	0.42	0.31	0.37	0.23	0.31	0.19	2.89	1.33
4.9	0.39	0.29	0.34	0.21	0.27	0.18	2.73	1.28
5	0.44	0.25	0.35	0.19	0.29	0.15	2.86	1.22
6	2.36	1.25	1.69	0.74	1.61	0.43	16.37	7.31
7	1.50	0.76	1.09	0.36	1.07	0.04	10.17	2.61
8	1.02	0.38	0.43	0.19	0.37	0.01	5.17	0.87
9	0.58	0.11	0.30	0.05	0.13	0.00	2.58	0.27
10	0.40	0.03	0.19	0.01	0.02	0.00	1.36	0.08
>10	0.81	0.31	0.49	0.24	0.27	0.22	3.99	1.43
Total	545.35	545.35	435.34	435.35	406.38	406.38	1371.04	1371.05

Table 7-10: Comparison of VD versus Independent Growth and 1.2v versus 2.0v Repair Strategies

Comparison of 2R12 Projected Voltages Using VD Growth

Voltage Category	SG 2-1		SG 2-2		SG 2-3		SG 2-4		
	POPCD Projected	POD 0.6	POPCD Projected	POD 0.6	POPCD Projected	POD 0.6	POPCD Projected	POD 0.6	POPCD 2v RL
≤1v	751.80	406.13	561.66	320.61	576.29	312.50	1215.23	816.99	1236.19
>1v	105.09	139.22	88.86	114.73	70.77	93.87	363.23	554.04	486.25
>2v	20.87	38.34	17.99	29.99	13.97	26.00	90.30	201.97	162.49
>5v	0.65	6.67	0.57	4.18	0.47	3.48	4.01	39.64	16.69
>10	0.02	0.81	0.02	0.49	0.01	0.27	0.16	3.99	1.92
All	856.88	545.35	650.51	435.34	647.06	406.38	1578.46	1371.04	1722.45

Comparison of 2R12 Projected Voltages Using Independent Voltage Growth

Voltage Category	SG 2-1		SG 2-2		SG 2-3		SG 2-4			
	POPCD Projected	POD 0.6	POPCD Projected	POD 0.6	POPCD Projected	POD 0.6	POPCD Projected	POD 0.6	POPCD 2v RL	POD 0.6 2V RL
≤1v	721.39	401.51	538.50	316.10	548.71	304.18	1153.76	806.56	1174.56	827.74
>1v	135.82	143.84	111.88	119.25	98.05	102.20	424.13	564.49	547.34	687.30
>2v	27.45	28.08	21.20	21.04	20.76	20.41	82.43	142.14	125.48	185.27
>5v	0.80	2.84	0.63	1.59	0.58	0.71	2.92	12.57	4.03	13.69
>10	0.46	0.31	0.35	0.24	0.35	0.22	1.62	1.43	1.77	1.58
All	857.22	545.35	650.37	435.35	646.76	406.38	1577.89	1371.05	1721.90	1515.05

Table 7-11: Estimated BOC-12 Distribution for SG 2-4 Using POPCD

Voltage Bin	As-Found EOC-11	DCPP POPCD	Repaired Tubes	Calculated BOC-12	BOC-12 POD 0.6
0.1	0		0		
0.2	14	129.66	1	128.66	22.33
0.3	91	355.35	8	347.35	143.67
0.4	135	332.1	13	319.1	212
0.5	139	260.44	15	245.44	216.67
0.6	106	167.47	11	156.47	165.67
0.7	94	132.76	13	119.76	143.67
0.8	81	105.94	6	99.94	129
0.9	60	74.32	7	67.32	93
1	33	39.27	5	34.27	50
1.1	22	25.41	2	23.41	34.67
1.2	26	29.35	3	26.35	40.33
1.3	20	22.17	20	2.17	13.33
1.4	18	19.67	18	1.67	12
1.5	12	12.96	12	0.96	8
1.6	16	17.12	16	1.12	10.67
1.7	16	16.99	16	0.99	10.67
1.8	12	12.66	12	0.66	8
1.9	10	10.49	10	0.49	6.67
2	9	9.4	9	0.4	6
2.1	1	1.04	1	0.04	0.67
2.2	2	2.07	2	0.07	1.33
2.3	6	6.2	6	0.2	4
2.4	8	8.24	8	0.24	5.33
2.5	3	3.08	3	0.08	2
2.6	3	3.08	3	0.08	2
2.7	3	3.07	3	0.07	2
2.8	2	2.04	2	0.04	1.33
2.9	4	4.08	4	0.08	2.67
3	3	3.06	3	0.06	2
3.1	2	2.03	2	0.03	1.33
3.2	1	1.02	1	0.02	0.67
3.3	2	2.03	2	0.03	1.33
3.4	3	3.04	3	0.04	2
3.5	1	1.01	1	0.01	0.67
3.6	1	1.01	1	0.01	0.67
3.7	0		0		
3.8	2	2.02	2	0.02	1.33
3.9	0		0		
4	0		0		
4.1	1	1.01	1	0.01	0.67
4.2	2	2.02	2	0.02	1.33
4.3	1	1.01	1	0.01	0.67
4.4	1	1.01	1	0.01	0.67
4.5	1	1.01	1	0.01	0.67
4.6	1	1.01	1	0.01	0.67
4.7	1	1.01	1	0.01	0.67
4.8	0		0		
4.9	1	1.01	1	0.01	0.67
5	3	3.02	3	0.02	2.00
6	6	6.03	6	0.03	4
7	2	2.01	2	0.01	1.33
8	0		0		
9	0		0		
10	0		0		
11	0		0		
12	0		0		
13	0		0		
14	0		0		
15	0		0		
>20	1	1.0003	1	0.0003	0
Total	982	1842.8	265	1577.80	1371.03

Figure 7-1: SG 2-1 EOC-12 Projected Voltage Distributions Using VDG

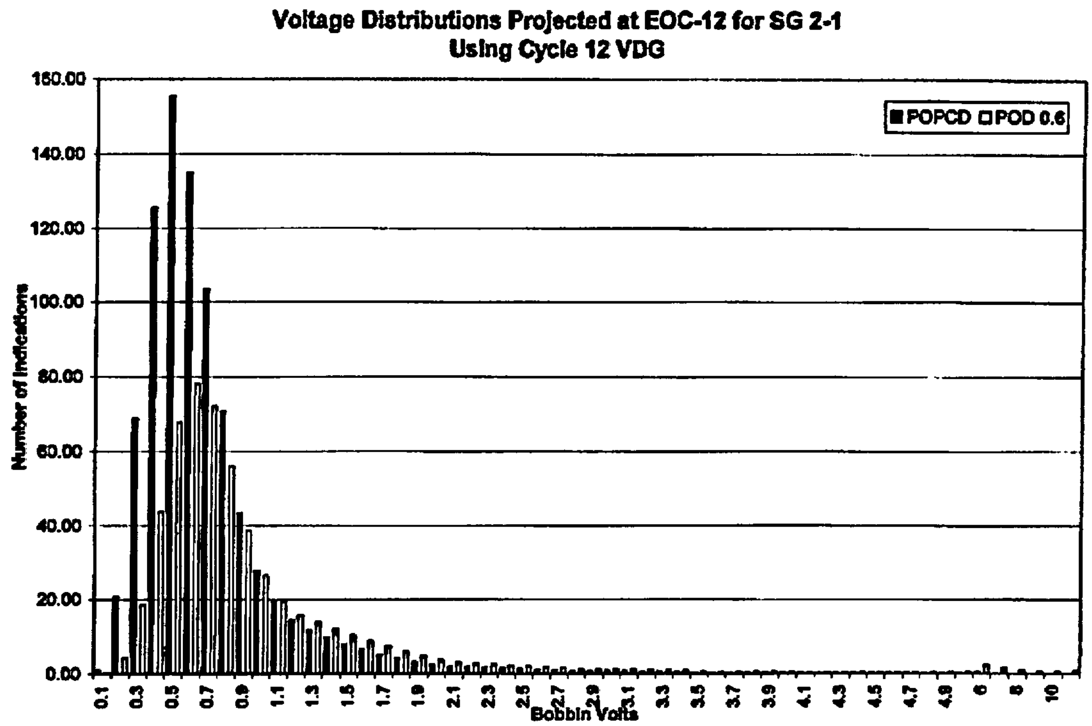


Figure 7-2: SG 2-1 EOC-12 Projected Voltage Distributions Using Independent Growth

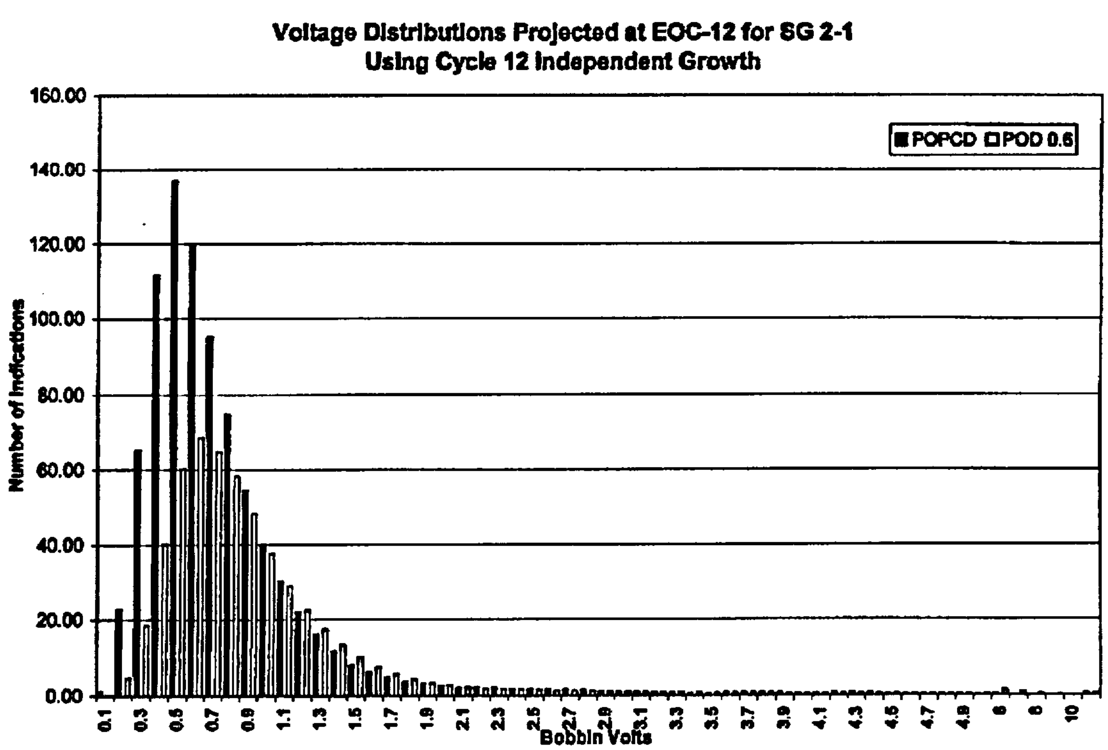


Figure 7-3: SG 2-2 EOC-12 Projected Voltage Distributions Using VDG

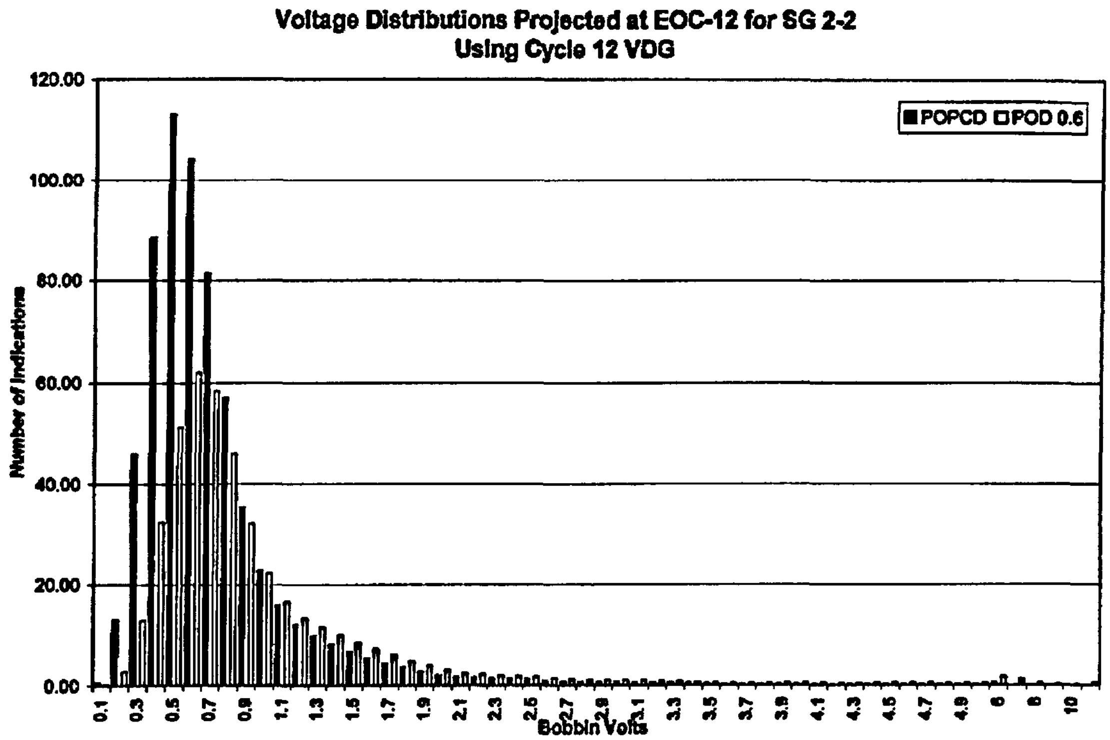


Figure 7-4: SG 2-2 EOC-12 Projected Voltage Distributions Using Independent Growth

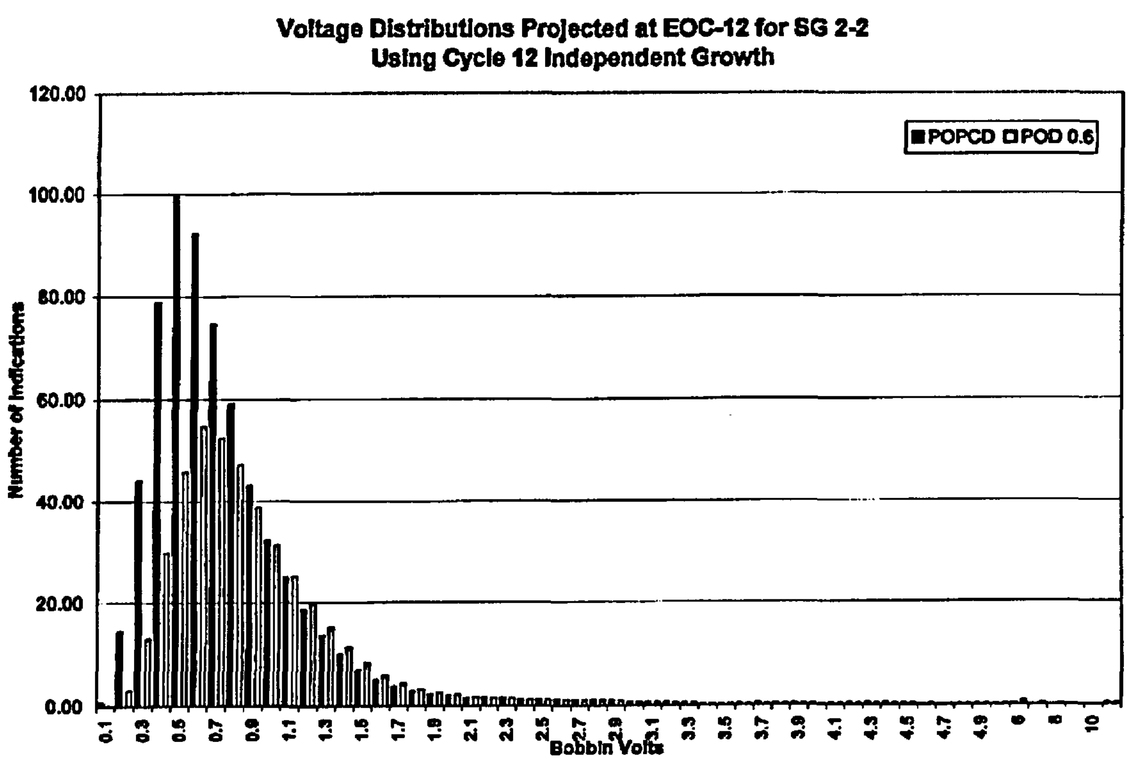


Figure 7-5: SG 2-3 EOC-12 Projected Voltage Distributions Using VDG

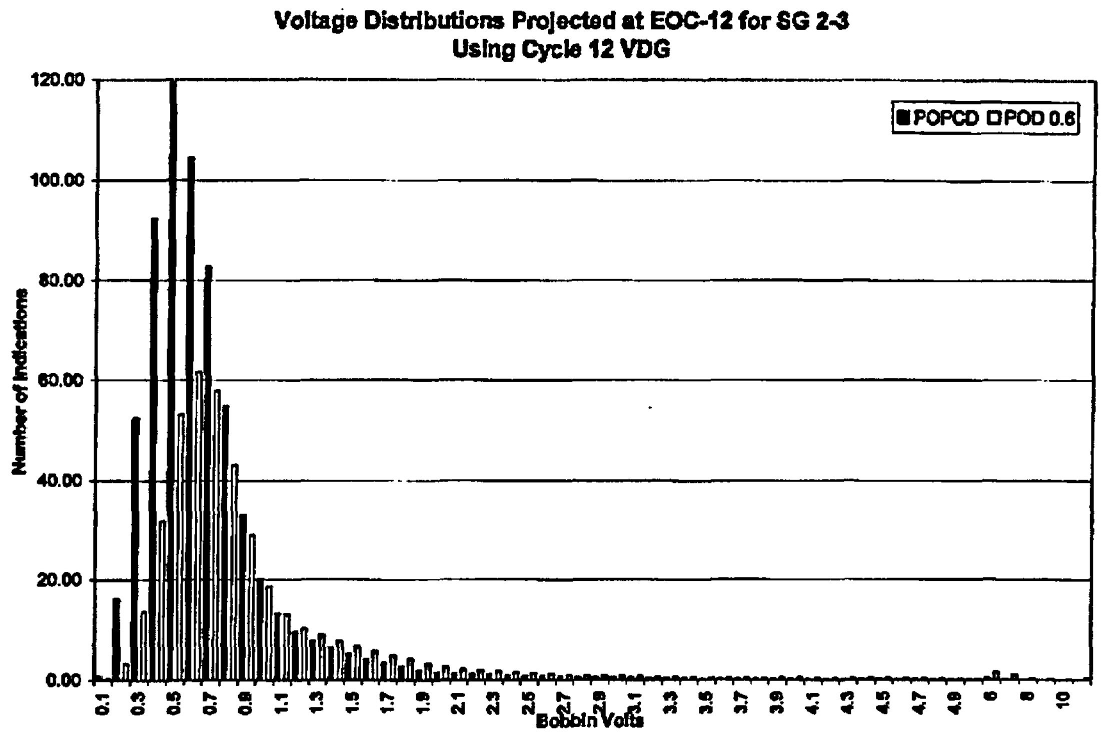


Figure 7-6: SG 2-3 EOC-12 Projected Voltage Distributions Using Independent Growth

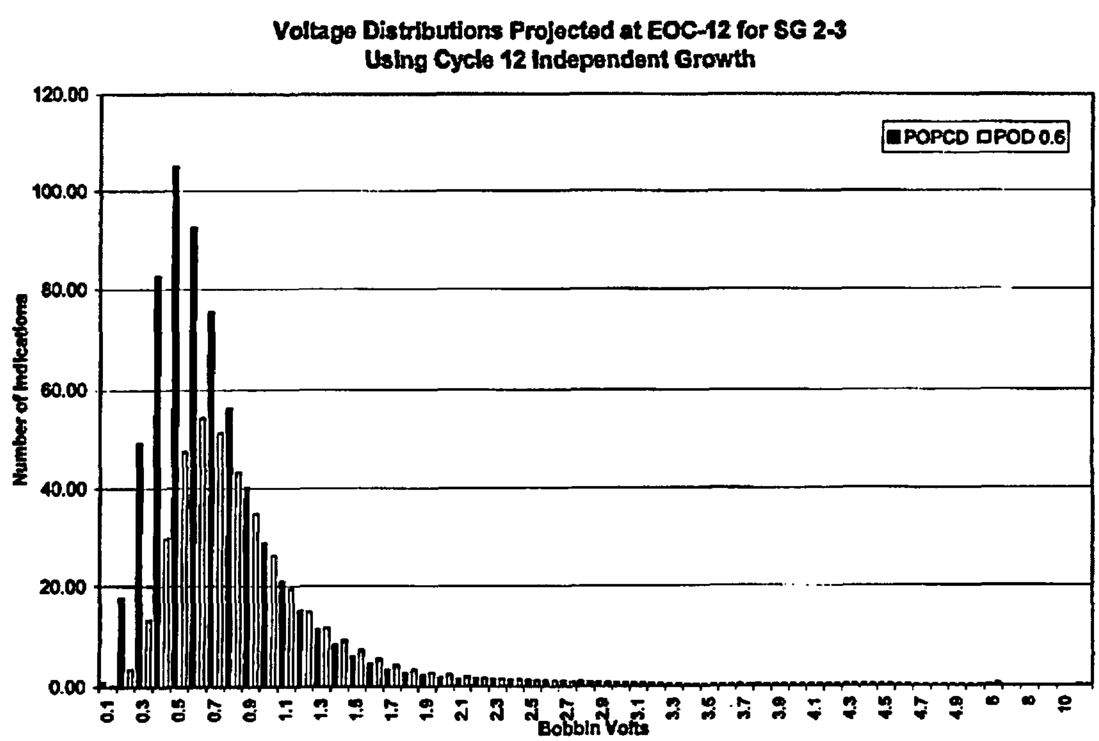


Figure 7-7: SG 2-4 EOC-12 Projected Voltage Distributions Using VDG

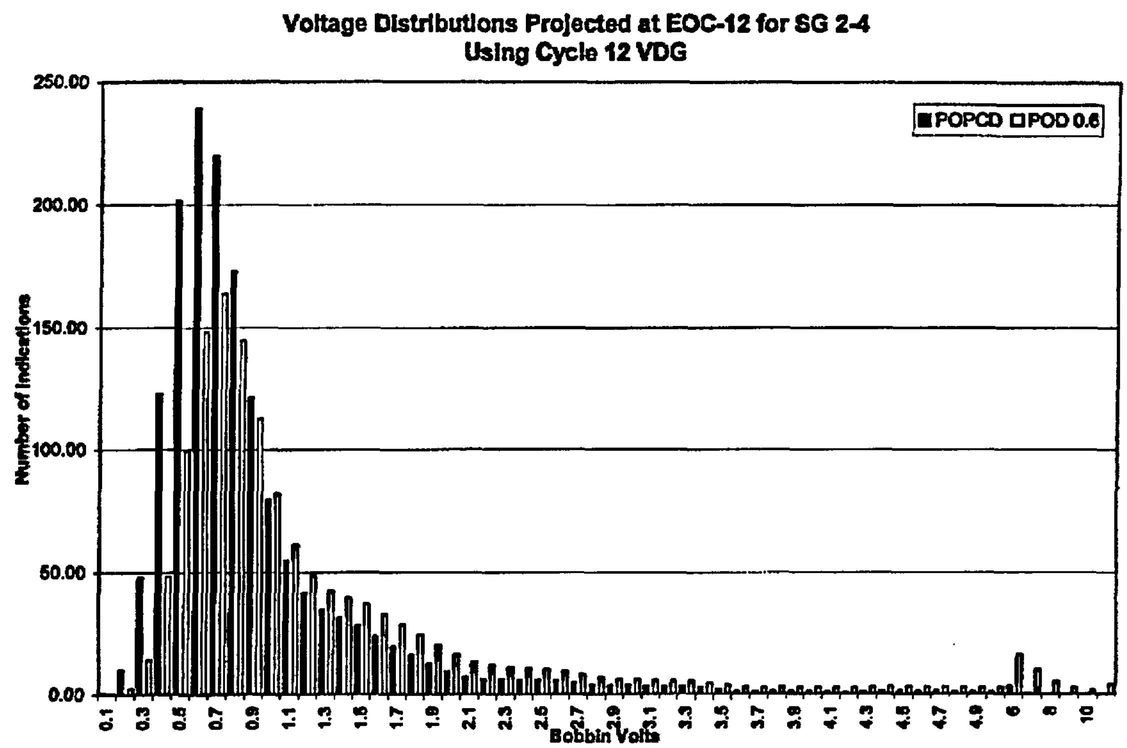
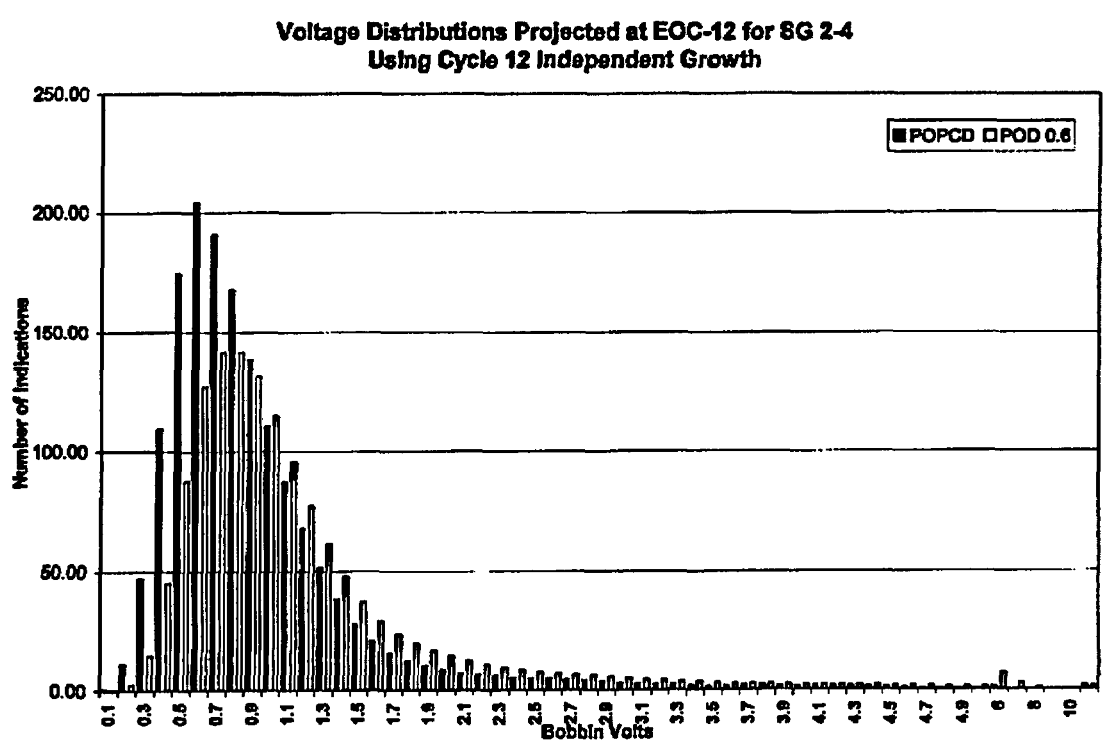


Figure 7-8: SG 2-4 EOC-12 Projected Voltage Distributions Using Independent Growth



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SPECIAL REPORT 03-02

ATTACHMENT 1 TO ENCLOSURE 4

WESTINGHOUSE REPORT
"COMPARISON OF DIABLO CANYON 2 DATA WITH EXISTING ARC CORRELATIONS"
(UPDATE OF ODSCC DATABASE FOR 7/8 INCH DIAMETER TUBES)

Comparison of Diablo Canyon 2 Data with Existing ARC Correlations

1.0 Comparison of Additional Data with Existing ARC Correlations

This document reports on the evaluations performed using the results of leak rate and burst testing of the tube sections which were removed from Diablo Canyon Unit 2 in 2003 (SG 4, R35C57 and R44C45, TSPs 1 and 2). The destructive examination of the tubes was performed by Framatome Advance Nuclear Products (FANP) in Lynchburg, Virginia. A draft of the examination was provided to Westinghouse as Reference 1. The results from the leak tests of the indications were obtained from Reference 2 and the results from the destructive examinations, i.e., burst and tensile test results, were obtained from Reference 3. Bobbin amplitudes for the indications were obtained from Reference 4. The Diablo Canyon 2 pulled tube data germane to the alternate repair criteria (ARC) correlations, the material properties, leak rate and burst pressure characteristics, and the ODSCC indications bobbin amplitudes for ARC applications, are listed in Table 1. The reported leak test values result from adjusting the test data to reflect the pressure and temperature conditions of interest relative to the conditions that existed at the time the actual measurement was taken. The results from the burst and leak tests were compared to the database of similar test results for 7/8" outside diameter steam generator tubes. In addition, the effect of including the new test data in the reference database on the correlations used for the evaluation of outside diameter stress corrosion cracking (ODSCC) indications at tube support plate (TSP) elevations was evaluated. In summary, the test data are consistent with the database relative to the burst pressures, and the probability of leak as a function of the bobbin amplitude. One of the indications exhibited significant leakage relative to that expected at postulated steam line break (SLB) conditions, leading to a meaningful effect on the ODSCC leak rate correlations as well as nontrivial effect on the probability of leak (POL) correlation. The comparisons and evaluations are discussed in the following sections.

The reference database for comparison consisted of the data reported in Reference 5, the most recent addendum to the original ODSCC ARC report of Reference 6. Addendum 5 contains a complete listing of the current database, inclusive of prior addenda. It is noted that there were no leak rate data for 7/8" diameter tubes added to the database by Addenda 3 and 4; leak rate data from two plants were added to the database as documented in Addendum 5. The examination of the tube sections removed from Diablo Canyon 2 adds two data points to each of the regression analyses, burst pressure, probability of leak, and leak rate as a function of bobbin amplitude.

2.0 Suitability for Inclusion in the Database

The report information on the destructive examinations of the tube sections was reviewed relative to the EPRI guidelines for inclusion/exclusion of tube specimen data in the ARC database. This review revealed no morphology or other information that would lead to a conclusion that the data should not be included in the database. Therefore, the resulting correlations should be considered applicable to the use of ARC for indications in 7/8" diameter tubes in Westinghouse SGs. As previously noted, the results from the leak tests were adjusted for use in the database. The leak rate values reported in Table 1 reflect the results of the adjustments to match the conditions used for the rest of the database.

3.0 Burst Pressure versus Bobbin Amplitude

The result from burst tests, performed on both tube specimens which exhibited a non-zero bobbin amplitude at a TSP elevation location, were considered for evaluation. The measured burst pressures of the Diablo Canyon 2 tube specimens are depicted on Figure 1 and Figure 2 relative to the burst pressure correlation developed using the Reference 5 database. Figure 1 illustrates the results relative to a 90% tolerance band expected for future test results. The following observations are apparent from an examination of that figure:

1. A visual examination of the data relative to the EPRI database indicates that the measured burst pressures fall within the scatter band of the reference data.
2. The data points for both of the indications fall within the 95% confidence band for 90% of the population about the regression line (5% in each tail), hence no statistical anomaly is indicated.

The net result is that the visual examination of the plot of the data indicates that there is no significant departure from the reference database. Based on the placement of the new data it may be judged that there would be no significant effect on the analysis of the residuals of the regression; either on the scatter plot of the residuals as a function of the predicted burst pressures or on the normal probability plot of the residuals.

Since the Diablo Canyon 2 burst pressure data were not indicated to be from a separate population from the reference data, the regression analysis of the burst pressure on the common logarithm of the bobbin amplitude was repeated with the additional data included. A comparison of the regression results obtained by including these data in the regression analysis is provided in Table 2. Regression predictions obtained by including these data in the regression analysis are also shown on Figure 2. A summary of the changes is as follows:

1. Intercept — The intercept of the burst pressure, P_B, as a linear function of the common logarithm of the bobbin amplitude regression line is decreased by 0.1%, or about 8 psi. This has the effect of decreasing the predicted burst pressure as a function of the bobbin amplitude for small amplitudes. Although there is a tendency to decrease the value of the structural limit slightly, an examination of the figure reveals that the practical effects of the change are negligible.

2. Slope — The absolute slope of the regression line is increased by 0.7%, i.e., the slope is steeper with the additional data. This has the effect of decreasing the burst pressure as a function of bobbin amplitude for large indications. As with the change in the intercept, the tendency is to decrease the value of the structural limit, but the practical effect of the slope change is negligible.

3. Standard Error — There is an decrease in the standard error of the residuals of 0.4%. The effect of this change is reflected in a slightly smaller deviation of the 95% prediction line from the regression line, leading to a tendency to decrease the calculated value of the structural limit and insignificant changes in the probability of burst for a given voltage level. The tendency to increase the structural limit does not compensate fully for the decrease effected by changes in the intercept and slope.

The net effect of the changes on the 2560 psi differential pressure SLB structural limit (found as $1.4 \cdot \Delta P$), using 95%/95% lower tolerance limit material properties, is to decrease it by 0.2 V (to 7.5 V). The

corresponding change on the 2405 psi structural limit is a 0.2 V reduction (to 9.5 V). The decrease of the intercept and slope and the increase in the standard error leads to small changes in the expected probability of burst. Given the relatively small change in the structural limit, the change in the probability of burst would also be expected to be small. Predicted values of the probability of burst of a single indication as a function of the bobbin amplitude are illustrated on Figure 3. The probability of burst is reduced slightly up to an amplitude of about 1.0 V. Beyond that value the probability of burst is increased by a maximum of 8% at an amplitude of 12 V, beyond the effective range of interest.

4.0 Probability of Leak

The Diablo Canyon 2 data were examined relative to the reference correlation for the POL as a function of the common logarithm of the bobbin amplitude. Figure 4 illustrates the Diablo Canyon 2 data relative to the reference correlation. The lower amplitude specimen had a calculated POL of 52% and it leaked. The POL for the higher amplitude indication was calculated to be 0.99 and the indication leaked. There is no implication of irregular results, i.e., outlying behavior is not indicated.
In order to assess the quantitative effect of the new data on the correlation curve, the database was expanded to include the two Diablo Canyon 2 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 regression parameters with those for the reference database is shown in Table 3. These results indicate:

1. Intercept — A 1.0% reduction in the absolute value of the *logistic* intercept parameter. Since the intercept is negative, this increases the intercept slightly.

2. Slope — A 1.2% increase in the *logistic* slope parameter.

3. Variance/Covariance — The values of the elements of the covariance matrix of the parameters changed from 1.6 to 3%. Examination of Figure 4 indicates that there is a very slight increase in the POL in the range of about 1.5 to 20 V. However, the POL is of secondary importance in determining the total estimated leak rate and the effect on predicted 95th percentile values would be expected to be small.

4. Mean Square Error — The mean square error (deviance divided by number of degrees of freedom) increased by 2.4%. The deviance increased, however this is expected when data is added to the database because the deviance is akin to the error sum of squares. The Pearson standard deviation increased slightly from 57.9 to 59.4%. The ideal value for this indicator is unity, hence the change is insignificant.

In order to confirm the judgment that the changes are not significant, the reference correlation and the new correlation were also plotted on Figure 5 and Figure 6. The predicted POL for an indication with an amplitude of 0.1 V decreases by about 3%, increases by 8% for amplitudes slightly less than 2 V, increases by about 0.5% at 10 V, and the change is essentially nil at 20 V, see Figure 6. As noted, when the total leak rate is determined using the leak rate to bobbin volts correlation, the result is usually quite insensitive to the form of the POL function. So, the effect of the changes in the parameter values and variances would be expected to be small or immaterial relative to the calculation of the 95% confidence bound of the total leak rate from a SG.

5.0 Leak Rate vs. Bobbin Amplitude

The test leak rate values are listed in Table 1 for the tested specimens. The leak rate tests were performed at ambient conditions and the results adjusted to postulated accident conditions using the methodology described in Appendix B of Reference 6. The effect of the test results on the correlation parameters of the log leak rate to log bobbin voltage are listed in Table 4 for a differential pressures of 2560 and 2405 psi respectively. The inclusion of the Diablo Canyon data tends to reverse the effect of data included for the Addendum 5 update to the database, where two indications leaked more than expected based on the previous regression analysis. The changes due to the additional data are as follows (described for two values of the differential pressure associated with a postulated steam line break event):

1. Intercepts — The intercepts of the regression equations decreased in absolute value by 144 and 24% for postulated SLB event differential pressures of 2560 and 2405 psi respectively.

2. Slopes — The slopes of the regression equations increased by 16 and 14% for differential pressures of 2560 and 2405 psi respectively.

3. Standard Error Values — The standard deviations of the log leak rate prediction errors as a function of the log bobbin amplitude were essentially unchanged.

4. *p* Value — The one-sided *p* value for the correlation at a differential pressure of 2560 psi decreased from 7.6% to 4.3%, while the change for a ΔP of 2405 psi was from 2.3 to 1.0%. In other words, the one-sided 95% confidence interval for the population slope for the correlation of log leak rate to log bobbin amplitude does not include zero for either differential pressure of interest.

Figure 7 illustrates the results from the tests of the leaking specimens relative to the database for a differential pressure of 2560 psi. Figure 8 provides a similar illustration for a differential pressure of 2405 psi. Both figures illustrate the effect of the added data points on their respective fitted regression lines (the median of the log-normal distribution) and on the expected leak rate (the mean of the log-normal distribution). The net effect of adding the results is a decrease in the predicted leak rates for bobbin amplitudes up to about 10 V, regardless of the differential pressure of consideration, with a slight increase thereafter.

A scatter plot of the residuals of the regression analysis for a SLB differential pressure of 2405 psi is provided on Figure 10. A normal plot of the residuals is provided on Figure 11. Both of the charts are confirmatory of assumptions made in performing the regression analysis, i.e., the residual log leak rates are independent of the predicted log leak rates, and the residuals log leak rates approximate a normal distribution. Finally, an illustration of the combined effect of the added data on the POL and leak rate is provided by the ratio information presented on Figure 12.

The implication of the change in the *p* value is that an decreased number of Monte Carlo simulations will be performed considering that there is no correlation of the log leak rate to the log bobbin amplitude. The effects of the uncorrelated test data on the database itself are also listed in Table 4 for SLB differential pressures of 2560 and 2405 psi. The mean of the log leak rate data is increased by 3% for differential pressures of interest. The standard deviation of the log leak rate data increased by 1% for a ΔP of 2560 psi, and 2% for 2405 psi.

6.0 Consideration of EdF Data

A commitment was made by the industry prior to the preparation of Reference 3 that future updates of the ODSCC ARC database would include the results of consideration made to determine if statistical findings regarding the French data remained valid with the inclusion of new data. The original statistical findings were that there existed a systematic bias in the French data that resulted in a regression curve with a significantly higher intercept than the US data. Since the inclusion of the Diablo Canyon 2 data actually reduces the intercept of the regression curve, even though the reduction is slight, the previous statistical findings remain valid. The French data also included indications with large bobbin amplitudes that did not leak at SLB differential pressures. Since both of the Diablo Canyon 2 indications leaked, the occurrence associated with the French data continues to be counter to the corresponding experience with US data. In summary, the decision to exclude the French data from consideration for the analysis of US plants is supported by the Diablo Canyon 2 data.

7.0 General Conclusions

The review of the effect of the Diablo Canyon 2 data indicates that the burst pressure and the probability of leak correlations to the common logarithm of the bobbin amplitude are slightly changed by the inclusion of the test data. Therefore, it is likely that the conclusions relative to EOC probability of burst would not be significantly affected by the addition of the Diablo Canyon 2 data. This was illustrated on Figure 3. The effect of the data on the 95^{th} percentile of the total leak rate when only the POL is considered would also likely be small. However, the effect of the test data on the 95^{th} percentile of the total leak rate is expected to lead to significant reductions due to changes in the regression parameters of the log of the leak rate as function of the log of the bobbin amplitude. Finally, it is noted that the *p* value for the regression of the log of the leak rate on the log of the bobbin amplitude is reduced to a value less than 5%.

8.0 References

1. 51-5027436-00, *Diablo Canyon 2 Pulled Tubes Examination Report*. Framatome ANP, Lynchburg, VA, June 4, 2003.
2. 51-5025756-00, *Diablo Canyon Unit 2 Tube Pull Leak Rate Test Results*, Framatome, ANP, Lynchburg, VA, March 18, 2003.
3. 51-5028414-00, *DCPP 2R11 DE Input Transmittal to Westinghouse*, Framatome ANP, Lynchburg, VA, May 22, 2003.
4. 51-5027557-00, *2R11 DCPP Growth Rates*, Framatome ANP, Lynchburg, VA, May 13, 2003.
5. 1007660, *Steam Generator Tubing Outside Diameter Stress Corrosion Cracking at Tube Support Plates Database for Alternate Repair Limits, NP 7480-L, Addendum 5, 2002 Database*, EPRI, Palo Alto, November, 2002.
6. NP-7480-L, *Steam Generator Tubing Outside Diameter Stress Corrosion Cracking at Tube Support Plates - Database for Alternate Repair Limits, Volume 1: 7/8 Inch Diameter Tubing*, EPRI, Palo Alto, CA: August, 1996.
7. CN-SGDA-03-41, "ODSCC ARC Database Update for 7/8" Diameter Tubes," Westinghouse Electric Company, Nuclear Services Division, Madison, PA, USA, June, 2003.

Table 1: Analysis Properties of the DCPP 2 Pulled Tube Sections for Inclusion in the ODSCC ARC Database

Tube Section	Bobbin Amplitude (Volts) [1.]	Yield + Ultimate (ksi) [2.]	Burst Pressure (ksi)	Probability of Leak at SLB	Leak Rate at 2405 psi (lph) [3.]	Leak Rate at 2560 psi (lph) [3.]
R35C57-2H	NDD	163.546	12.724	N/A	N/A	N/A
R44C45-2H	NDD	154.186	12.235	N/A	N/A	N/A
R35C57-2H	5.09	163.546	5.950	1	0.54	1.59
R44C45-2H	21.50	154.186	4.212	1	62.9	91.4

Notes:

1. Locations with an amplitude of NDD are included for information only.
2. The value of S_y+S_u is rounded to one decimal place for use in the regression analyses. The mill test reported (CMTR) values were 152 and 150 ksi respectively.
3. Leak rates were measured at room temperature and adjusted to accident conditions using the procedure described in Appendix B of Reference 6.

Table 2: Effect of Diablo Canyon 2 Data on the 7/8" Tube Burst Pressure vs. Bobbin Amplitude Correlation

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

Parameter	Addendum 5 Database [1]	Addendum 5+ Database	New / Old Ratio
Intercept, a_0	7.49325	7.48475	0.999
Slope, a_1	-2.37741	-2.39502	1.007
r^2	79.2 %	79.6 %	1.005
Std. Dev., σ_{Error}	0.88616	0.88248	0.996
Mean Log(V)	0.291958	0.306657	
SS of Log(V)	50.2333	51.4665	
N (data pairs)	97	99	
Structural Limit (2560 psi) [2]	7.67 V	7.54 V	0.982
Structural Limit (2405 psi) [2]	9.62 V	9.45 V	0.984
p Value for a_1 [3]	$1.9 \cdot 10^{-34}$	$1.4 \cdot 10^{-35}$	0.074
Reference σ_f	68.78 ksi [4]		

Notes: The number of significant figures reported simply corresponds to the output from the calculation code and does not represent true engineering significance.

(1) Slight departures from the published values in Reference 3 are due to a refinement in the analysis to apply consistent rounding of the strength values to a single decimal place prior to performing the regression analysis.

(2) Values reported correspond to applying a safety factor of 1.4 on the differential pressure associated with a postulated SLB event.

(3) Numerical values are reported only to compare the calculated result to a criterion value of 0.05. For such small values the relative change is statistically meaningless.

(4) This is the flow stress value to which all data was normalized prior to performing the regression analysis.

Table 3: Effect of Diablo Canyon 2 Data on the Probability of Leak Correlation

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

Parameter	Addendum 5 Database	Addendum 5+ Database	New / Old Ratio
Intercept, β_1	-5.1017	-5.0503	0.990
Slope, β_2	7.3483	7.4342	1.012
V_{11} (1)	1.3742	1.3299	0.968
V_{12}	-1.7365	-1.7253	0.994
V_{22}	2.6428	2.6861	1.016
DoF (2)	113	115	
Deviance	30.21	31.47	1.042
Pearson SD	0.579	0.594	1.026
MSE	0.267	0.274	1.024

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

(2) Degrees of freedom.

Table 4: Effect of Diablo Canyon 2 Data on the 7/8" Tubes Leak Rate vs. Bobbin Amplitude Correlation (2560 & 2405 psi) $$Q = 10^{[b_3 + b_4 \log(Volts)]}$$			
Parameter	Addendum 5 Database Value	Addendum 5+ Database	Effect Ratio
SLB ΔP = 2560 psi			
Intercept, b_3	-0.069101	-0.168379	2.44
Slope, b_4	0.716972	0.832018	1.16
Index of Deter., r^2	7.5 %	9.9 %	1.32
Std. Error, σ_{Error} (b_5)	0.810766	0.807234	1.00
Mean of Log(Q)	0.72205	0.74522	1.03
Std. Dev. of Log(Q)	0.82764	0.83604	1.01
p Value for b_4	7.6%	4.3%	0.56
SLB ΔP = 2405 psi			
Intercept, b_3	-0.534841	-0.664317	1.24
Slope, b_4	0.969885	1.106101	1.14
Index of Deter., r^2	14.0%	17.5%	1.25
Std. Error, σ_{Error} (b_5)	0.772839	0.772757	1.00
Mean of Log(Q)	0.53539	0.55024	1.03
Std. Dev. of Log(Q)	0.81822	0.83625	1.02
p Value for b_4	2.3%	1.0%	0.42
Common Data			
Data Pairs, N	29	31	
Mean of Log(V)	1.10347	1.09805	
SS of Log(V)	2.78407	2.99300	
Note: The number of significant figures reported simply corresponds to the output from the calculation code and does not represent true engineering significance.			

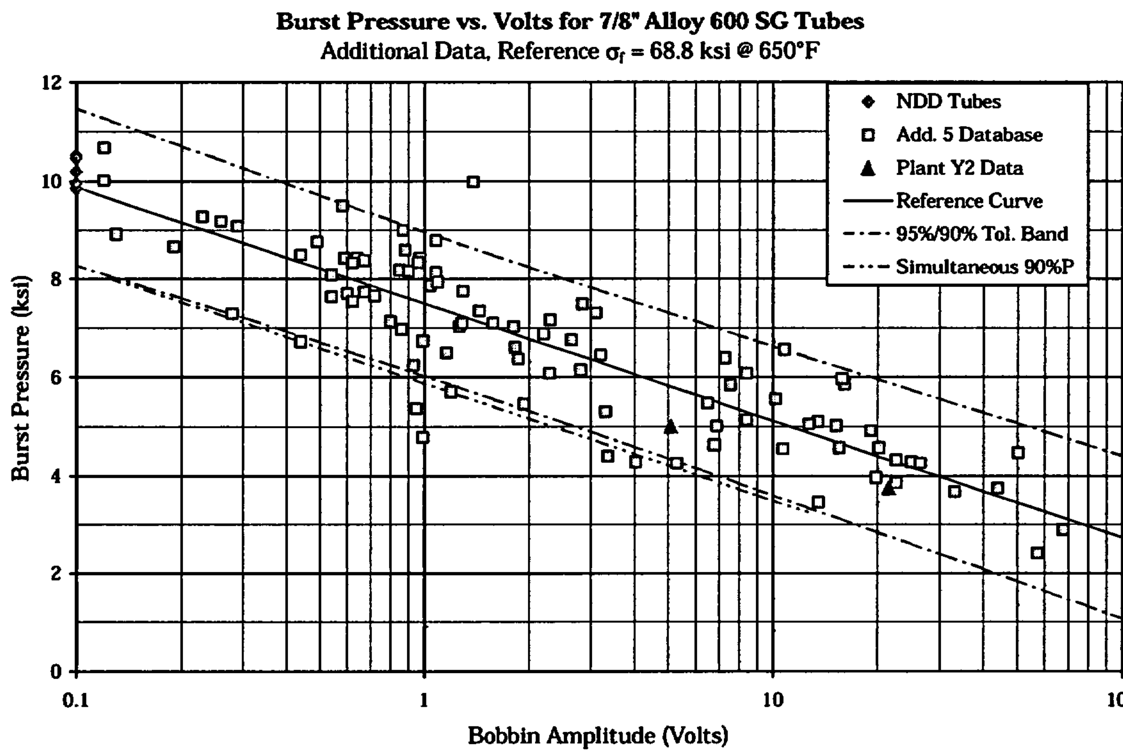


Figure 1: Comparison of additional test data to database tolerance bounds.

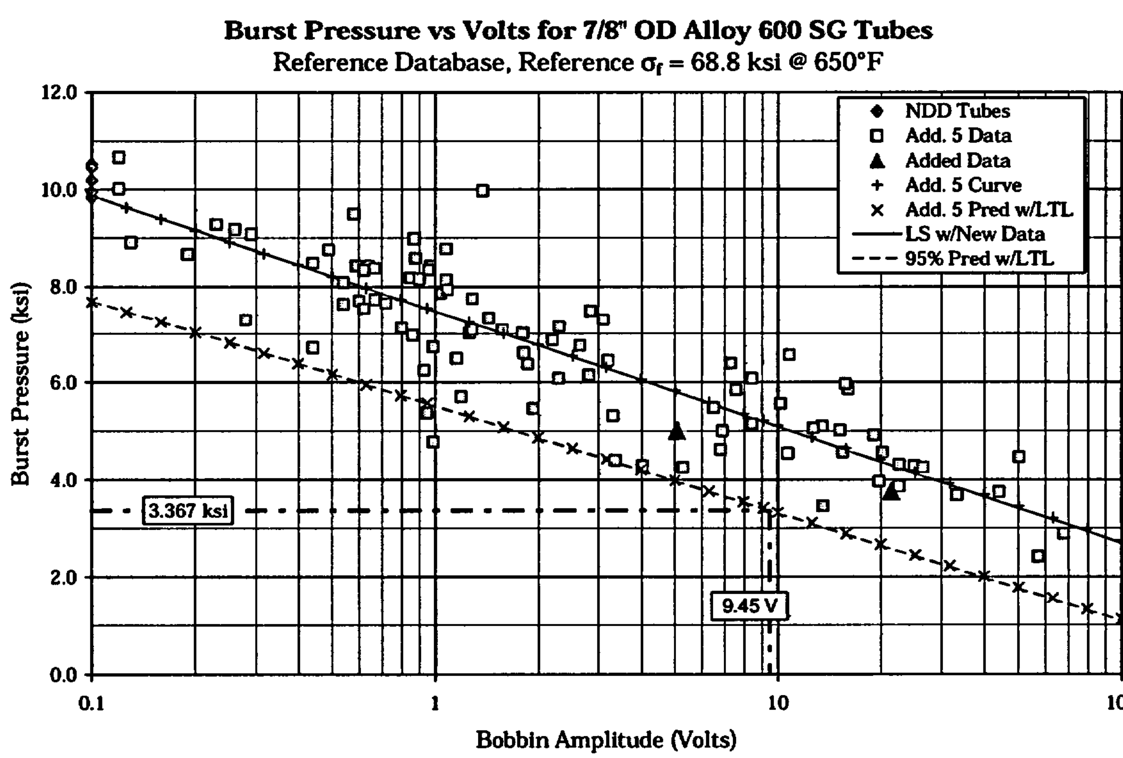


Figure 2: Effect of additional data on the burst pressure correlation.

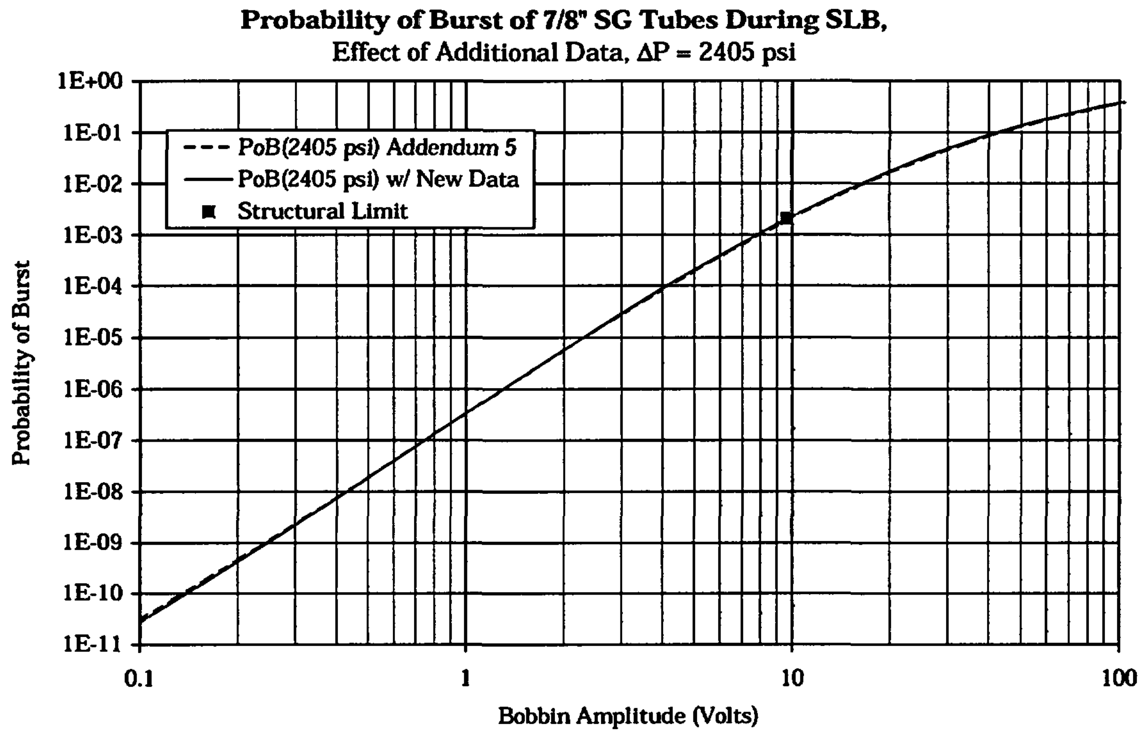


Figure 3: Effect of additional data on the probability of burst at 2405 psi

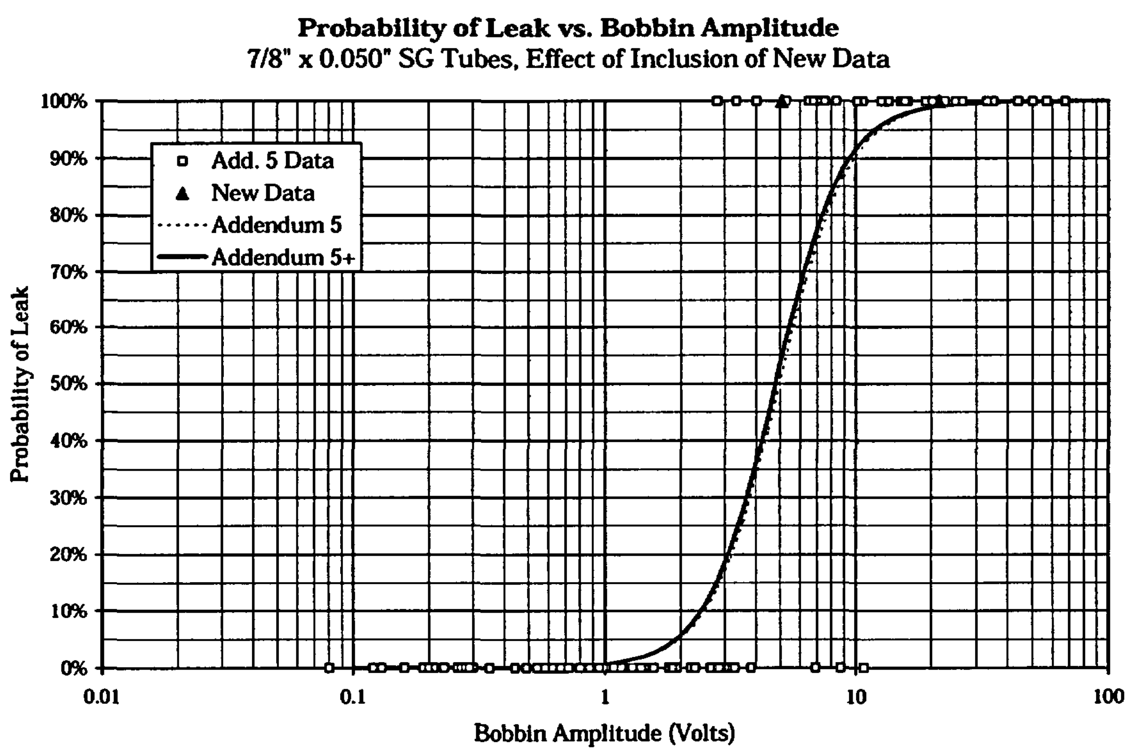


Figure 4: Effect of the additional data on the probability of leak correlation

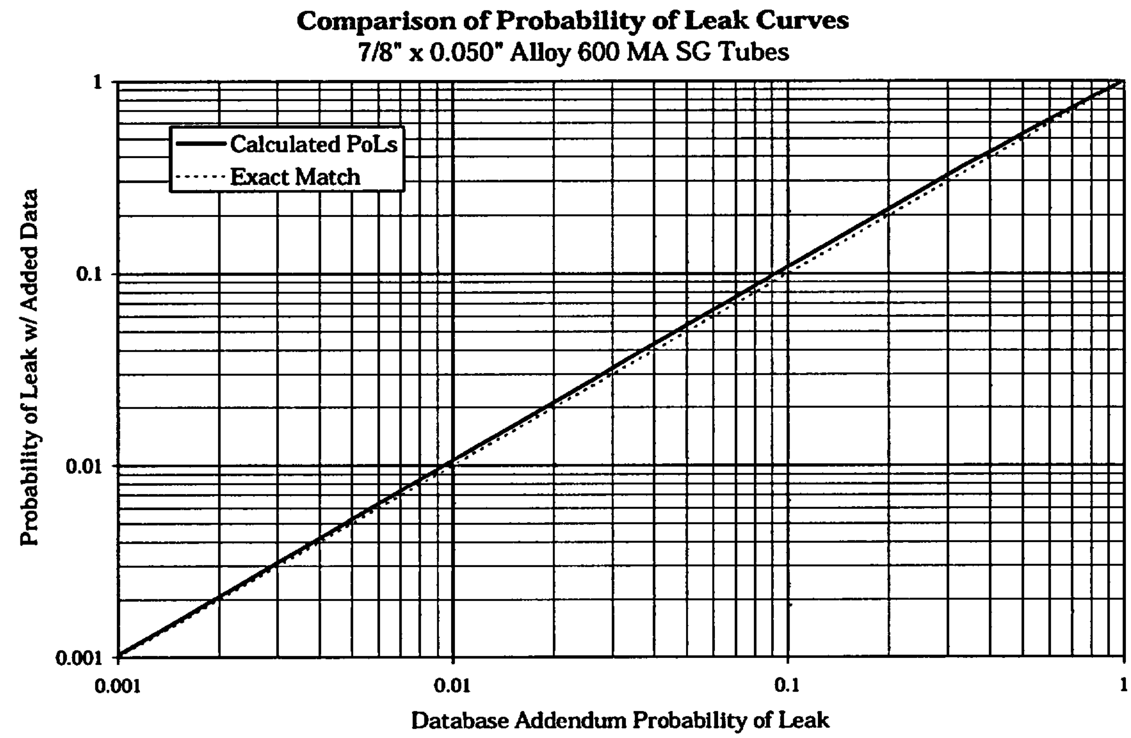


Figure 5: Change in the POL by the addition of the new data.

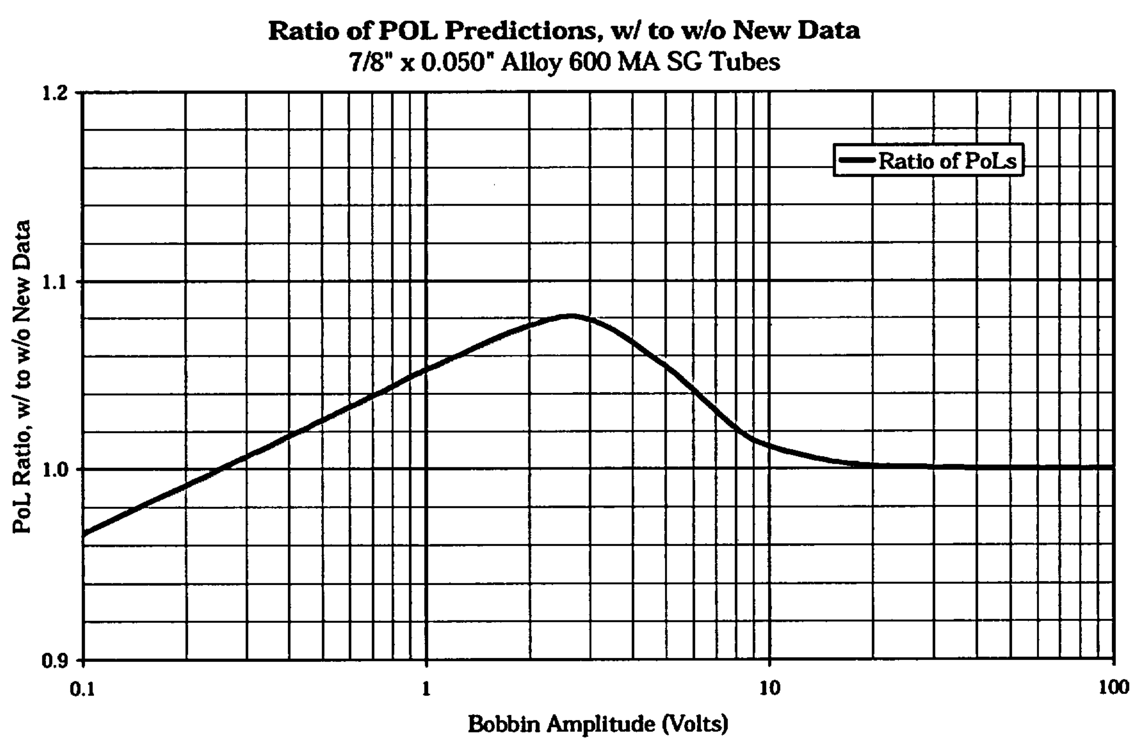


Figure 6: Ratio of after to before POL as a function of bobbin amplitude.

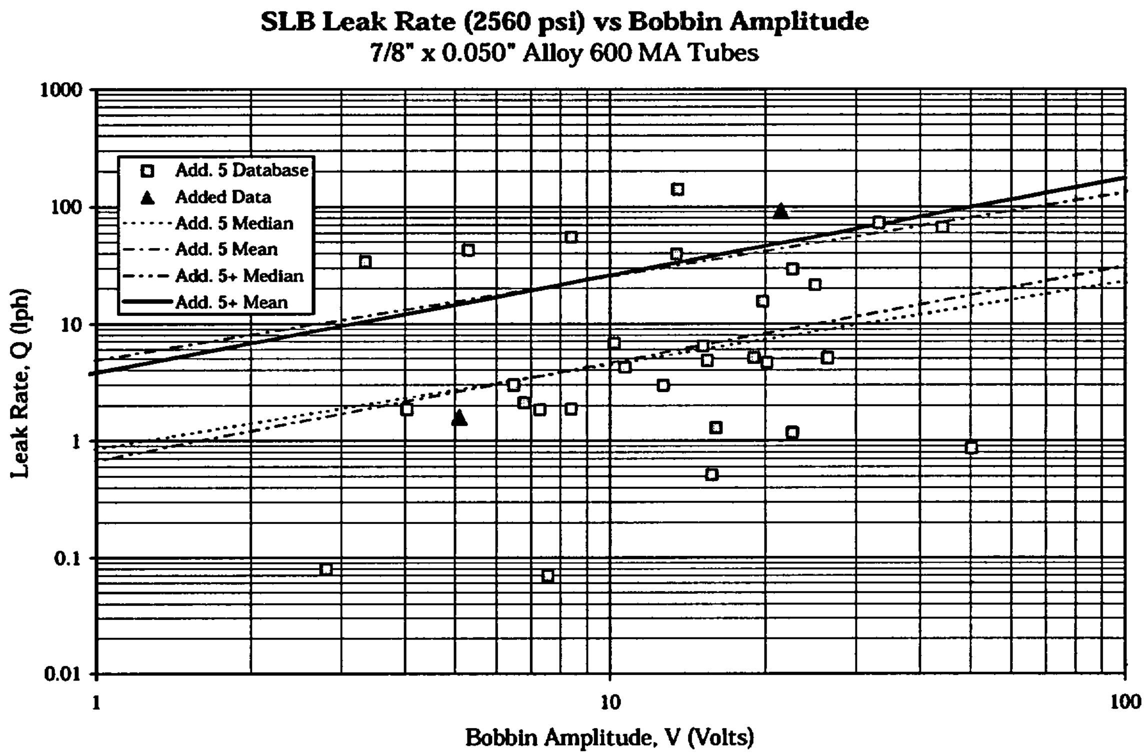


Figure 7: Effect of additional data on the leak rate at 2560 psid

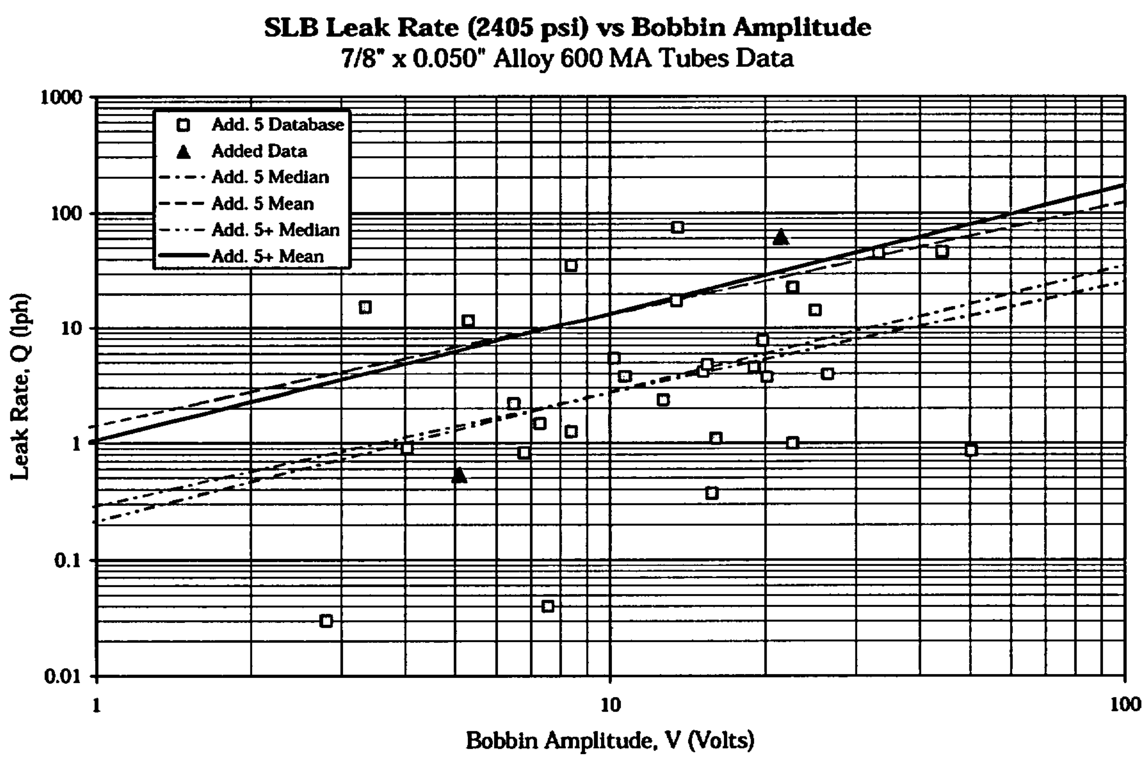


Figure 8: Effect of the additional data on the leak rate at 2405 psid

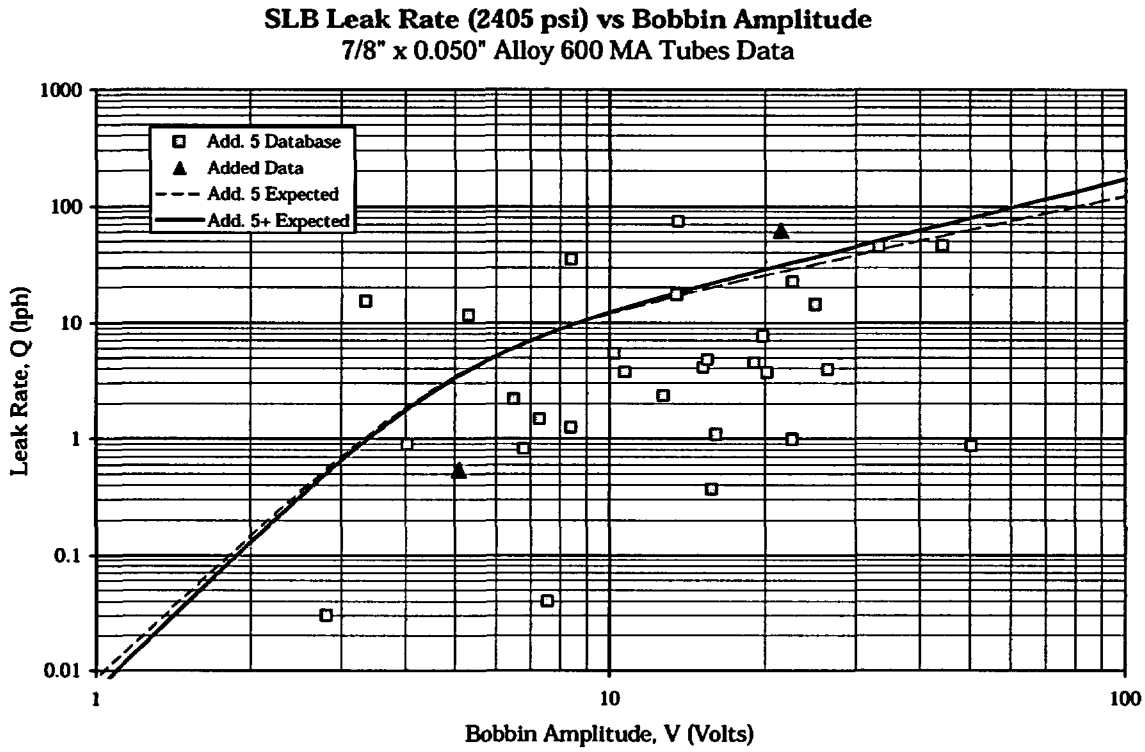


Figure 9: Net effect on combined POL & leak rate at 2405 psid

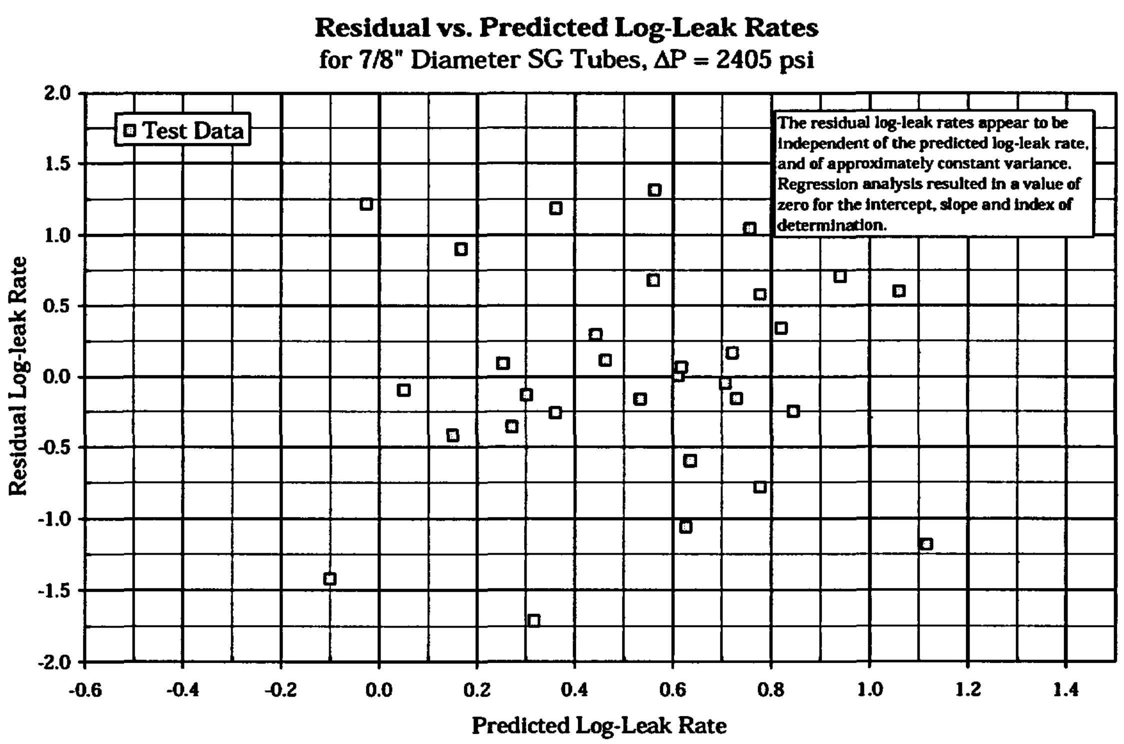


Figure 10: Residual scatter plot for SLB ΔP of 2405 psi.

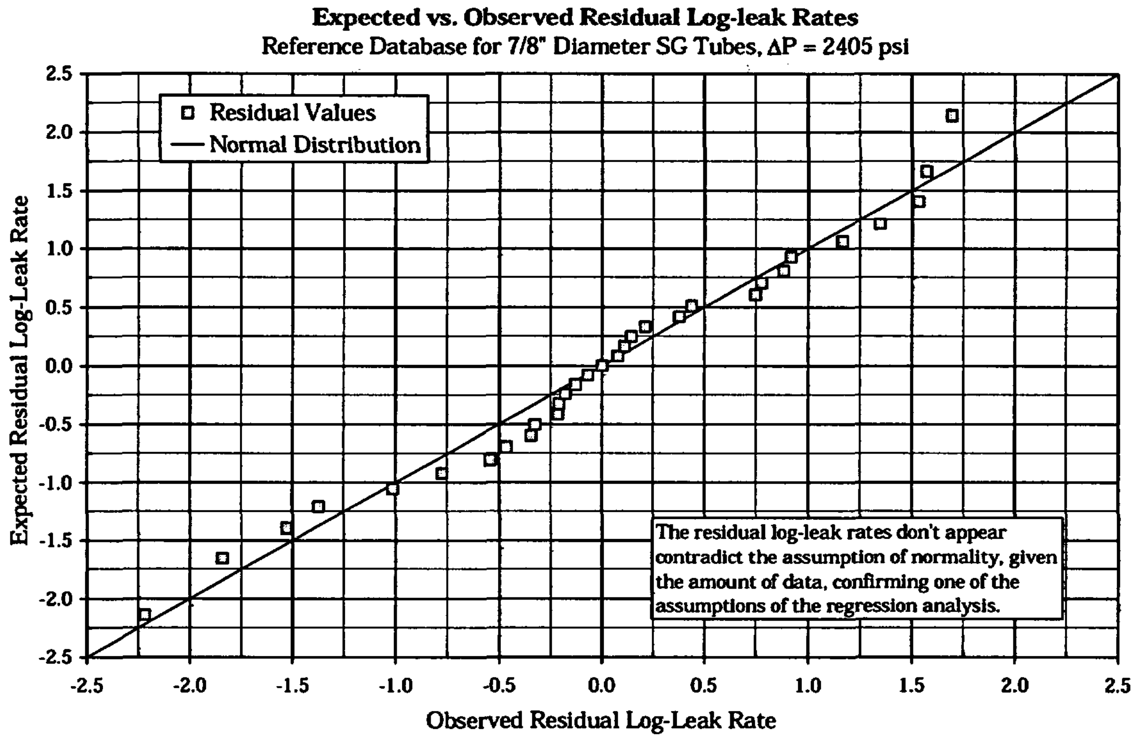


Figure 11: Residual normal plot for SLB ΔP of 2405 psi.

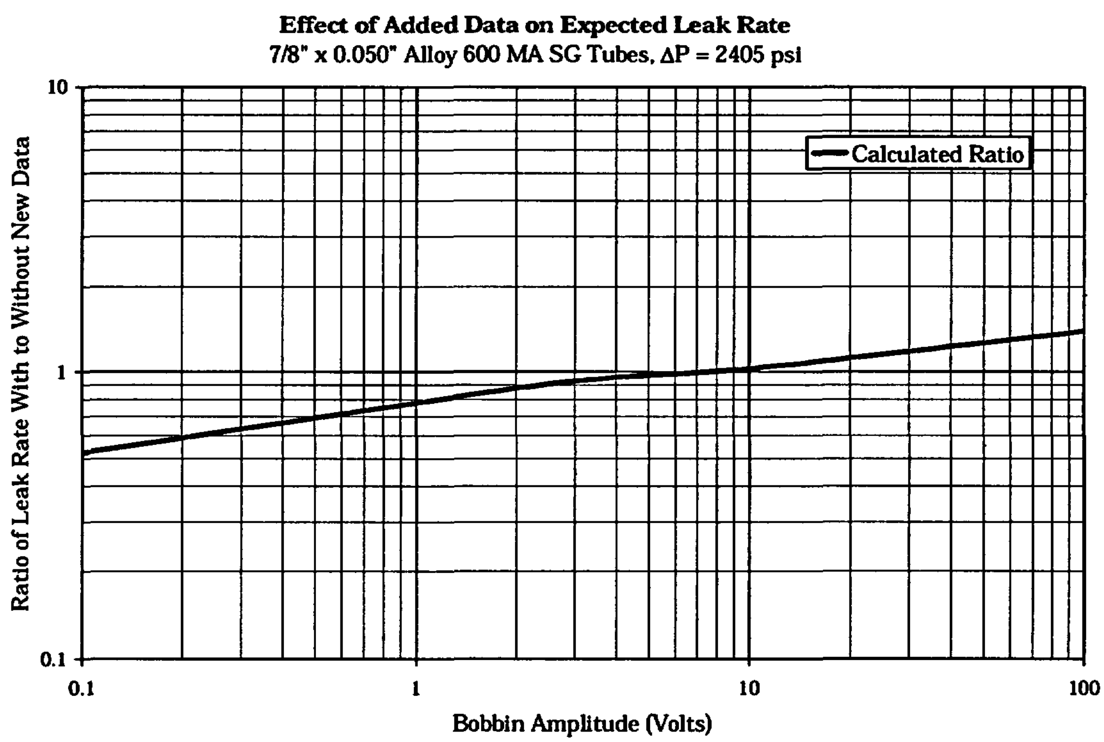


Figure 12: Ratio of expected leak rate as a function of amplitude.

SPECIAL REPORT 03-02

ATTACHMENT 2 TO ENCLOSURE 4

WESTINGHOUSE REPORT
"VOLTAGE DEPENDENT GROWTH BIN WIDTH DETERMINATION"

Voltage Dependent Growth
Bin Width Determination

1.0 Introduction

The application of growth rates to predict end-of-cycle (EOC) voltage distributions from beginning-of-cycle (BOC) amplitude distributions for the evaluation of outside diameter stress corrosion cracking (ODSCC) of steam generator (SG) tubes is described in Reference 1. It is recognized therein that the growth rate of the degradation may depend on the current size of the indication, i.e., the growth of an indication during one cycle of operation can depend on the size or amplitude at the beginning of the cycle. Utilities employing alternate repair criteria (ARC) for the disposition of ODSCC indications at tube intersections with drilled tube support plate (TSP) holes in Westinghouse SGs are advised to be alert for the appearance of voltage dependent growth (VDG). It is further recommended that use of VDG techniques be considered in the Monte Carlo analyses performed to predict distributions of indications that may be present at the end of the next operating cycle.

The Monte Carlo simulation of the growth of tube degradation indications is accomplished by randomly sampling the empirical distribution function (EDF) of the observed growth rates from previous operating periods (guidelines for the analysis are provided in Reference 1). If VDG is suspected, the data may be separated to form an EDF for low voltage indications and one or more independent EDFs for higher voltage indications. The existing practice has been for an engineer familiar with the analysis to make a judgment from an examination of the data as to where the demarcation points should be between voltage growth regions. The purpose of this document is to describe a mathematical method that can be applied to determine where the demarcation locations should be based on the data being analyzed. This allows for the growth data to be "binned" according to a mathematical indicator, albeit weak, of where the growth rates are changing.

Analyses were performed of tube ODSCC growth data for SG 2-4 at Diablo Canyon, Reference 2, to identify appropriate breakpoints for the performance of the operational assessment for the SG tubes. The analyses performed result in the identification of appropriate breakpoints for the performance of EOC predictions for Cycle 12

The rationale for the method is to minimize the sum of squares of prediction errors (SSE) from multiple linear regression relations of the growth data by adjusting the locations where one regression line would transition into another regression line. It is emphasized that the method is not for the purpose of developing regression relations for the prediction of future voltage values, that is done by sampling the EDFs, but only to identify those voltage locations where the results from an analysis of the data indicate a change in the relation, i.e., a change in the intercept and slope of the regression line. If two linear relations are used to describe the data the relationship would be characterized as being bilinear. The concept can be extended to consider descriptions of data which would be characterized as trilinear and quadrilinear. An Excel™ workbook with the data and formulae used for the analysis accompanies this report.

2.0 Piecewise Linear Regression Analysis

The concept of piecewise linear regression analysis arises from the concept of the use of "dummy" variables in multiple regression analysis, Reference 3 for example. The purpose of the analysis is to depict relations where the dependent variable (EOC amplitude) follows a particular linear relation up to some specific value of the independent variable (BOC amplitude) An example of a bilinear dependence relation is illustrated on Figure 1. To the left of the breakpoint, i.e., the discontinuity between line slopes, the linear relation follows one intercept and slope combination and to the right of the breakpoint the relation follows a different combination. A trilinear regression relation is illustrated on Figure 2 and a quadrilinear regression relation is illustrated on Figure 3. Each of these are discussed in the following sections relative to the analysis of the Diablo Canyon data.

3.0 Analysis

The analysis of the growth data to determine breakpoints turns out to be somewhat insensitive to the locations determined for the breakpoints. However, this means that the past practice of using engineering judgment did not likely result in significant contributions to the overall uncertainty of the analysis results. The following sections describe considerations made to process the data and the types of analyses that can be performed. Three levels of piecewise linear regression were considered, bilinear, trilinear, and quadrilinear. The results for the quadrilinear fits did not aid in understanding the data and are not recommended. Conclusions are provided at the end of this section.

3.1 Upper Range Number of Data

One of the considerations that has been made regarding growth rates since the inception of VDG concepts has been with regard to the number of indications in the upper range of the data. If the number of indications is too few the determination of the breakpoint can be significantly skewed by one or two indications. For example, there was one extremely high growth value associated with the data of SG 2-4. If the analysis algorithm does not restrict the number of indications in the upper range to some minimum value a breakpoint at the extreme indication will be calculated. This is because the square of the error of prediction for that indication is much larger than for the other indications. The minimum number of data for the upper range was established to be fifteen based on engineering judgment. If the number is chosen too small, the influence of a single large indication could bias the results of the analysis to always converge to the minimum allowable. The experience with using the number fifteen has been that the analysis generally converges to leaving a larger number of indications in the upper bin. This is evident by the results illustrated on the figures accompanying the following discussions for piecewise linear regression analysis. It is also noted that for these analyses the single largest growth value was omitted from consideration. Inclusion would have the effect of always making he solution converge to the bin limitation instead of a true solution.

3.2 Bilinear Regression

Table 1 illustrates a data set used in a bilinear regression analysis of the Diablo Canyon 2 SG 2-4 growth data. A snapshot of the screen from the Excel™ worksheet analysis of the data is shown on Figure 4 and the discussion of the analysis is keyed to the cell coordinates of that figure. The original independent variable data are listed in column B with the initial dependent data in column D. The dummy independent variable data, one set, are listed in column C. Each cell in column C contains a formula that returns the maximum of the difference between the independent variable, X_i, at that row and the breakpoint value, X_{BP}, which is listed in cell F5. Thus the regression line is of the form,

$$V_G = b_0 + b_1 V_1 + b_2 \langle V_1 - V_{BP} \rangle, \qquad (1)$$

where the coefficients, b_0 through b_2, are found by a standard least squares procedure. The angle brackets, ⟨ and ⟩, indicate a singularity notation that is zero if the operation in the brackets is negative or zero and the value of the operation otherwise. Here it is understood that the exponent on the brackets is unity. Examination of the equation shows that the intercept and slope when V_1 is less than V_{BP} are b_0 and b_1 respectively. When the converse is true the intercept is b_0 minus $b_2 \cdot V_{BP}$ and the slope becomes b_1 plus b_2. The principle extends readily to multiple breakpoints.

In many instances the value of the breakpoint is known *a priori* and the regression proceeds in the usual fashion. The approach to the analysis of the growth data is to perform the analysis in a manner in which the value of the breakpoint is also determined. A nonlinear regression analysis could be performed to effect a solution. An equally valid approach, the method employed herein, is to use the Excel solver routine to calculated the value of the breakpoint that results in a minimum value for the sum of squares of the errors of regression. The solver interface window for the analysis of this document is illustrated on Figure 5 and the information depicted is keyed to the cell coordinates shown on Figure 4. The target cell, J9, is the sum of squares of the prediction errors from the regression analysis. The breakpoint value is entered in cell F5; the solver routine changes the value in that cell to minimize the value calculated for the target cell. There are two constraints identified in the interface window, the solution value has to be less than or equal to the number in cell G8, identified as "Bound 2," and greater than or equal to the value in cell F8, "Bound 1." The value of the first bound was picked (engineering judgment) as a standard for the width of the first data region. The value in cell G8 is obtained from the data in column D using the value in cell G9 to count from the bottom of the data. This then determines the upper bound value allowed for the solution. Cell G6 contains the actual number of data in the upper range and serves as a check that the solution is actually less than the bounding value. One other feature of the regression analysis is noted. The intercept term for the regression equation was restricted to zero, shown in cell K5. This is not a necessary feature and the determination of the breakpoints is likely insensitive to this specification. The solution value for this case was 0.62, comfortably greater than the lower bound and significantly less than the upper bound. The results of the regression analysis for a sample set of data are illustrated separately on Figure 6.

3.3 Trilinear Regression

The worksheet for the performance of a trilinear analysis is shown on Figure 7. The solver interface is shown on Figure 8. A point to note is that there are two cells to be changed to effect the desired solution, F5 and G5. In addition, the lower bound constraint is only on the value in cell F5 and the upper bound constraint is on the value in cell G5. The other point is that the cell to minimize the value has been specified as J7, which is the standard error of prediction. This is really the same specification since the standard error of prediction is the square root of the sum of squares of the errors of prediction after dividing by the degrees of freedom. The equation for a trilinear regression analysis is,

$$V_G = b_0 + b_1 V_1 + b_2 \langle V_1 - V_{B1} \rangle + b_3 \langle V_1 - V_{B2} \rangle, \quad (2)$$

where V_{B1} and V_{B2} are the two breakpoints needed in the analysis. The solution is independently illustrated on Figure 9. The trilinear regression analysis illustrated is for a different data set than used for the bilinear regression, upper range values from the growth during Cycle 10 were included to increase the probability of experiencing some of the larger growth values. The sum of squares of the errors is greater for the trilinear regression than for the bilinear because of the difference in the data sets. However, the improvement, measured by decreasing the SSE, obtained by increasing the complexity of the model was marginal at best. Although the SSE was only marginally improved, the use of the trilinear regression was and is recommended where practical. Recall that the purpose of the analysis is not to fit useable functions to the data, but only to find locations where there is evidence that the growth may be changing. The results are readily apparent from an examination of the information presented on Figure 7. An additional breakpoint is found at location 1.66 Volts which results in greater predicted growth for the larger values. This is a desirable feature to include in the operational assessment. There are 19 data pair included in the solution for the upper bin, indicating that the solution was not converging to the remaining single highest growth value. Had the single extreme growth value been included in these analyses, the solution would have converged to whatever limit was in place for the upper bin, e.g., 15 in this case.

3.4 Quadrilinear Regression

The expansion of the model from three to four line segments follows in the same manner as increasing the number of segments from two to three. A worksheet for performing a quadrilinear regression analysis of the data is illustrated on Figure 10, where provisions have been made to include three breakpoints and three bounds for the breakpoints (a lower bound for the first breakpoint, and upper bounds for the second and third). The solver screen for performing the analysis is shown on Figure 11. One constraint has been added to account for the additional breakpoint. The equation for a quadrilinear regression analysis is,

$$V_G = b_0 + b_1 V_1 + b_2 \langle V_1 - V_{B1} \rangle + b_3 \langle V_1 - V_{B2} \rangle + b_4 \langle V_1 - V_{B3} \rangle, \quad (3)$$

where V_{B1}, V_{B2} and V_{B3} are the three breakpoints to be calculated. The results of extending the model to consider four regression lines are illustrated on Figure 12. An undesirable consequence,

the third line has a lower slope than the second line, is immediately apparent. This is counter to expectation and is an a flag that the added complexity should not be included in the model.

By comparing the numerical information on Figure 10 with that on Figure 4, it is apparent that the improvement in the SSE is minimal 85.9 versus 86.3. A similar result is obtained if the trilinear fit is compared to the bilinear fit.

4.0 Application to Diablo Canyon 2 Data

4.1 SG 2-4 Cycle 11 Growth Data

As previously noted, data were obtained from the examination of the SG tubes at DC 2 during refueling outage 11, referred to as 2R11, Reference 2, and analyzed to estimate locations for the breakpoints for the analysis considering voltage dependent growth. The data were used to develop the information presented in this report for operational assessment of the DC 2 SG tubes. The steam generator with the most significant degradation and growth was SG 2-4 (Diablo Canyon Unit 2, SG 4).

The Cycle 11 growth data for the 975 indications found in the SG were analyzed using a piecewise linear regression analysis and breakpoints of 0.61 and 1.66 Volts were obtained. A second analysis was performed by adding the 30 largest indications in the SG from the inspection at the end of Cycle 10 of operation to the Cycle 11 data. The number of indications corresponded to a growth breakpoint value of 1.17 Volts which was obtained from the analysis of the growth data for that cycle. The analysis is discussed in the following section. The results of the analysis indicate that the breakpoints for the Cycle 11 growth rates should be at 0.59 and 1.66 Volts for a three region simulation. It is noteworthy that the breakpoints obtained from both analyses are similar and the upper break point is unaffected by the presence of the Cycle 10 indications. This is likely due to the fact that most of the indications had BOC amplitudes that were less than the upper breakpoint value.

4.2 SG 2-4 Cycle 10 Growth Data

The growth data from Cycle 10 for SG 2-4, a total of 488 indications, were analyzed using the same techniques to find breakpoints in the growth that would minimize the corrected sum of squares of deviations from the piecewise regression predictions. The Excel screen for the analysis is shown of Figure 13. The results of the analysis indicate that breakpoints of 0.69 and 1.17 Volts should be used for analyses employing the Cycle 10 growth data. The dependence of growth on BOC amplitude is significant above the second breakpoint where it is apparent that the change in slope is somewhat dramatic. The results are illustrated in larger scale on Figure 14.

The Cycle 10 data also provide an illustration a potential drawback in using quadrilinear regression without a restriction on the minimum number of data that may be used for the third segment or piece of the curve. A near step function results as illustrated on Figure 15. This results from the influence of the large growth value at about 1.25 volts, i.e., minimization of the standard error of the regression is achieved by having a step at that value, with a smaller slope for the fourth segment of the curve. The noted point, and two others, is also influential in the determination of the slope of the third segment for the trilinear regression. A comparison of the two curves shows

that the growth in the range of less than 1.2 Volts is less than if the trilinear curve is used, in the range of 1.2 to 1.5 Volts the growth is greater if the quadrilinear curve is used, and growth for indications greater than 1.5 Volts is greater if the trilinear curve is used. Figure 16 illustrates the solution for the same data if a limitation on the number of data for the third segment is used. In this case the growth rate in the range below about 1.2 Volts is greater for the trilinear curve and slightly lower thereafter to about 1.5 Volts. It should be noted that for the trilinear fit the number of data in the upper bin is 30 even though the specified minimum was 15. For the quadrilinear fit the number of data in the third and fourth bins exactly matches the specified minimum. Thus, the analysis is converging to the specified limits instead of seeking out the natural breakpoint. As for the analysis of the Cycle 11 data, there is no advantage to using a quadrilinear fit to determine the breakpoints.

5.0 Summary

The purpose in performing the analysis was to "let the data determine" where the breakpoints should be.

1. The trilinear regression performs as well as quadrilinear regression. The standard error of the regression and, hence, the correlation coefficients are the same. The increase in complexity of the model is not indicated since it does not improve the fit. There may be instances where the quadrilinear model simply converges to the specified limits instead of a pseudo natural breakpoint.

2. The analyst should reject adding lines to the model if any succeeding slopes are less than their predecessors.

3. Although the trilinear fit is recommended because of its potential flexibility in handling growth variations, there may be occasions when the bilinear fit is acceptable.

4. Improvements in the fit in going from a bilinear to a trilinear model are not large, e.g., the reduction in the SSE can be absolutely and relatively small. This would normally indicate that the increase in complexity is not balanced by the improvement in the model. However, the use of a trilinear curve permits more sensitivity to the voltage dependent growth and therefore has an engineering advantage.

5. There may not be statistically best locations for the breakpoints. Several choices may offer similar results. However, the analysis results do indicate where changes in the growth rate as a function of initial amplitude are likely to be occurring.

The analysis methodology for location of the breakpoints should be included in the next Addendum to the database document for the ODSCC ARC analyses.

Breakpoints for the Diablo Canyon 2 operational assessment using the SG 2-4 Cycle 11 growth rate modified to include large growth values from Cycle 10 should be at 0.59 and 1.66 Volts for a three region simulation of the growth rates. Breakpoints for the analysis of the Cycle 10 data for the same SG should be set at 0.69 and 1.17 Volts respectively.

6.0 References

1. NP-7480-L, "Steam Generator Tubing Outside Diameter Stress Corrosion Cracking at Tube Support Plates Database for Alternate Repair Limits, EPRI, Palo Alto, CA, USA (October 2002).
2. 51-5027557-00, "2R11 DCPP Growth Rates," Framatome ANP, Lynchburg, VA, USA, May 13, 2003.
3. Draper, N. and Smith, H., *Applied Regression Analysis, Second Edition*, John Wiley & Sons, New York, NY, USA (1981).

Table 1: Bilinear Regression Sample Data			
Index Number	Previous Voltage	Dummy Variable 1	Volts / EFPY
1	0.09	0.00	0.06
2	0.09	0.00	0.10
3	0.10	0.00	0.10
4	0.10	0.00	0.11
5	0.11	0.00	0.03
6	0.11	0.00	0.05
7	0.11	0.00	0.07
8	0.12	0.00	0.05
9	0.12	0.00	0.08
...	...	...	...
967	1.77	1.15	0.04
968	1.82	1.20	1.35
969	1.87	1.25	1.44
970	1.90	1.28	2.62
971	1.91	1.29	0.04
972	1.92	1.30	2.15
973	1.96	1.34	1.46
974	1.97	1.35	0.24
975	2.00	1.38	1.83

Table 2: Cycle 10 Data Added to Cycle 11		
Index Value	BOC Amplitude (Volts)	Growth (Volts/EFPY)
1	1.18	0.13
2	1.18	0.38
3	1.19	0.21
4	1.20	0.08
5	1.20	0.50
6	1.21	0.46
7	1.22	0.37
8	1.22	0.54
9	1.23	0.00
10	1.25	0.29
11	1.25	0.66
12	1.26	0.19
13	1.26	2.89
14	1.28	0.18
15	1.28	1.01
16	1.30	0.08
17	1.30	0.13
18	1.31	1.10
19	1.34	1.38
20	1.35	0.01
21	1.35	1.88
22	1.39	2.55
23	1.47	0.00
24	1.47	0.53
25	1.58	2.53
26	1.62	0.10
27	1.64	1.25
28	1.76	1.65
29	1.89	1.74
30	1.93	0.80

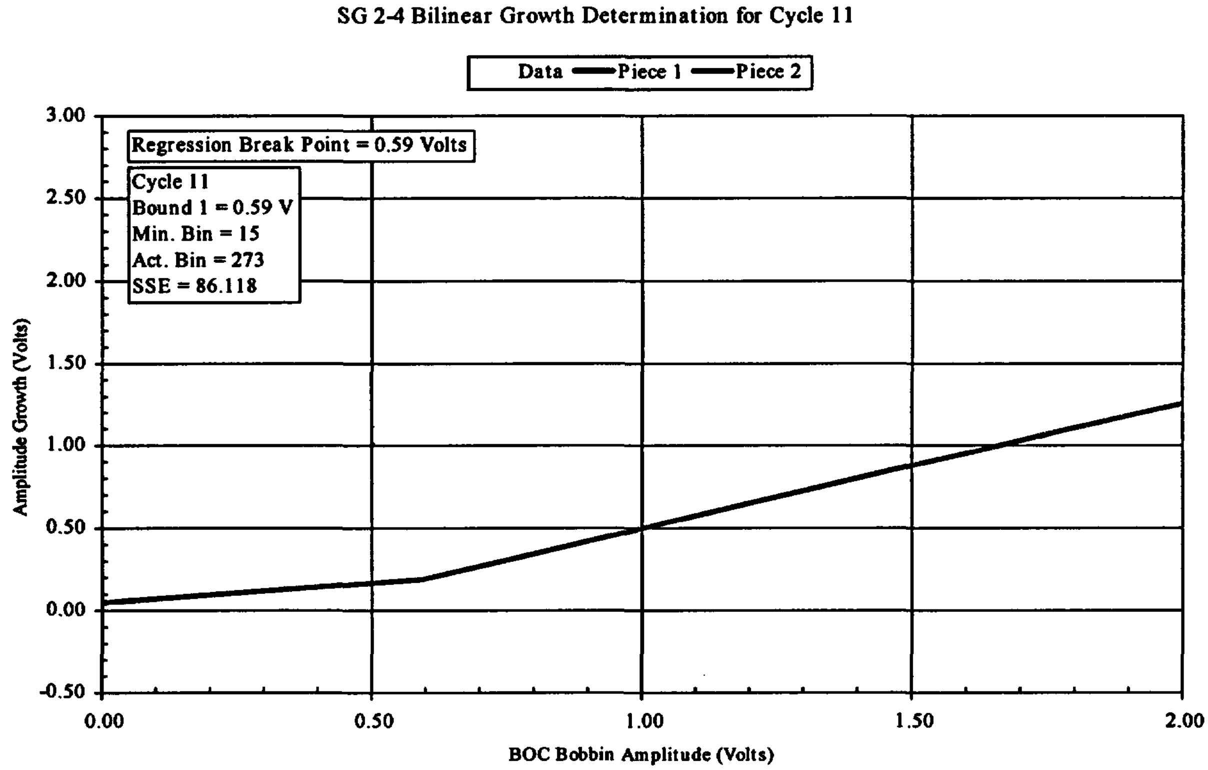


Figure 1: Bilinear Regression Line Illustration

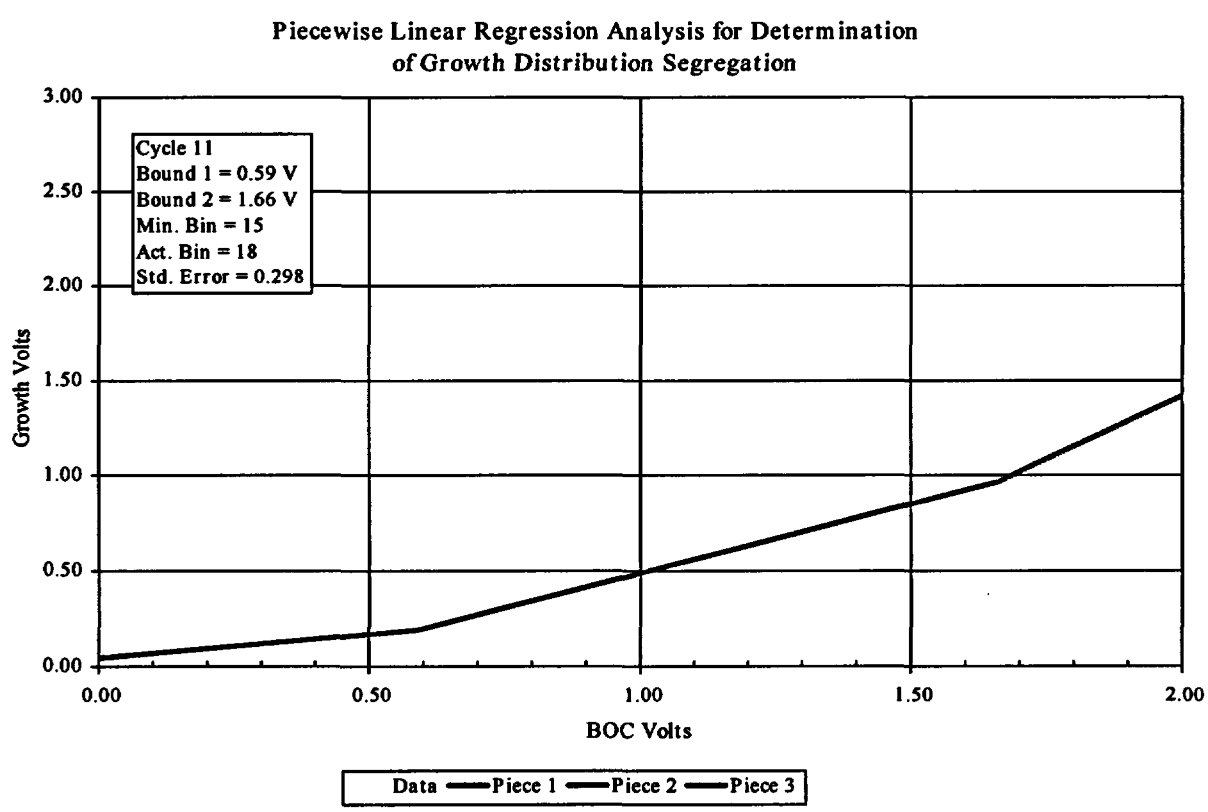


Figure 2: Trilinear regression line illustration

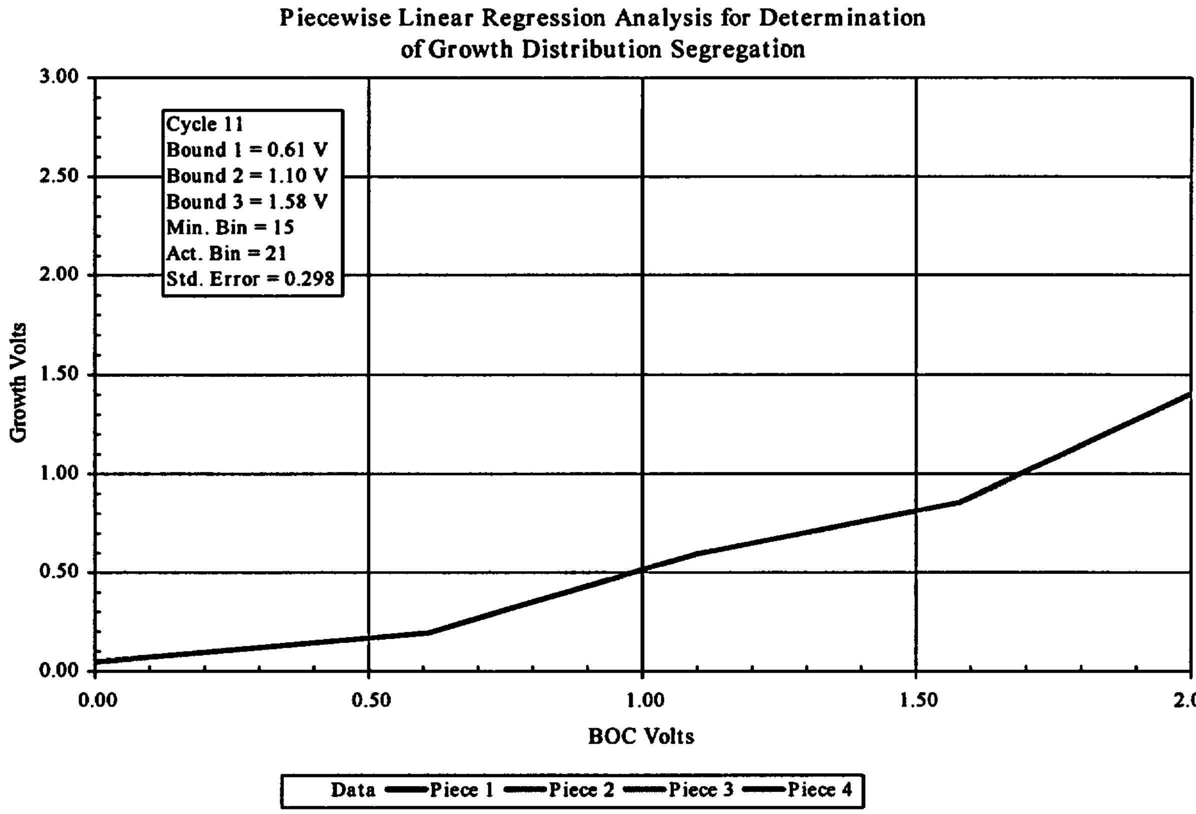


Figure 3: Quadrilinear regression line illustration

Bilinear Regression of Growth Data for SG 2-4, Cycle 11

	A	B	C	D
3		X1	X2	
4	Index	Prev Voltage	Dummy 1	Volts / EFPY
5	1	0.09	0.00	0.06
6	2	0.09	0.00	0.10
7	3	0.10	0.00	0.10
8	4	0.10	0.00	0.11
9	5	0.11	0.00	0.03
10	6	0.11	0.00	0.05
11	7	0.11	0.00	0.07
12	8	0.12	0.00	0.05
13	9	0.12	0.00	0.08
14	10	0.12	0.00	0.09
15	11	0.12	0.00	0.09
16	12	0.12	0.00	0.13
17	13	0.12	0.00	0.13
18	14	0.12	0.00	0.14
19	15	0.13	0.00	0.06
20	16	0.13	0.00	0.06
21	17	0.13	0.00	0.06
22	18	0.13	0.00	0.09
23	19	0.13	0.00	0.10
24	20	0.13	0.00	0.11
25	21	0.13	0.00	0.12
26	22	0.14	0.00	0.01
27	23	0.14	0.00	0.02
28	24	0.14	0.00	0.03
29	25	0.14	0.00	0.04
30	26	0.14	0.00	0.06
31	27	0.14	0.00	0.07
32	28	0.14	0.00	0.08
33	29	0.14	0.00	0.09
34	30	0.14	0.00	0.09
35	31	0.14	0.00	0.10
36	32	0.14	0.00	0.11
37	33	0.14	0.00	0.12
38	34	0.14	0.00	0.12

Regression Break Point = 0.59 Volts

	F	G	H	I	J	K	L
3			Bilinear Regression				
4	Xp1			b2	b1	b0	
5	0.59		Coefs	0.52262	0.2373	0.047791	Coefs
6	Act Bin	273	SE b's	0.09874	0.06887	0.027932	SE b's
7	Bound 1	Bound 2	R-Sqr	32.7%	0.29766	#N/A	SE Y
8	0.5	1.665	F	236.143	972	#N/A	DoF
9	Min. Bin	15	SSR	41.8439	86.118	#N/A	SSE

	N	O
3	Regression Line	
4	X's	Predict Volts
5	0.00	0.05
6	0.59	0.19
7	2.00	1.26

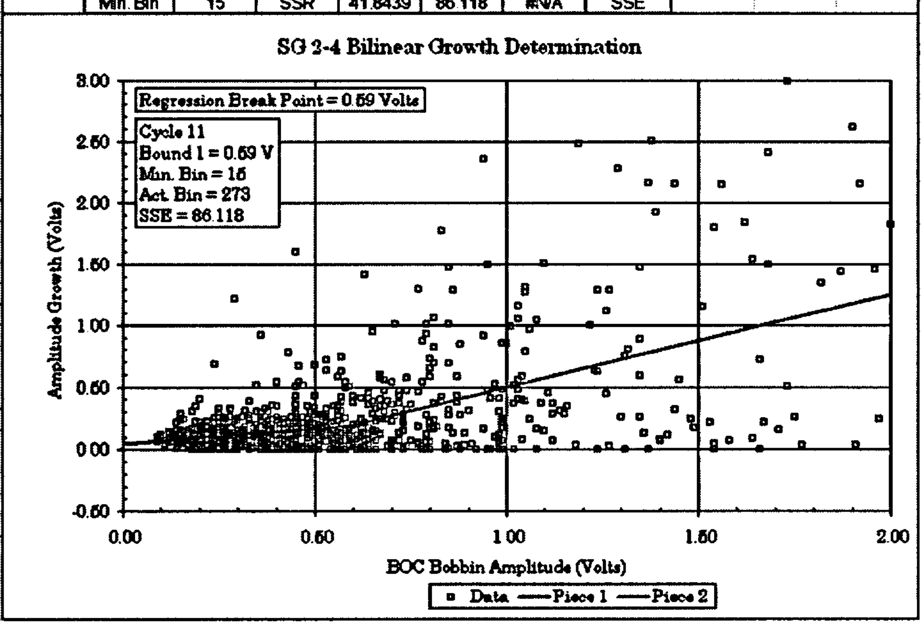


Figure 4: Excel screen for bilinear regression analysis

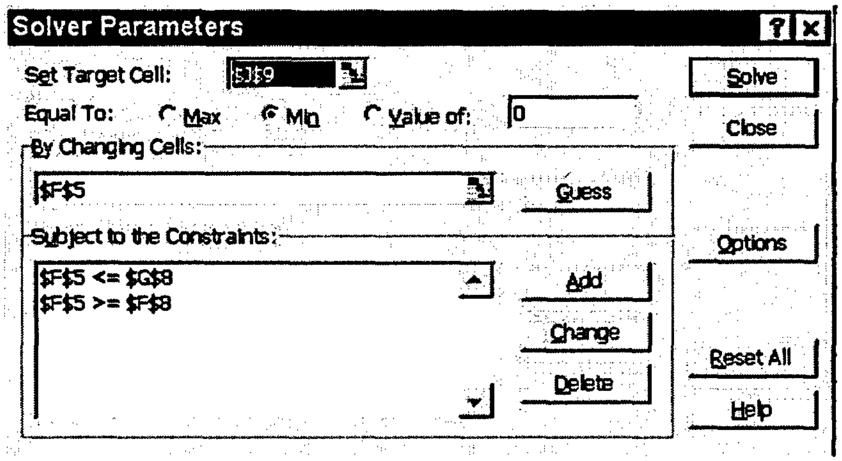


Figure 5: Excel solver screen for bilinear regression analysis

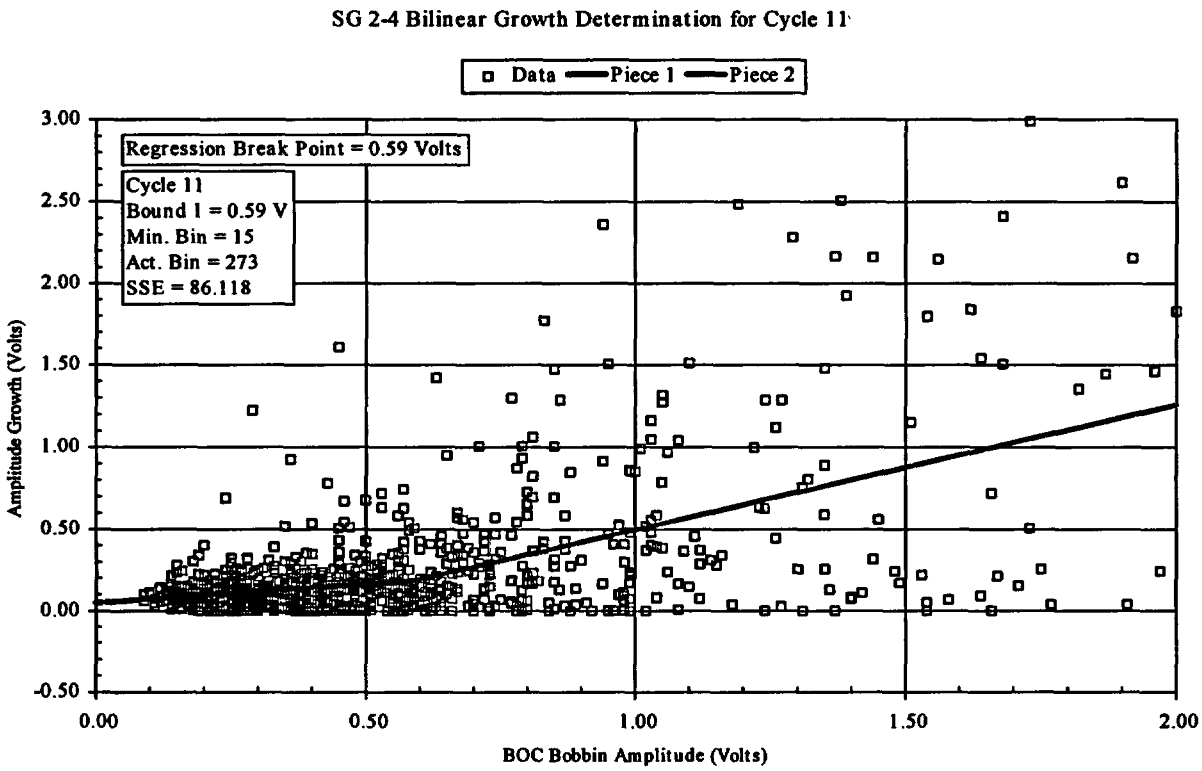
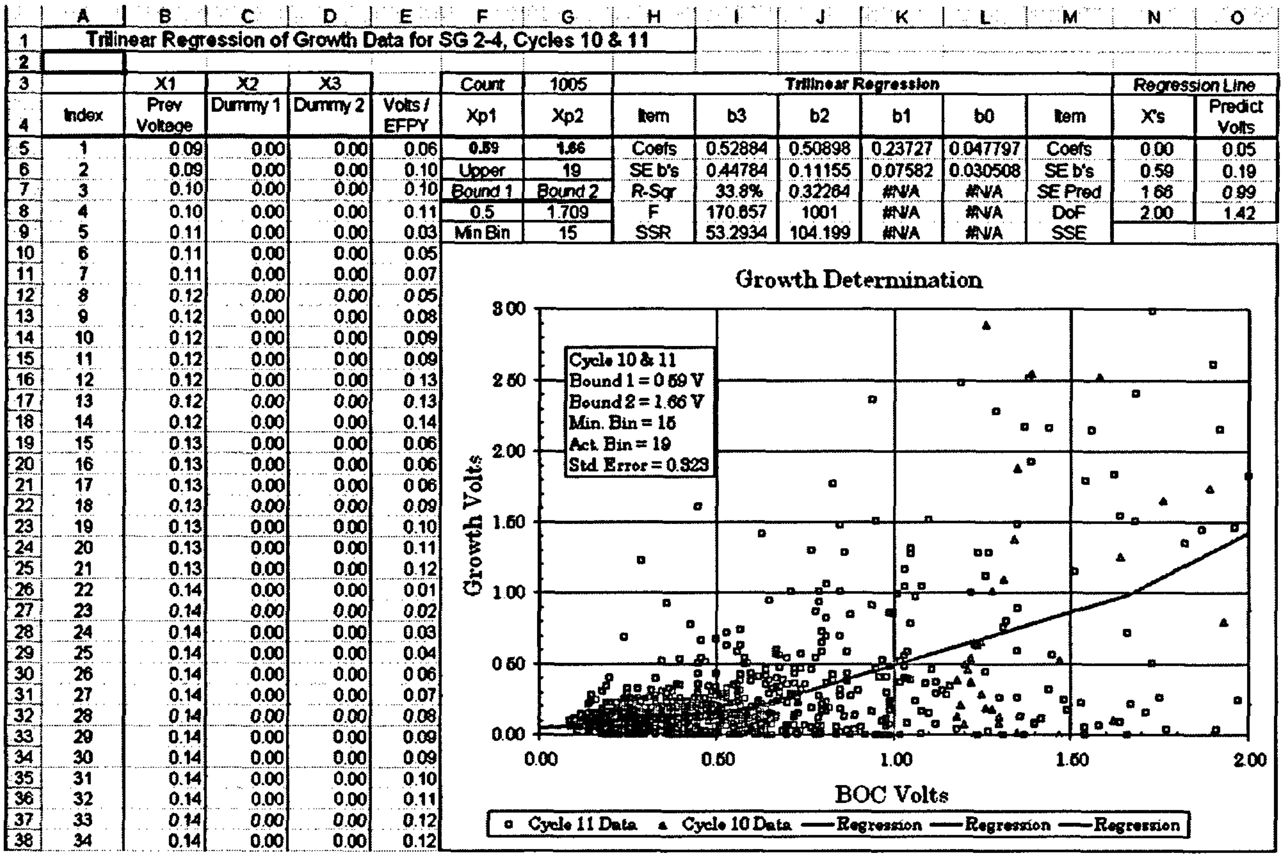


Figure 6: Bilinear regression lines for SG 2-4 Cycle 11 Growth Data



Row	A: Index	B: X1 Prev Voltage	C: X2 Dummy 1	D: X3 Dummy 2	E: Volts / EFPY
5	1	0.09	0.00	0.00	0.06
6	2	0.09	0.00	0.00	0.10
7	3	0.10	0.00	0.00	0.10
8	4	0.10	0.00	0.00	0.11
9	5	0.11	0.00	0.00	0.03
10	6	0.11	0.00	0.00	0.05
11	7	0.11	0.00	0.00	0.07
12	8	0.12	0.00	0.00	0.05
13	9	0.12	0.00	0.00	0.08
14	10	0.12	0.00	0.00	0.09
15	11	0.12	0.00	0.00	0.09
16	12	0.12	0.00	0.00	0.13
17	13	0.12	0.00	0.00	0.13
18	14	0.12	0.00	0.00	0.14
19	15	0.13	0.00	0.00	0.06
20	16	0.13	0.00	0.00	0.06
21	17	0.13	0.00	0.00	0.06
22	18	0.13	0.00	0.00	0.09
23	19	0.13	0.00	0.00	0.10
24	20	0.13	0.00	0.00	0.11
25	21	0.13	0.00	0.00	0.12
26	22	0.14	0.00	0.00	0.01
27	23	0.14	0.00	0.00	0.02
28	24	0.14	0.00	0.00	0.03
29	25	0.14	0.00	0.00	0.04
30	26	0.14	0.00	0.00	0.06
31	27	0.14	0.00	0.00	0.07
32	28	0.14	0.00	0.00	0.08
33	29	0.14	0.00	0.00	0.09
34	30	0.14	0.00	0.00	0.09
35	31	0.14	0.00	0.00	0.10
36	32	0.14	0.00	0.00	0.11
37	33	0.14	0.00	0.00	0.12
38	34	0.14	0.00	0.00	0.12

Row	F	G	H	I	J	K	L	M	N	O
3	Count	1005	Trilinear Regression						Regression Line	
4	Xp1	Xp2	Item	b3	b2	b1	b0	Item	X's	Predict Volts
5	0.59	1.66	Coefs	0.52884	0.50898	0.23727	0.047797	Coefs	0.00	0.05
6	Upper	19	SE b's	0.44784	0.11155	0.07582	0.030508	SE b's	0.59	0.19
7	Bound 1	Bound 2	R-Sqr	33.8%	0.32264	#N/A	#N/A	SE Pred	1.66	0.99
8	0.5	1.709	F	170.657	1001	#N/A	#N/A	DoF	2.00	1.42
9	Min Bin	15	SSR	53.2934	104.199	#N/A	#N/A	SSE		

Figure 7: Excel screen for trilinear regression analysis

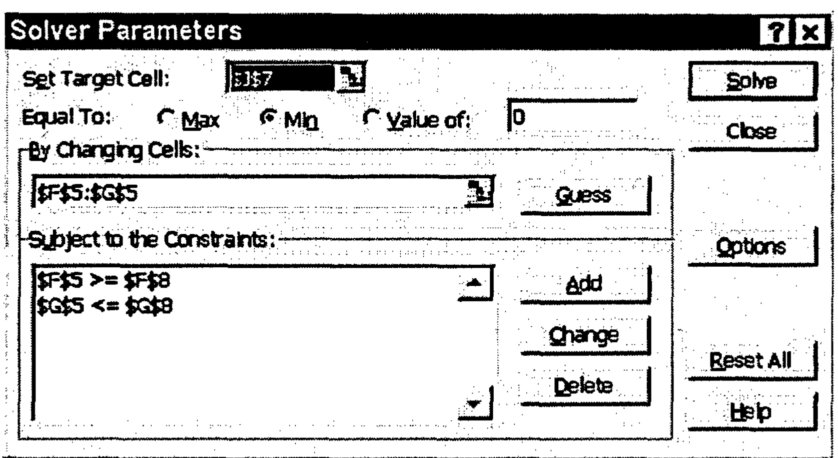


Figure 8: Excel solver screen for trilinear regression analysis

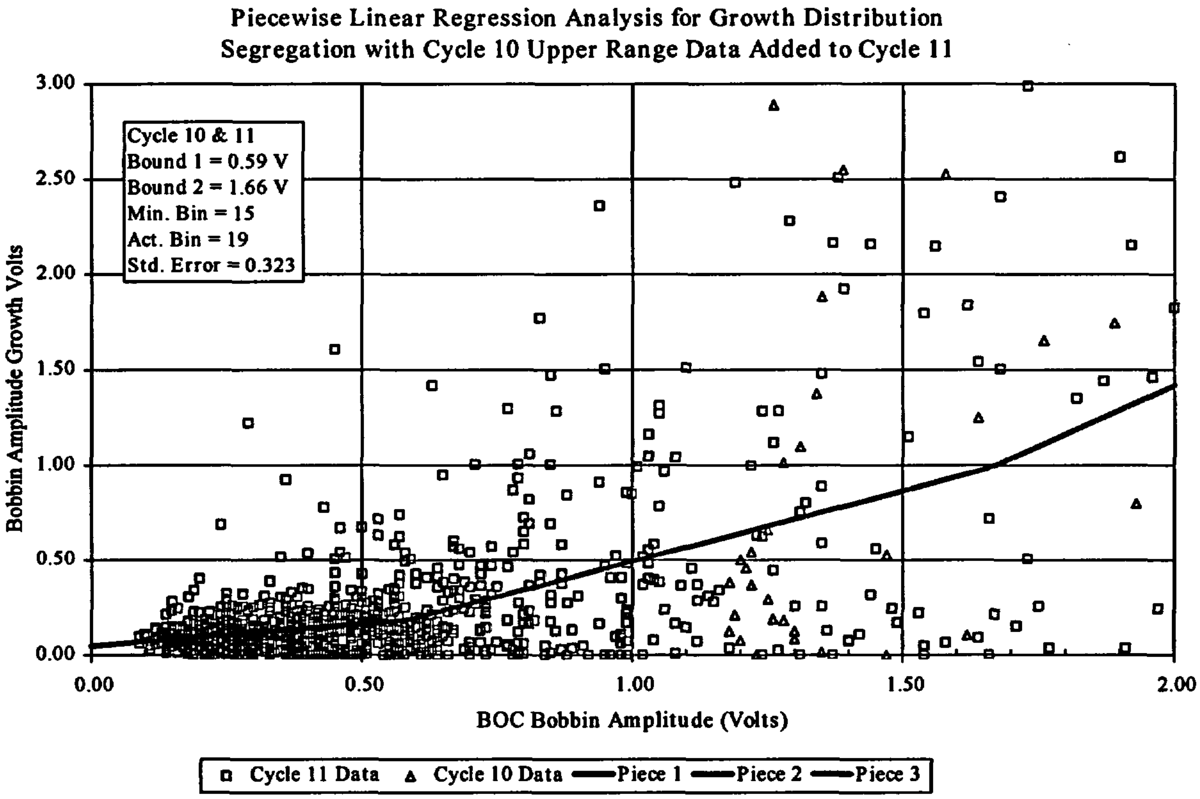


Figure 9: Trilinear regression lines for SG 2-4 Cycle 11 growth data

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
1	Quadrilinear Regression of Growth Data for SG 2-4, Cycle 11															
2									Cycle							
3		X1	X2	X3	X4				11	Quadrilinear Regression						
4	Index	Prev Voltage	Dummy 1	Dummy 2	Dummy 3	Volts / EFPY	Xp1	Xp2	Xp3	Item	b4	b3	b2	b1	b0	Item
5	1	0.09	0.00	0.00	0.00	0.06	0.61	1.10	1.58	Coefs	0.757186	-0.27413	0.579332	0.239746	0.047118	Coefs
6	2	0.09	0.00	0.00	0.00	0.10		Act. Bin	21	SE b's	0.50295	0.253105	0.151708	0.071886	0.028407	SE b's
7	3	0.10	0.00	0.00	0.00	0.10	Bound 1	Bound 2	Bound 3	R-Sqr	32.9%	0.29762	#N/A	#N/A	#N/A	SE Y
8	4	0.10	0.00	0.00	0.00	0.11	0.50	1.40	1.87	F	118.6568	970	#N/A	#N/A	#N/A	DoF
9	5	0.11	0.00	0.00	0.00	0.03		Min. Bin	15	SSR	42.04141	85.82058	#N/A	#N/A	#N/A	SSE
10	6	0.11	0.00	0.00	0.00	0.05										
11	7	0.11	0.00	0.00	0.00	0.07										
12	8	0.12	0.00	0.00	0.00	0.05										
13	9	0.12	0.00	0.00	0.00	0.08										
14	10	0.12	0.00	0.00	0.00	0.09										
15	11	0.12	0.00	0.00	0.00	0.09										
16	12	0.12	0.00	0.00	0.00	0.13										
17	13	0.12	0.00	0.00	0.00	0.13										
18	14	0.12	0.00	0.00	0.00	0.14										
19	15	0.13	0.00	0.00	0.00	0.06										
20	16	0.13	0.00	0.00	0.00	0.06										
21	17	0.13	0.00	0.00	0.00	0.06										
22	18	0.13	0.00	0.00	0.00	0.09										
23	19	0.13	0.00	0.00	0.00	0.10										
24	20	0.13	0.00	0.00	0.00	0.11										
25	21	0.13	0.00	0.00	0.00	0.12										
26	22	0.14	0.00	0.00	0.00	0.01										
27	23	0.14	0.00	0.00	0.00	0.02										
28	24	0.14	0.00	0.00	0.00	0.03										
29	25	0.14	0.00	0.00	0.00	0.04										
30	26	0.14	0.00	0.00	0.00	0.06										
31	27	0.14	0.00	0.00	0.00	0.07										
32	28	0.14	0.00	0.00	0.00	0.08										
33	29	0.14	0.00	0.00	0.00	0.09										
34	30	0.14	0.00	0.00	0.00	0.09										
35	31	0.14	0.00	0.00	0.00	0.10										
36	32	0.14	0.00	0.00	0.00	0.11										
37	33	0.14	0.00	0.00	0.00	0.12										
38	34	0.14	0.00	0.00	0.00	0.12										

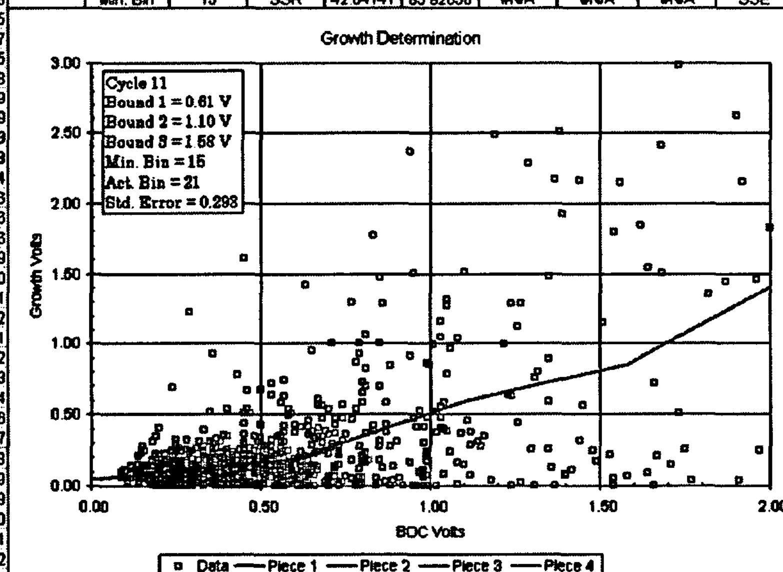


Figure 10: Excel screen for quadrilinear regression analysis

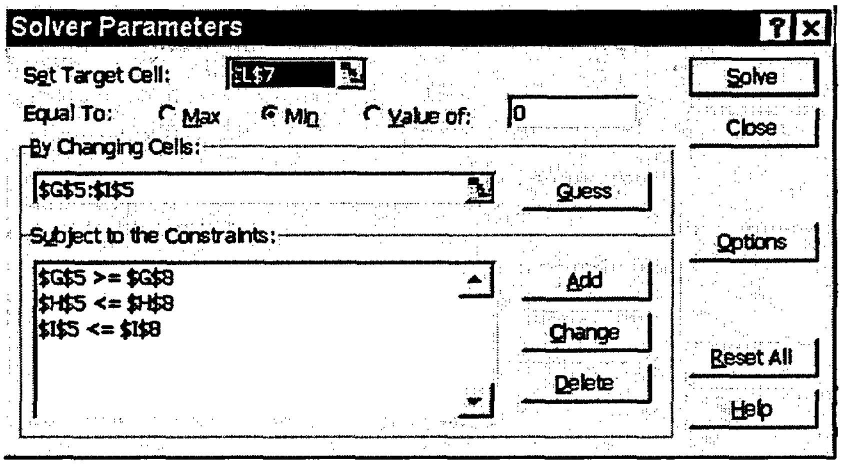


Figure 11: Excel solver screen for trilinear regression analysis

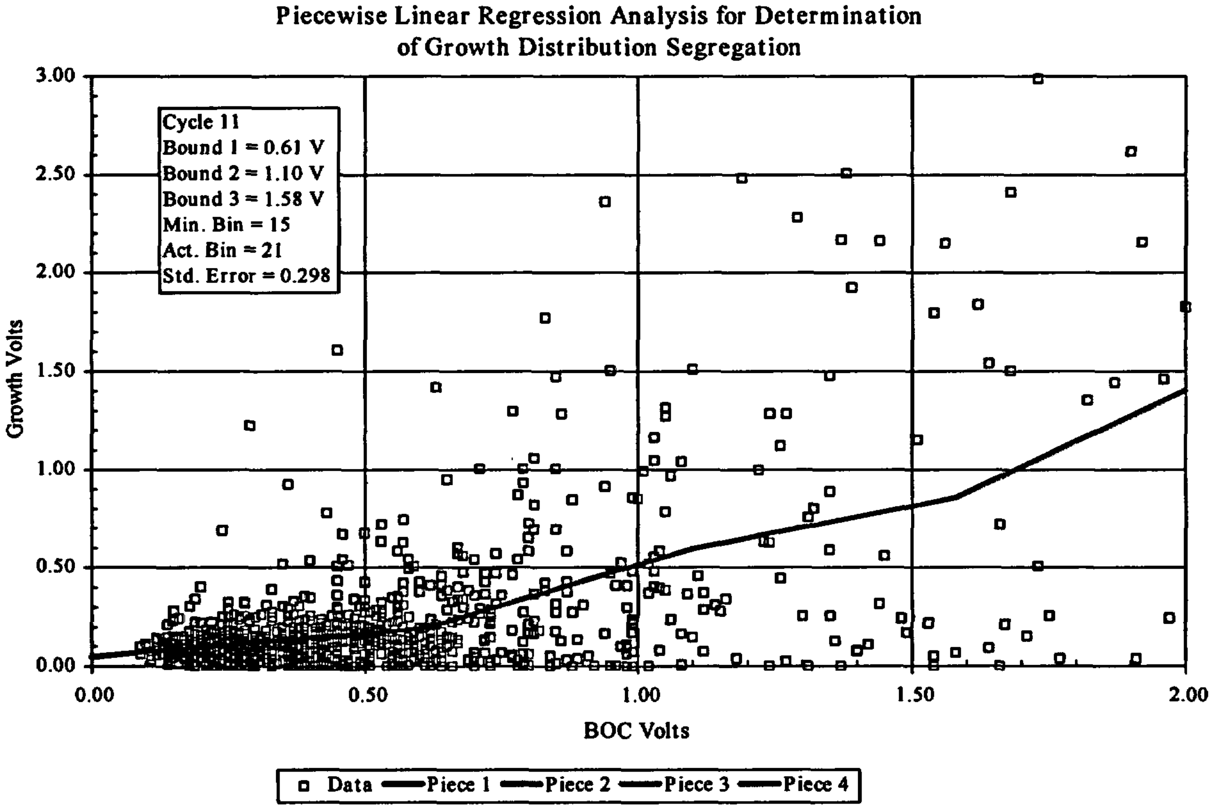


Figure 12: Quadrilinear regression of SG 2-4 Cycle 11 growth data

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
1	Trilinear Regression of Growth Data for SG 2-4, Cycle 10														
2															
3		X1	X2	X3				Tri-Linear Regression						Regression Line	
4	Index	Prev Voltage	Dummy 1	Dummy 2	Volts / EFPY	Xp1	Xp2		b3	b2	b1	b0		X's	Predict Volts
5	1	0.09	0.00	0.00	0.19	0.69	1.17	Coefs	0.75179	0.57116	0.11249	0.092858	Coefs	0.00	0.09
6	2	0.12	0.00	0.00	0.10	Element	30	SE b's	0.28264	0.17758	0.07993	0.035554	SE b's	0.69	0.17
7	3	0.12	0.00	0.00	0.41	Bound 1	Bound 2	R-Sqr	33.2%	0.25584	#N/A	#N/A	SE Pred	1.17	0.50
8	4	0.13	0.00	0.00	0.05	0.50	1.28	F	80.0806	484	#N/A	#N/A	DoF	2.00	1.69
9	5	0.13	0.00	0.00	0.14	Min Bin	15	SSR	15.7247	31.6798	#N/A	#N/A	SSE		
10	6	0.14	0.00	0.00	0.15										
11	7	0.14	0.00	0.00	0.15										
12	8	0.14	0.00	0.00	0.16										
13	9	0.14	0.00	0.00	0.20										
14	10	0.15	0.00	0.00	0.08										
15	11	0.15	0.00	0.00	0.09										
16	12	0.15	0.00	0.00	0.21										
17	13	0.16	0.00	0.00	0.01										
18	14	0.16	0.00	0.00	0.02										
19	15	0.16	0.00	0.00	0.03										
20	16	0.16	0.00	0.00	0.06										
21	17	0.16	0.00	0.00	0.11										
22	18	0.16	0.00	0.00	0.15										
23	19	0.16	0.00	0.00	0.16										
24	20	0.17	0.00	0.00	0.00										
25	21	0.17	0.00	0.00	0.04										
26	22	0.17	0.00	0.00	0.11										
27	23	0.17	0.00	0.00	0.21										
28	24	0.18	0.00	0.00	0.06										
29	25	0.18	0.00	0.00	0.10										
30	26	0.18	0.00	0.00	0.21										
31	27	0.18	0.00	0.00	0.22										
32	28	0.19	0.00	0.00	0.03										
33	29	0.19	0.00	0.00	0.15										
34	30	0.19	0.00	0.00	0.19										
35	31	0.20	0.00	0.00	0.00										
36	32	0.20	0.00	0.00	0.03										
37	33	0.20	0.00	0.00	0.03										
38	34	0.20	0.00	0.00	0.04										

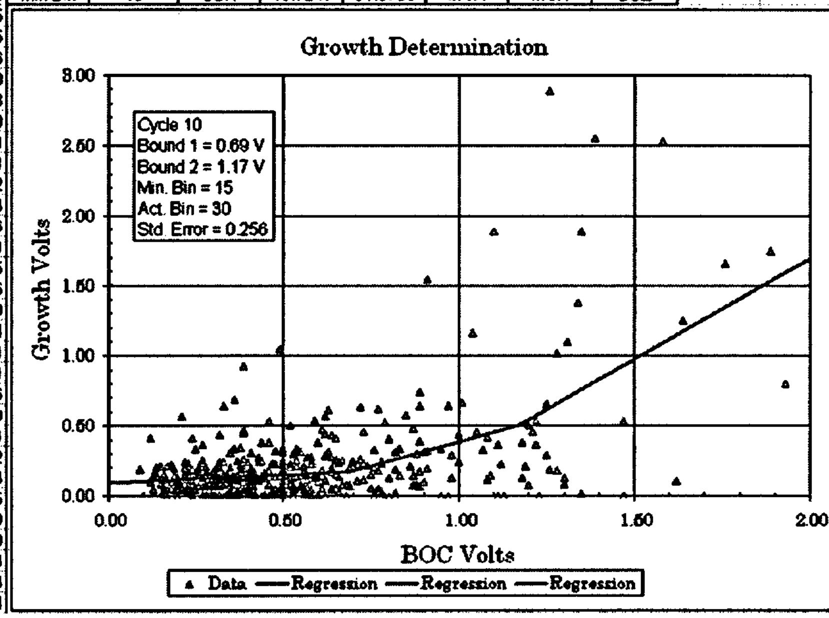


Figure 13: Excel screen for SG 2-4 Cycle 10 growth data

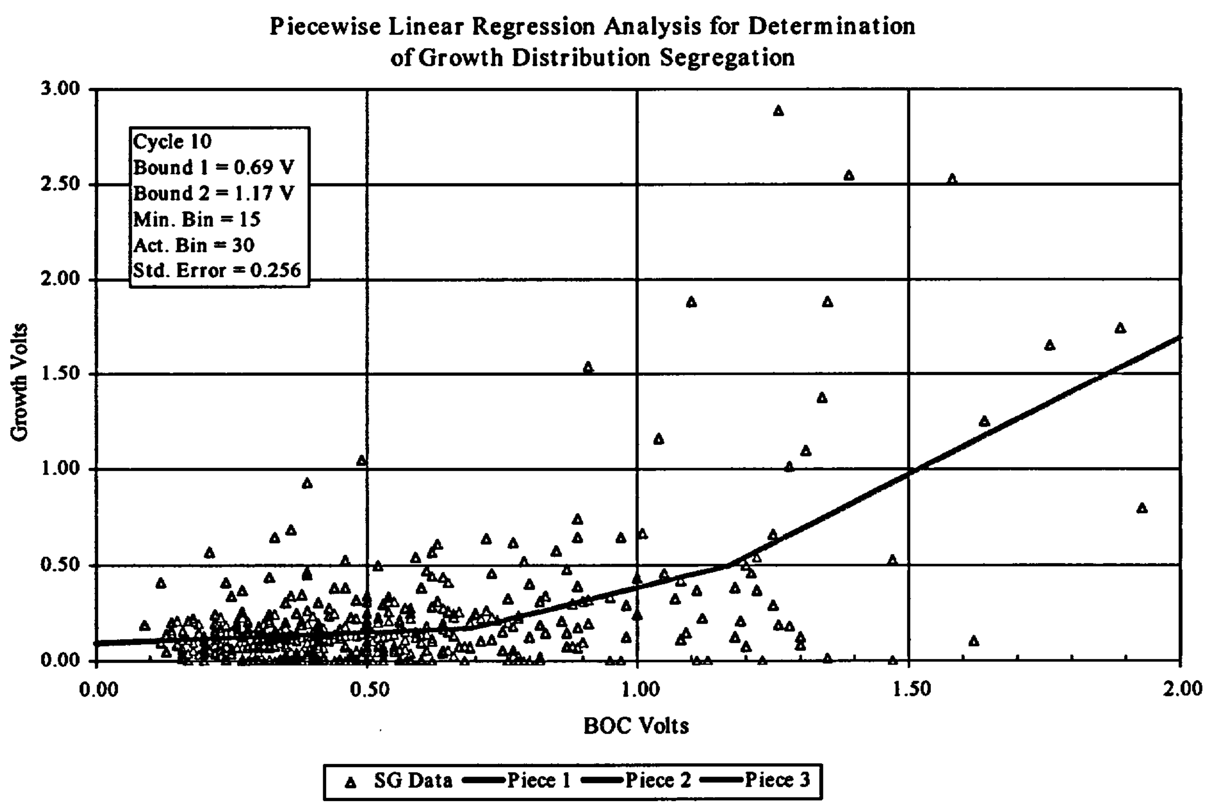


Figure 14: Trilinear regression of SG 2-4 Cycle 10 growth data

Illustration of an unsatisfactory analysis result.

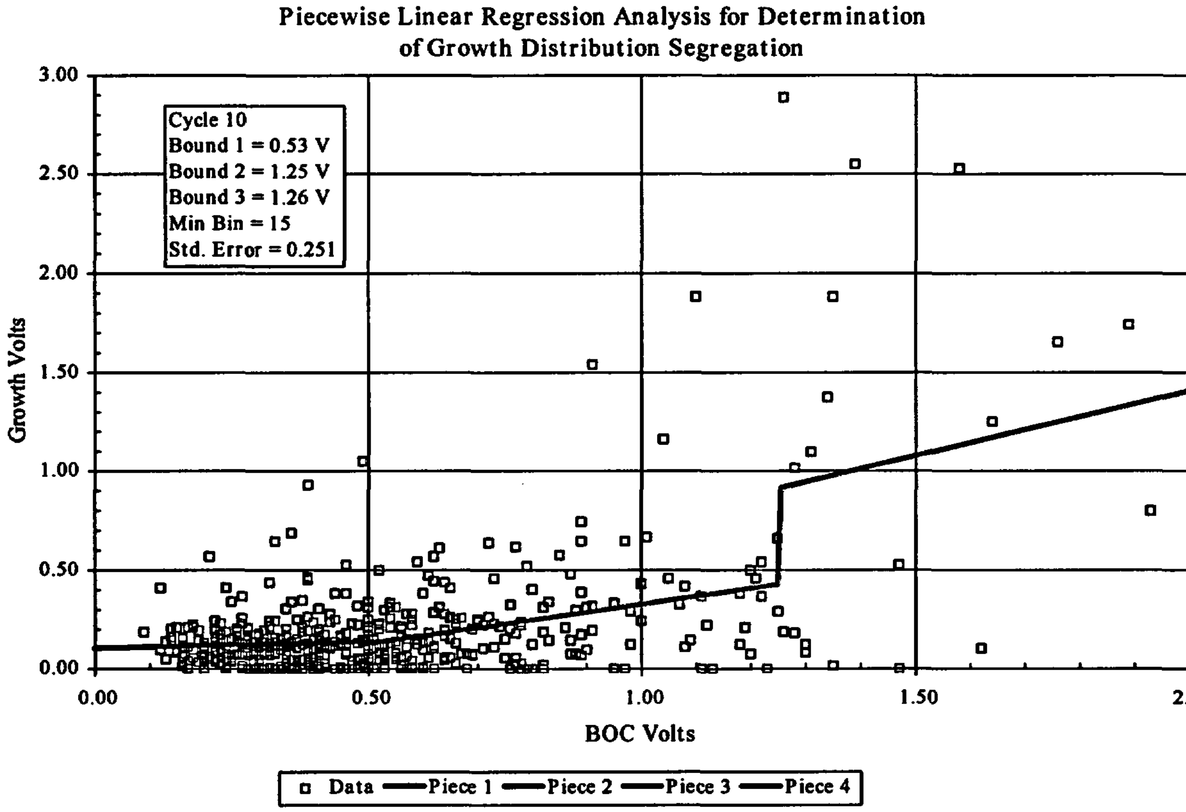


Figure 15: Quadrilinear regression w/o a data limit on Piece 3

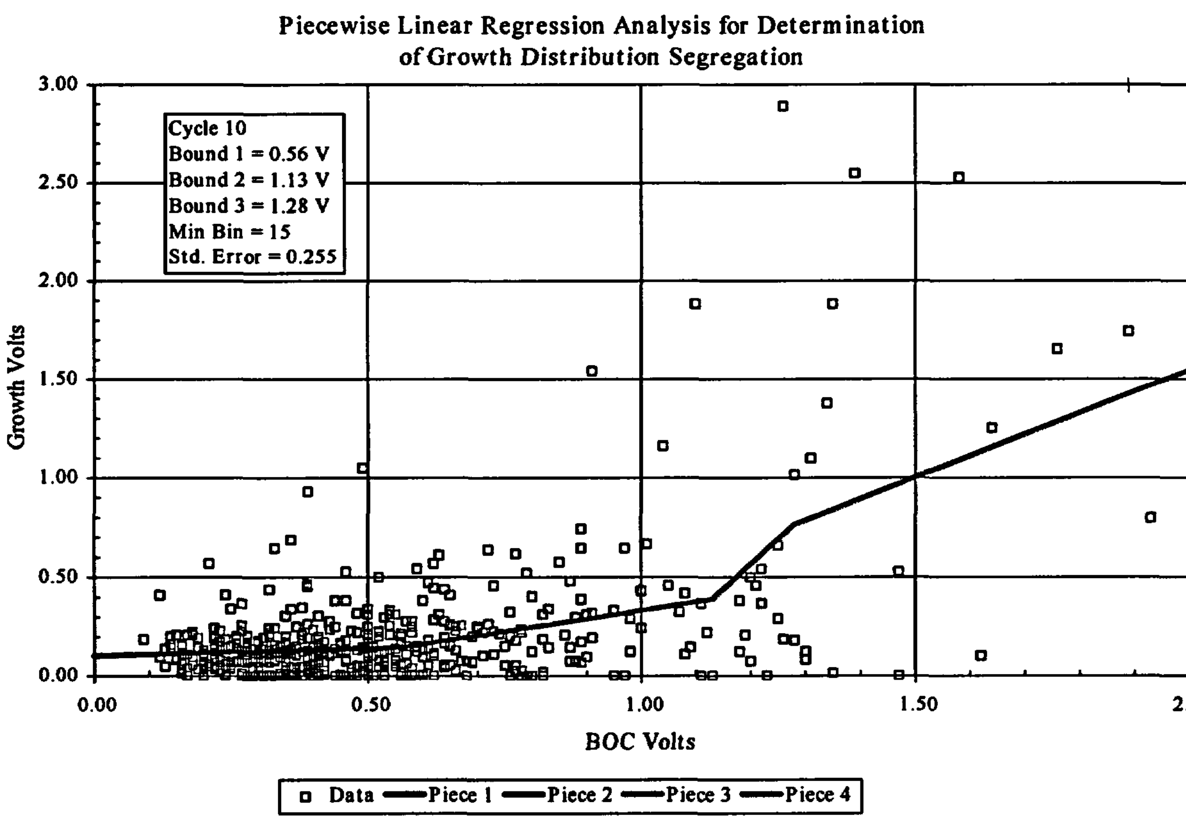


Figure 16: Quadrilinear regression of SG 2-4 Cycle 10 growth data