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June 2, 2004

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

SUBJECT: Generic Letter 95-05 Alternate Repair Criteria Methodology Updates

PROJECT NUMBER: 689

NRC Generic Letter 95-05 provides guidance for implementing an alternate repair criterion (ARC) for steam generator tubes with outside diameter stress corrosion cracking (ODSCC) at tube support plate (TSP) locations. In response to this generic letter, industry developed a database for use when inspecting tubing with this degradation mode and has periodically submitted addenda to update the database with current information. The last addendum (5) was submitted to you in February 2003. Addendum 6 should be completed this summer. The purpose of this letter is to submit in advance of addendum 6:

- An update on generic Probability of Prior Cycle Detection (POPCD) methods,
- A new methodology for applying voltage dependent growth (VDG) based on a statistical analysis, and
- Methods for potentially including the influence of extreme growth values in the ARC analyses (Outlier Method).

Your approval of the enclosed generic POPCD update is requested in time to allow use of the method during this fall's steam generator inspections. The NRC has indicated that a review of the Outlier Method will be necessary to support approval of POPCD. Therefore, your review of the Outlier Method should be planned accordingly. The VDG method is statistically based on a more formal methodology than the method used previously. Since the method implements the guidance of GL 95-05 to assess growth data for beginning-of-cycle dependence and does not conflict with the GL guidance, the VDG methodology does not appear to require NRC approval.

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The enclosed information should be reviewed concurrently with the new methods for preventive tube plugging and for dealing with eddy current signal noise during tube inspections. NEI submitted these methods to the NRC in April.

Enclosure 1 provides guidance for developing the probability of detecting steam generator (SG) tubing degradation based on the "Probability of Prior Cycle Detection". The POPCD method was initially described in Reference 1, and the latest update to the data was provided in Reference 2. NRC has already approved POPCD on a plant-specific basis for one cycle at Diablo Canyon Unit-2 (Reference 3). Pacific Gas and Electric requested NRC approval of these POPCD methods for long term application to Diablo Canyon Units 1 and 2 in PG&E letter to NRC dated March 18, 2004 (License Amendment Request 04-01).

Enclosure 2 provides methods for potentially including the influence of extreme growth values in the ARC analyses (Outlier Method). The recommended method described in Section 6.3 of the enclosure, samples the historically based distribution and frequency of large extreme growth values, which are dependent upon tube size. This Outlier Method is to be applied in conjunction with POPCD in the determination of a licensee's "Probability of Detection" (POD).

Enclosure 3 provides methods developed for applying "Voltage Dependent Growth Break Point Determination" (VDG) based on a statistical analysis that defines the number and voltage values for the break points between voltage growth bins. The VDG methods in the previous ARC database addenda were developed from Braidwood and Byron experiences and were assumed to be necessary only with the application of a 3 volt ARC limit. The Diablo Canyon Unit 2 (DCPP2) experience in 2003 demonstrated that voltage dependent growth could become significant for repair limits of 2 volts.

The proprietary information in Enclosures 1 through 3 is supported by the signed affidavits in Enclosure 4. The affidavits set forth the basis on which the information may be withheld from public disclosure by the Commission and addresses with specificity, the consideration listed in paragraph (b)(4) of Section 2.790 of the Commission's regulations. Accordingly, we respectfully request that the information, which is proprietary to EPRI, be withheld from public disclosure in accordance with 10 CFR 2.790. The non-proprietary version of this information is provided in Enclosure 5 through 7.

Consistent with previous submittals supporting NRC review of GL 95-05 data base addenda, we believe any NRC staff review of the enclosed information is exempt from the fee recovery provision contained in 10 CFR Part 170. This submittal provides information that may be helpful to NRC staff when evaluating licensee submittals provided in response to Generic Letter 95-05. Such reviews are exempted under §170.11, Exemptions, Subpart (a)(1)(iii). This provision states, (a)

"No application fees, license fees, renewal fees, inspection fees, or special project fees shall be required for...(1) A special project that is a request/report submitted to the NRC--(iii) as a means of exchanging information between industry organizations and the NRC for the specific purpose of supporting the NRC's generic regulatory improvements or efforts".

If you have any questions on this matter, please contact me, 202-739-8080; am@nei.org or Jim Riley at 202-739-8137; jhr@nei.org.

Sincerely,

Alex Marion

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Enclosures

c: Jack R. Strosnider, Jr, NRC
Louise Lund, NRC
Kenneth Karwoski, NRC
Emmett Murphy, NRC

References:

1. EPRI Topical Report NP 7480-L, Addendum 1, "Steam Generator Tubing Outside Diameter Stress Corrosion Cracking at Tube Support Plates Database for Alternate Repair Limits 1996 Database Update," dated November 1996.
2. EPRI Topical Report NP 7480-L, Addendum 5, "Steam Generator Tubing Outside Diameter Stress Corrosion Cracking at Tube Support Plates Database for Alternate Repair Limits, Update 2002," dated January 2003.
3. NRC Letter, G. S. Shukla (NRC) to G. M. Rueger (PG&E), "Review of Diablo Canyon Nuclear Power Plant, Unit No. 2 – Issuance of Amendment – Revised Steam Generator Voltage-Based Repair Criteria Probability of Detection Method for Diablo Canyon Unit 2 Cycle 12 (TAC No. MB9742)," dated October 21, 2003.

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PROBABILITY OF PRIOR CYCLE DETECTION UPDATES

Non-Proprietary Version

Enclosure 5

Probability of Prior Cycle Detection (POPCD) Updates

1.0 Introduction

This report provides guidelines for developing steam generator (SG) detection probabilities based on the Probability of Prior Cycle Detection (POPCD). The POPCD method was initially described in Reference 1 with the latest update to the data provided in Reference 2 and was developed for application with the NRC GL 95-05 (Reference 3) voltage based repair criteria. GL 95-05 requires NRC approval for implementing POPCD. This report provides POPCD guidelines and results supporting a generic industry POPCD submittal for NRC approval, and includes an option for applying a plant specific POPCD when adequate data is available on a plant specific basis. NRC approval of POPCD was provided for DCPP Unit-2, Cycle 12 in Reference 4. The POPCD guidelines and data of this report reflect changes to References 1 and 2 based on the NRC review reflected in the DCPP approval of Reference 4.

POPCD is defined in Section 2 including the classification of indications for POPCD analyses. Methods for calculating POPCD distributions including uncertainties are given in Section 3. Growth rate and noise considerations for POPCD applications are provided in Sections 4 and 5. Section 6 summarizes benchmarking results for industry wide POPCD applications. Section 7 provides the POPCD evaluation for the industry database with Section 8 defining requirements for applying plant specific POPCD distributions. Sections 9 and 10 provide reporting requirements for POPCD applications and conclusions of the report. References are provided in Section 11.

2.0 POPCD Definition and Classification of Indications

2.1. POPCD Definition

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

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

Notes for POPCD definition:

1. RPC is intended to include an RPC probe or equivalent such as a +Point coil.
2. RPC confirmed means a bobbin flaw signal was detected with a RPC probe.
3. Not RPC inspected means a flaw signal was detected with a bobbin probe and was not further inspected with a RPC probe.

This definition of POPCD is based on the premise that all indications that can contribute significantly to burst and leakage for voltage-based repair criteria application can be confirmed by rotating pancake coil (RPC) inspections. The term RPC is meant to include an RPC probe or equivalent, which includes a +Point coil. The POPCD definition that is used for ODSCC ARC analyses is based on RPC confirmed indications plus indications not RPC inspected.

This application of the RPC results is applied to exclude from POPCD the probable false bobbin calls that would not contribute to tube integrity concerns at EOC_{n+1} for both previously reported and new indications. The use of RPC confirmation provides a measure of confidence that irrelevant prior and new bobbin calls are not allowed to influence the POD either as an increase or a decrease in the POD. EOC_n bobbin calls that were RPC no detectable degradation (NDD) at EOC_n but were RPC confirmed or not inspected at EOC_{n+1} are included in POPCD as bobbin detected indications at EOC_n. This can be interpreted as a difference in the application of RPC to define a 'true' indication at EOC_{n+1} from that at EOC_n. The intent is that the EOC_{n+1} RPC should define the significance of the bobbin indication for POD considerations such that the insignificant RPC NDD indications are excluded from POPCD for both previously reported and new bobbin indications. The inclusion of RPC NDD EOC_n bobbin indications as detected indications in POPCD when RPC confirmed or not inspected at EOC_{n+1}, but excluding EOC_{n+1} RPC NDD from POPCD is consistent with the GL 95-05 Section 2.b.1 guidelines. This guideline requires that all bobbin indications at EOC_n are to be included in the OA independent of RPC confirmation with the alternative, upon NRC approval, that a fraction of RPC NDD indications may be excluded. The appropriate fraction to exclude would be the indications that remain RPC NDD at EOC_{n+1}, which is the fraction excluded from POPCD. In addition, including the EOC_n RPC NDD in the BOC_{n+1} population together with decreasing POPCD by considering these indications as undetected approximates double accounting for these indications in defining the BOC_{n+1} population. If GL 95-05 is revised to exclude all RPC NDD from the OA BOC_{n+1} population, it would be acceptable to define the EOCn RPC NDD bobbin indications as undetected in the POPCD calculations.

The POPCD approach treats all new indications at an inspection as having been undetected at the prior inspection even though some of the new indications may have initiated during the operating cycle. The application of POPCD for OA then accounts for newly initiated indications as well as previously undetected indications. This differs from the conventional POD definitions based on only detection of known flaws, but is applied for the operational assessments to eliminate the need for additional terms to account for newly initiated indications.

The single-cycle basis for a POPCD evaluation assumes that large flaws would be detected during the EOC_{n+1} inspection. This assumption is supported by the industry POPCD database of 37 inspections. The multi-cycle development of a POPCD database over sequential inspections provides additional assurance that the potential for large undetected indications is included in POPCD. If an indication is undetected, it can be expected to grow over subsequent inspections to a detectable level. When detected, it is included at the BOC voltage as an undetected or new indication. As an example, for a 3-volt undetected indication, it can be expected that further growth would lead to detection at the next inspection and the indication would be included in POPCD as a 3-volt undetected indication. The industry data includes up to 5 successive inspections in a plant with noise levels (i.e., support plate residuals) significantly higher than currently active SGs. Nine inspections from the 2 units of the plant with high noise levels account for 70 percent of the new or undetected indications above 1.6 volts, including 4 of the 5 new indications above 2.5 volts in the industry database. However, none of the undetected indications exceeded 3.2 volts.

2.2. Classification of Indications and Assignment for POPCD Analyses

3.0 Calculation of the POPCD Distribution Including Uncertainties

3.1. Loglogistic Fitting

3.2. Monte Carlo Techniques

3.3. Goodness of Fit Assessment

4.0 Growth Rate Considerations for POPCD Applications

4.1. Provision for Outlier Growth Rates

4.2. Development of Growth Rate Distributions

5.0 Noise Considerations for POPCD Applications

6.0 Benchmarking of POPCD

7.0 POPCD Evaluation for the Industry Database

7.1. Industry POPCD Distribution

7.2. Effect of Uncertainties in the Upper Voltage Range

7.3. Comparisons of Industry POPCD with DCPP POPCD, ANL POD from Round Robin Testing and EPRI POD from Multiple Analyst Testing

8.0 Option for Developing Plant Specific POPCD Distributions

9.0 Continuing Assessment and Reporting for POPCD

10.0 Conclusions

11.0 References

1. EPRI Topical Report NP 7480-L, Addendum 1, "Steam Generator Tubing Outside Diameter Stress Corrosion Cracking at Tube Support Plates Database for Alternate Repair Limits 1996 Database Update," dated November 1996.
2. EPRI Topical Report NP 7480-L, Addendum 5, "Steam Generator Tubing Outside Diameter Stress Corrosion Cracking at Tube Support Plates Database for Alternate Repair Limits, Update 2002," dated January 2003.
3. Generic Letter 95-05, "Voltage-Based Repair Criteria for Westinghouse Steam Generator Tubes Affected by Outside Diameter Stress Corrosion Cracking," dated August 3, 1995
4. NRC Letter, G. S. Shukla (NRC) to G. M. Rueger (PG&E), "Review of Diablo Canyon Nuclear Power Plant, Unit No. 2 – Issuance of Amendment – Revised Steam Generator Voltage-Based Repair Criteria Probability of Detection Method for Diablo Canyon Unit 2 Cycle 12 (TAC No. MB9742)," dated October 21, 2003.
5. EPRI Report, "Extreme Values of ODSCC ARC Indications or Growth," unpublished, prepared for submittal to the NRC.
6. EPRI Report, "Voltage Dependent Growth Breakpoints Determination," unpublished, prepared for submittal to the NRC.
7. WCAP-14277, Revision 1, "SLB Leak Rate and Tube Burst Probability Analysis Methods for ODSCC at TSP Intersections," December 1996
8. Nuclear Energy Institute Letter, D. Modeen (NEI) to Document Control Desk (NRC), "Steam Generator Degradation Specific Management Database, Addendum 2 and Responses to NRC Requests for Additional Information (RAI)," dated September 14, 1998.
9. Letter from Lawrence F. Womack, PG&E, to the NRC, "Diablo Canyon Unit 2, PG&E Response to NRC Questions on 2R11 Steam Generator Tube Inspections," dated September 30, 2003.
10. Letter from David H. Oatley, PG&E, to the NRC, "Supplemental Information to Support License Amendment Request 03-10, Revised Steam Genertor Voltage-based Repair Criteria Probability of Detection Method for Diablo Canyon Unit 2 Cycle 12," dated September 3\0, 2003
11. NUREG/CR-6791, ANL-02/07, "Evaluation Current Reliability Results from the Steam Generator Mock-Up Analysis Round-Robin," Published November 2002, Argonne National Laboratory.
12. Jackson, P. S., EPRI Project 6424/RP-3580, Tetra Eng. Group, Inc., TR-95-001, "Probability of Detection by Bobbin Inspection," February 6, 1995.

Table 1: Data Table for Tracking Indications Between EOCn and EOCn+1

EOCn				BDD at EOCn+1						BND at EOCn+1					
				BDD w/o RPC		BDD w/RDD		BDD w/RND		BND w/o RPC		BND w/RDD		BND w/RND	
				Plugged	Not Plugged	Plugged	Not Plugged	Plugged	Not Plugged	Plugged	Not Plugged	Plugged	Not Plugged	Plugged	Not Plugged
BDD at EOCn	BDD w/o RPC														
	BDD w/ RDD														
	BDD w/ RND														
BND at EOCn	BND w/o RPC														
	BND w/ RDD														
	BND w/ RND														

General Notes:

- The column letters correspond to the column letters in POPCD Table 2.
- No Count = Indications not detected by bobbin or RPC are not counted or needed for POPCD.
- BDD = Bobbin detected indication
- BND = Bobbin NDD intersection
- RDD = RPC detected indication
- RND = RPC NDD intersection

Specific Notes:

1) For EOCn bobbin indications that are confirmed by RPC or detected only by RPC, EOCn+1 RPC should be performed when bobbin is NDD and the number in this category will be "0" for future inspections.

2) If indications are RPC confirmed at EOCn but RPC NDD at EOCn+1, the causative factors for this change in RPC detection should be discussed in the ARC 90 day report

Table 2. 7/8" Plant Data Summary Evaluation for POPCD

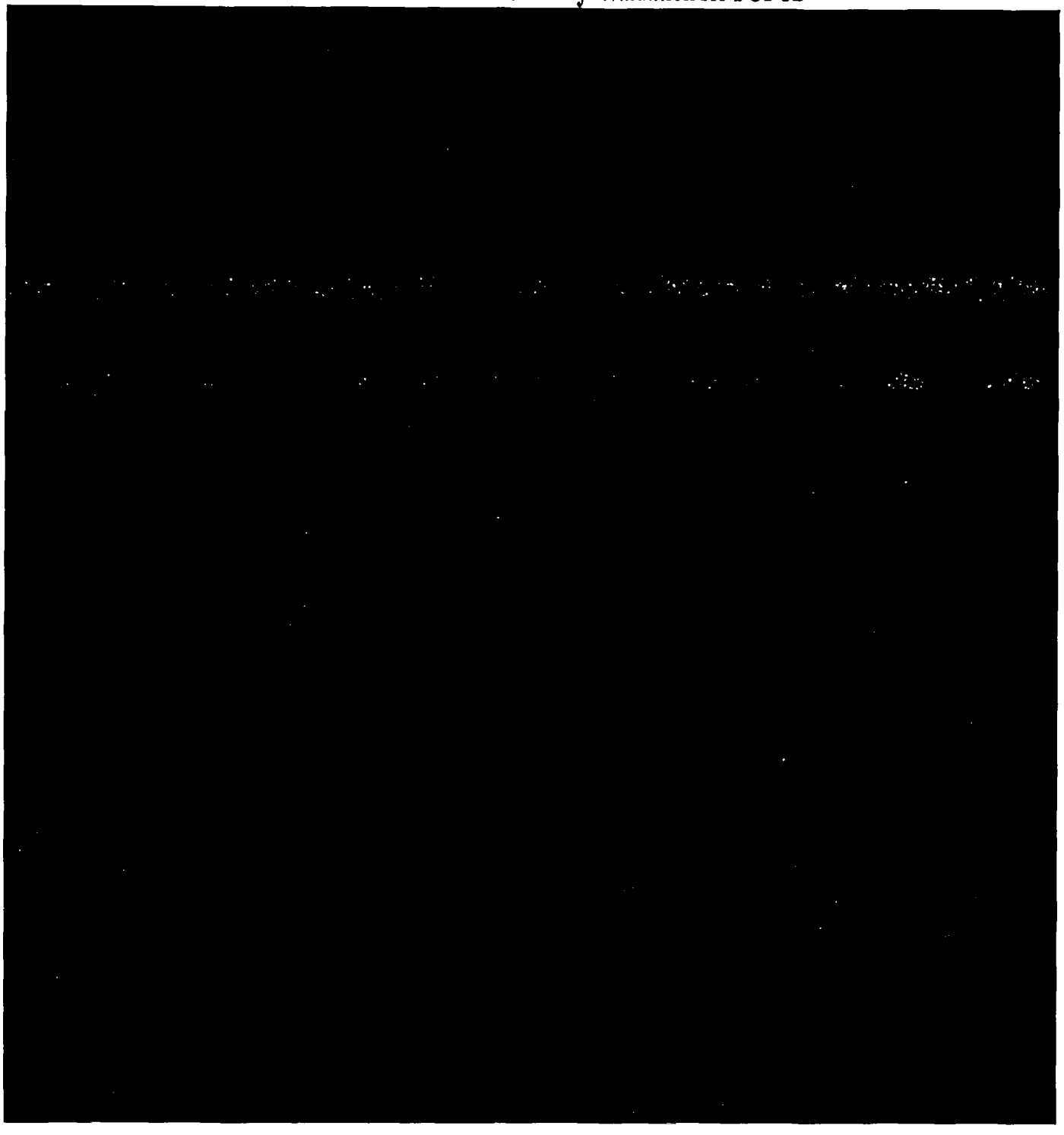

Table 2. 7/8" Plant Data Summary Evaluation for POPCD (con't)

[redacted]

Table 3. 3/4" Plant Data Summary Evaluation for POPCD

[redacted]

Table 3. 3/4" Plant Data Summary Evaluation for POPCD (con't)

[redacted]

Table 4. 3/4" and 7/8" Summary Evaluation for POPCD

[redacted]

Table 4. 3/4" and 7/8" Summary Evaluation for POPCD (con't)

[redacted]

Figure 1

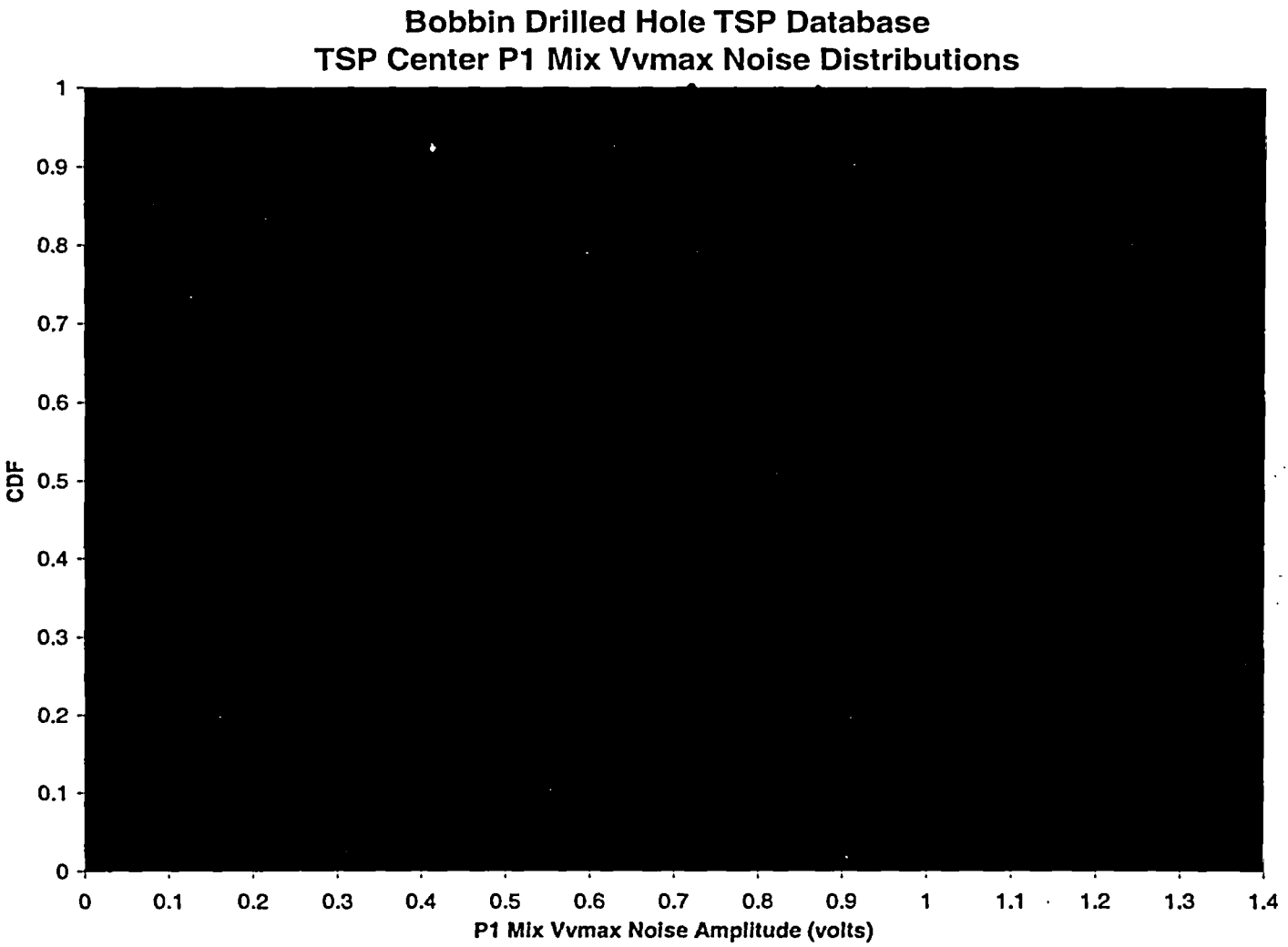
Bobbin Drilled Hole TSP Database
TSP Center P1 Mix Vvmax Noise Distributions
CDF
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
1.1
1.2
1.3
1.4
P1 Mix Vvmax Noise Amplitude (volts)

Figure 2

Generic Industry POPCD as Function of Bobbin Amplitude: 7/8" Tubing

Weighted Generalized Linear Model Loglogistic Solution

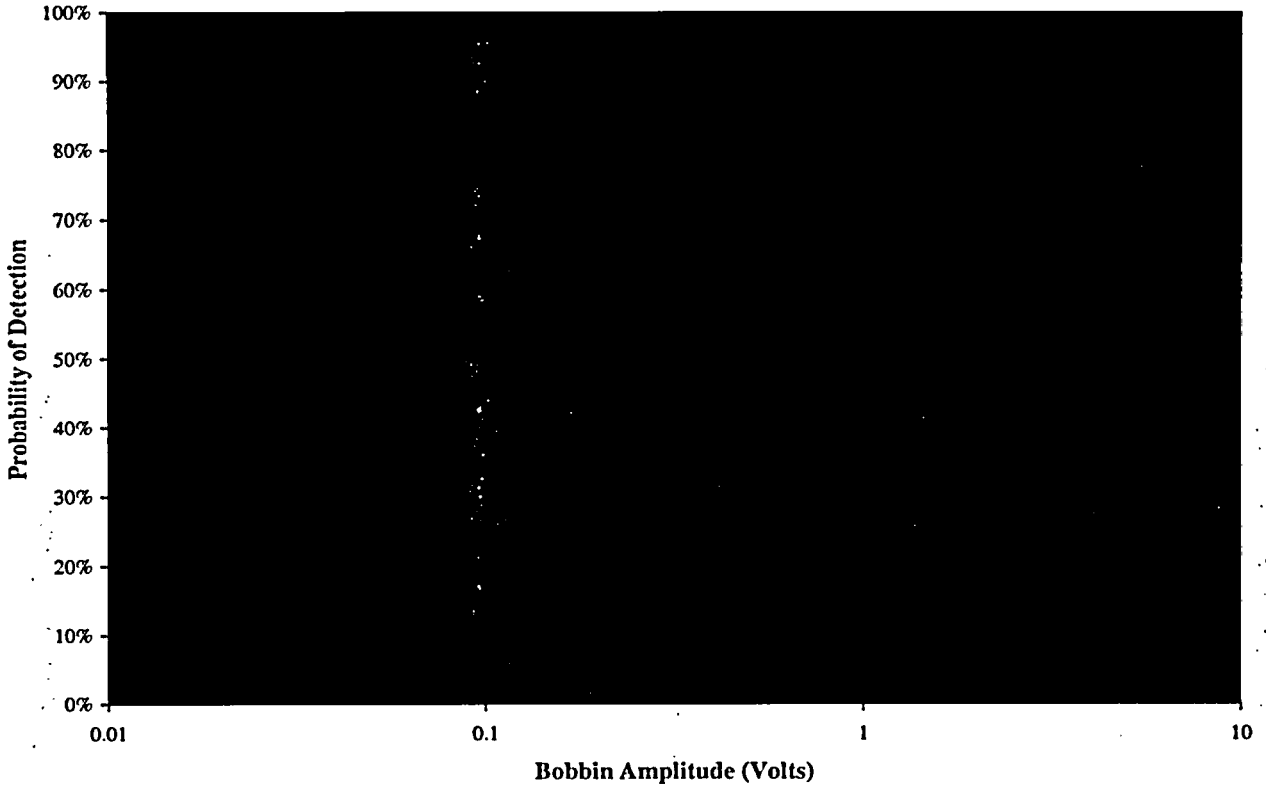

Figure 3

Generic Industry POPCD as Function of Bobbin Amplitude: 3/4" Tubing

Weighted Generalized Linear Model Loglogistic Solution

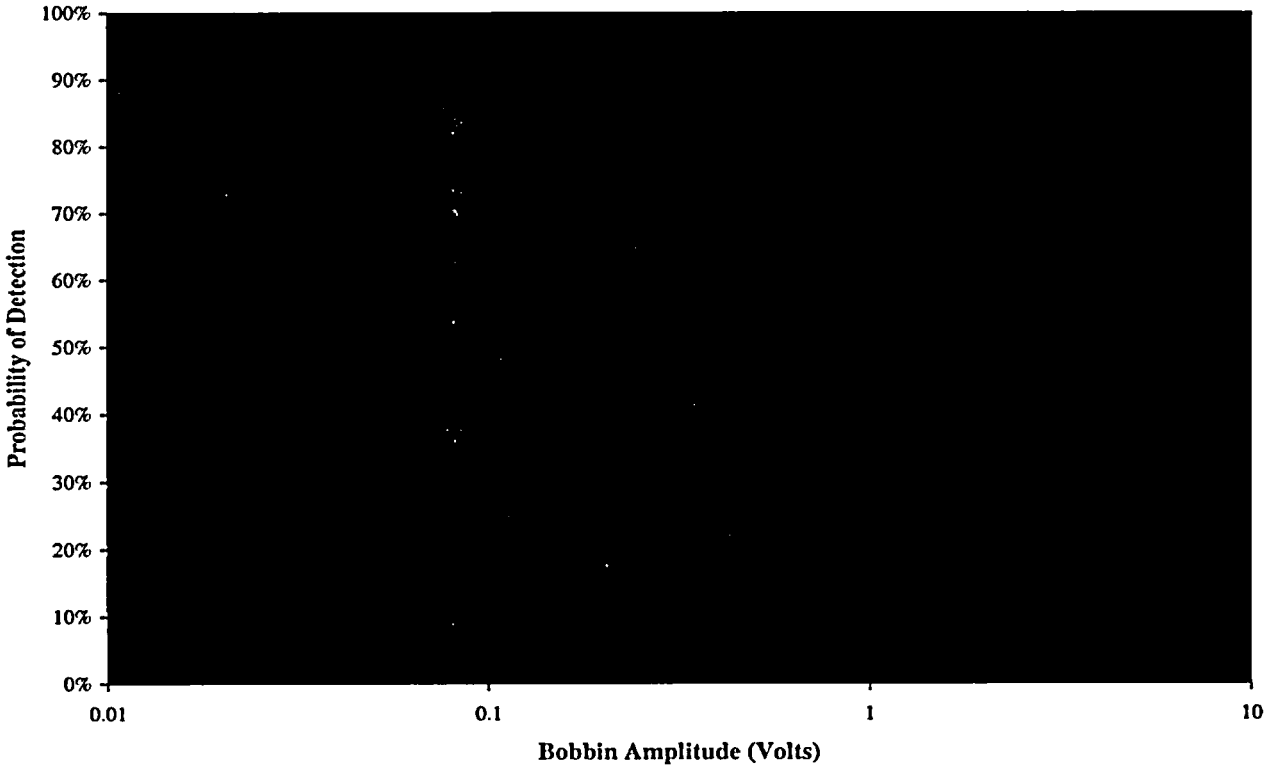

Figure 4

Generic Industry POPCD as Function of Bobbin Amplitude
Comparison of Combined 7/8" + 3/4" POPCD with 7/8" POPCD and 3/4" POPCD
Weighted Generalized Linear Model Loglogistic Solution

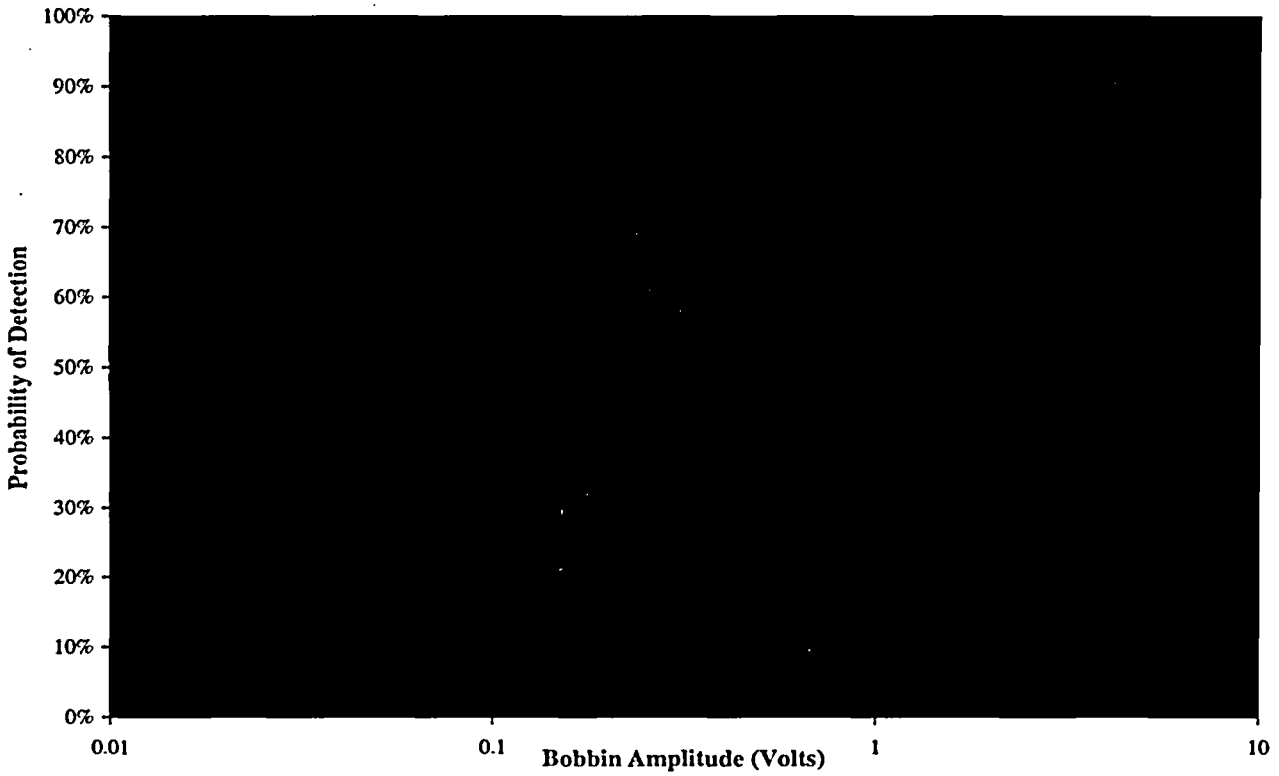

Figure 5

Figure 6

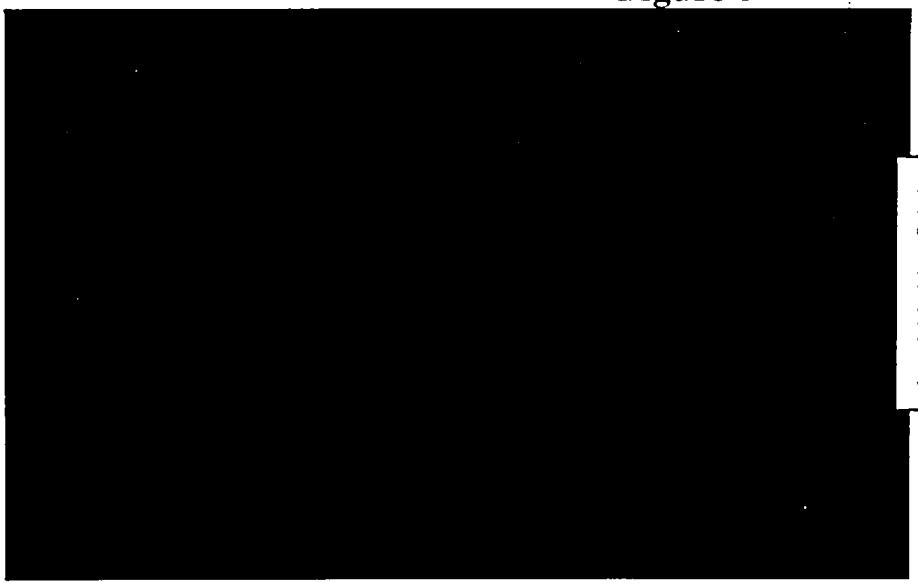

Figure 4a. (Percent of Correct TSP BC Calls) Results as a function of Bobbin Coil voltage for TSP cracks. The POD has been evaluated for ODSCC at the TSP.

Figure 4b. (POD) Logistic fit curves for BC POD as a function of voltage for Axial ODSCC and IDSCC in TSP.

Figure 7

Figure 8

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EXTREME VALUES OF ODSCC INDICATIONS OR GROWTH

Non-Proprietary Version

Enclosure 6

Extreme Values of ODSCC ARC Indications or Growth

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Extreme Values of ODSCC ARC Indications Growth

1.0 INTRODUCTION

Alternate repair criteria (ARC) have been in use for outside diameter stress corrosion cracking (ODSCC) indications in steam generator (SG) tubes since the early 1990's[1]. The criteria apply to tubes in Westinghouse SGs with drilled hole tube support plates (TSPs) when the cracking is confined to the crevice between the tube and the TSP. A detailed description of the criteria and the conditions for their application is provided in Generic Letter (GL) 95-05, Reference 1, issued by the United States Nuclear Regulatory Commission (NRC). The ARC replace the 40% depth criterion generally used for SG tube degradation with a repair limit based of the eddy current test (ECT) bobbin coil amplitude. The ARC plugging limit for plants with 3/4 inch nominal diameter tubes is 1 volt and the limit for plants with 7/8 inch diameter tubes is 2 volts.[2] Typical maximum or extreme indication amplitudes are usually expected to be on the order of 5V. The largest value found in an inspection of a SG is an extreme, although extremes may also be defined as any indication exceeding a specified threshold. The values meeting the latter definition are usually referred to as exceedances. Five methods are evaluated in this report for potentially including the influence of extreme growth values in the ARC analyses. The recommended method, as noted in Section 11.0, is described in Section 6.3 and is based on sampling the frequency and distribution of large extreme growth values, which are dependent upon tube size based on historical data. This extreme growth methodology is to be applied in conjunction with the use of POPCD as the licensed POD since the use of a POD of 0.6 already includes large numbers of high voltage indications in the BOC distribution

[1] The first applications were referred to as interim plugging criteria or IPC.
[2] Specific exceptions to these standard limits have been approved for use by the NRC staff on a case basis.

2.0 REGULATORY TOPICS OF INTEREST

2.1 Function of the Analysis

2.2 The "Fractional Flaw Paradox"

2.3 Extreme Growth of Indications at V. C. Summer

3.0 OBJECTIVE OF THE ANALYSES

4.0 DISTRIBUTION OF ODSCC ARC GROWTH RATES

4.1 Analysis of SG Data

4.2 Generic Letter Requirements

3

4.3 Root Cause of Extreme Growth

4.4 Growth Rate Predictions

5.0 POTENTIAL APPROACHES

6.0 INSERTION OF RANDOM EXTREME VALUES

6.1 Factors Affecting Growth

6.1.1 Maturity of the Population of Indications

6.1.2 Number of Indications in the SG

6.1.3 Chemistry of the Secondary Side

6.1.4 Temperature of Operation

6.1.5 Normal Operation Differential Pressure

6.1.6 Adjustment of Voltage Growth

6.2 Simulation Approach Based on SG ARC Applications

6.3 Simulations Based on the Total Number of Indications

7.0 EXTREME VALUE DISTRIBUTIONS

8.0 FITTING A DISTRIBUTION FUNCTION TO THE GROWTH RATE

9.0 EMPIRICAL/EXPONENTIAL SIMULATION OF GROWTH RATES

4

9.1 The Empirical Model

9.2 Fitting the Exponential Distribution

9.3 Simulation of the Empirical-Exponential Distribution

9.4 Conclusions

10.0 CHEBYSHEV'S INEQUALITY

11.0 SUMMARY/RECOMMENDATION

12.0 REFERENCES

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2. Presentation Material, "DCPP Unit 2 Steam Generators Operational Assessment for Voltage-Based Alternate Repair Criteria," PG&E and NRC Staff Meeting, One White Flint, Rockville, MD, pp. 42–56 (April 15, 2003).
3. DCL-03-076, "Docket No. 50-323, OL-DPR-82 Diablo Canyon Unit 2 Special Report 03-02 – Results of Steam Generator Inspections for Diablo Canyon Power Plant Unit 2 Eleventh Refueling Outage," Pacific Gas & Electric Company, Diablo Canyon Power Plant, Avila Beach, CA (June 23, 2003).
4. NRC IN 2003-13, "Steam Generator Tube Degradation at Diablo Canyon," United States Nuclear Regulatory Commission, Office of Nuclear Reactor Regulation, Washington, DC (August 28, 2003).
5. NP-7480L, "Steam Generator Tubing Outside Diameter Stress Corrosion Cracking at Tube Support Plates Database for Alternate Repair Criteria, 1996 Database Update," a.k.a. Addendum 1, EPRI, Palo Alto, CA (1996).
6. LTR-SGDA-03-137, "Voltage Dependent Growth Bin Width Determination," Westinghouse Electric Company LLC, Madison, PA (June 17, 2003).
7. Presentation Material, "DCPP Unit 2 Steam Generators Operational Assessment and Cause Analysis," PG&E and NRC Staff Meeting, One White Flint, Rockville, MD, pp. 42–56 (March 4, 2003).
8. Presentation Material, "DCPP Unit 2 Steam Generators Operational Assessment for Voltage-Based Alternate Repair Criteria," PG&E and NRC Staff Meeting, One White Flint, Rockville, MD (April 15, 2003).
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Tables

Table 1: List of Plants That Use/Used the ODSCC ARC		
Index	Plant	Still In-Use

Table 2: List of Extreme Growth Values, Volts/EFPY Adjusted to 610°F				
Index	Plant Name	Plant ID	Tube Size (inch)	Growth, ΔV (Volts)

Table 3: Listing of Extremes of Growth (Spring 2004, M = 115,179 Indications)						
Index	Tube Diameter	Indications N	ΔV_2 600°F	ΔV_2 603°F	ΔV_2 610°F	ΔV_2 620°F

Table 3: Listing of Extremes of Growth (Spring 2004, M = 115,179 Indications)						
Index	Tube Diameter	Indications N	ΔV_2 600°F	ΔV_2 603°F	ΔV_2 610°F	ΔV_2 620°F

Table 4: Summary of Large V. C. Summer Indications (FDB Elevation, 1993)				
Steam Generator	Row	Column	Bobbin Amplitude	Location

Table 5: Probability of Large Extremes for Two Sample Sizes				
Number of Large Extremes	Probability of Large Extremes Based on M = 100,000 & K = 20			
	Sample 500	Frequency in 100,000	Sample 1,000	Frequency in 100,000

Table 6: Total Expected Number of Extremes				
M (Total)	K (Extremes)	Pr(Extreme)	N (Indications)	Number of Sims
115,179	21	0.000182	500	100,000
z (Extremes)	Pr(z)	Pr(Not z)	Pr(≤ z)	SG Sims with z
Extremes Limited to 7/8" Tubes				
M (Total)	K (Extremes)	Pr(Extreme)	N (Indications)	Number of Sims
56,874	3	0.000053	500	100,000
z (Extremes)	Pr(z)	Pr(Not z)	Pr(≤ z)	SG Sims with z
Extremes Limited to 3/4" Tubes				
M (Total)	K (Extremes)	Pr(Extreme)	N (Indications)	Number of Sims
58,305	18	0.000309	500	100,000
z (Extremes)	Pr(z)	Pr(Not z)	Pr(≤ z)	SG Sims with z

Table 7: Exponential CDF Values		

Table 8: Estimates of Theta, θ, and Variance for Diablo Canyon Growth Data (Piecewise Empirical + Exponential)			
Tail Points, k	Parameter Theta, θ	Growth Variance, (Volts^2)	$\frac{d\theta}{dk}$

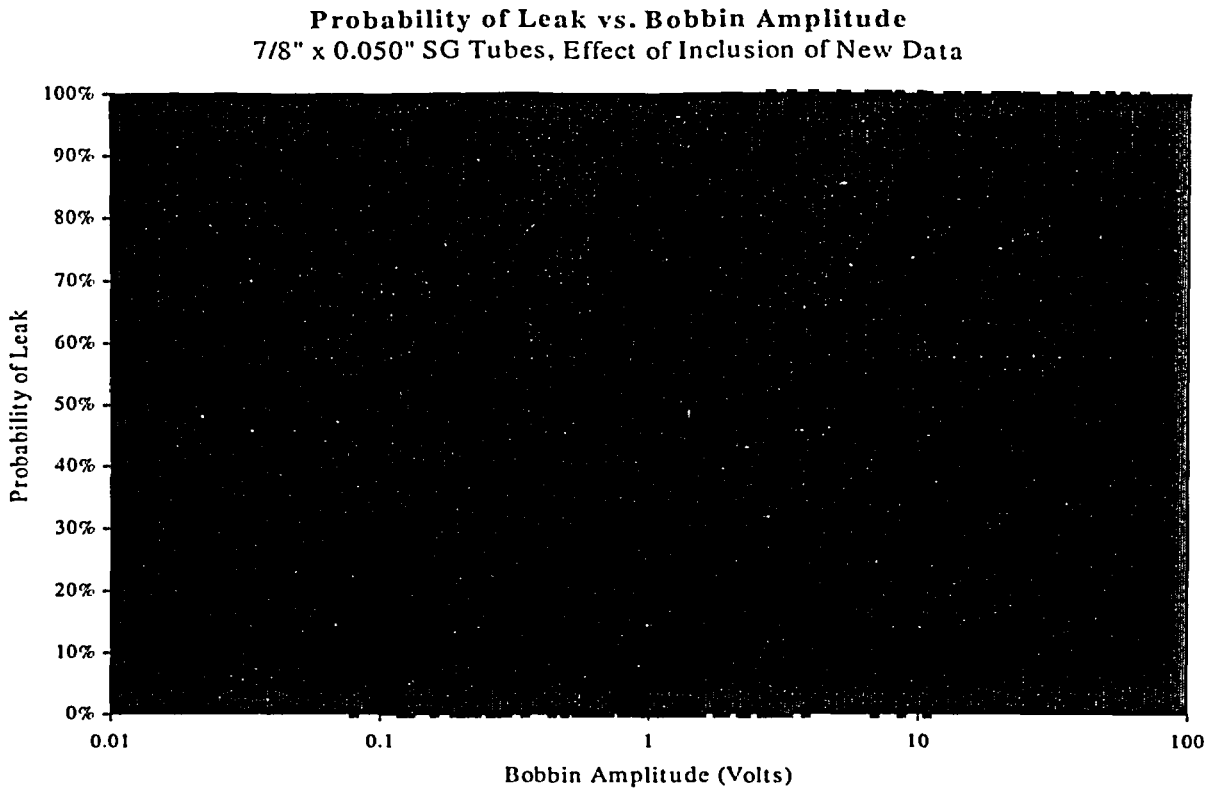

Figure 1: Probability of Leak for 7/8" Diameter Tubes

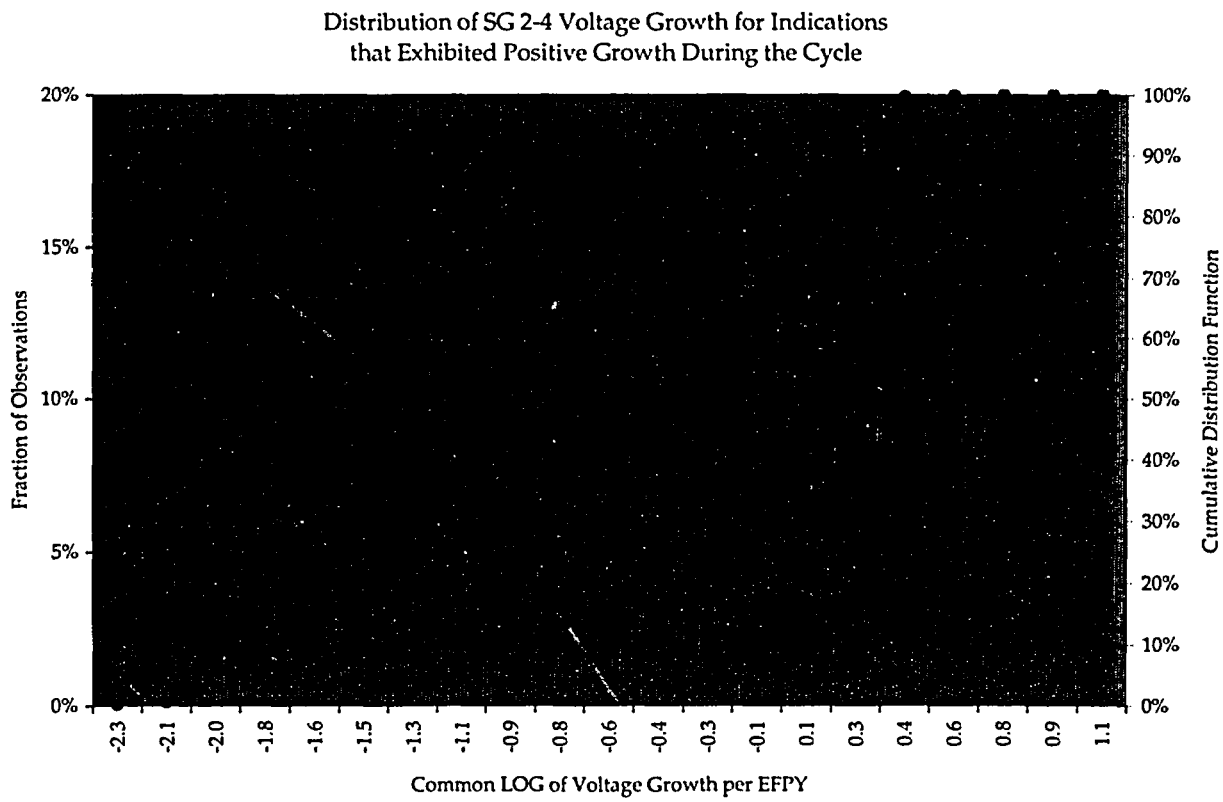

Figure 2: Distribution of Amplitude Growth for Cycle 11

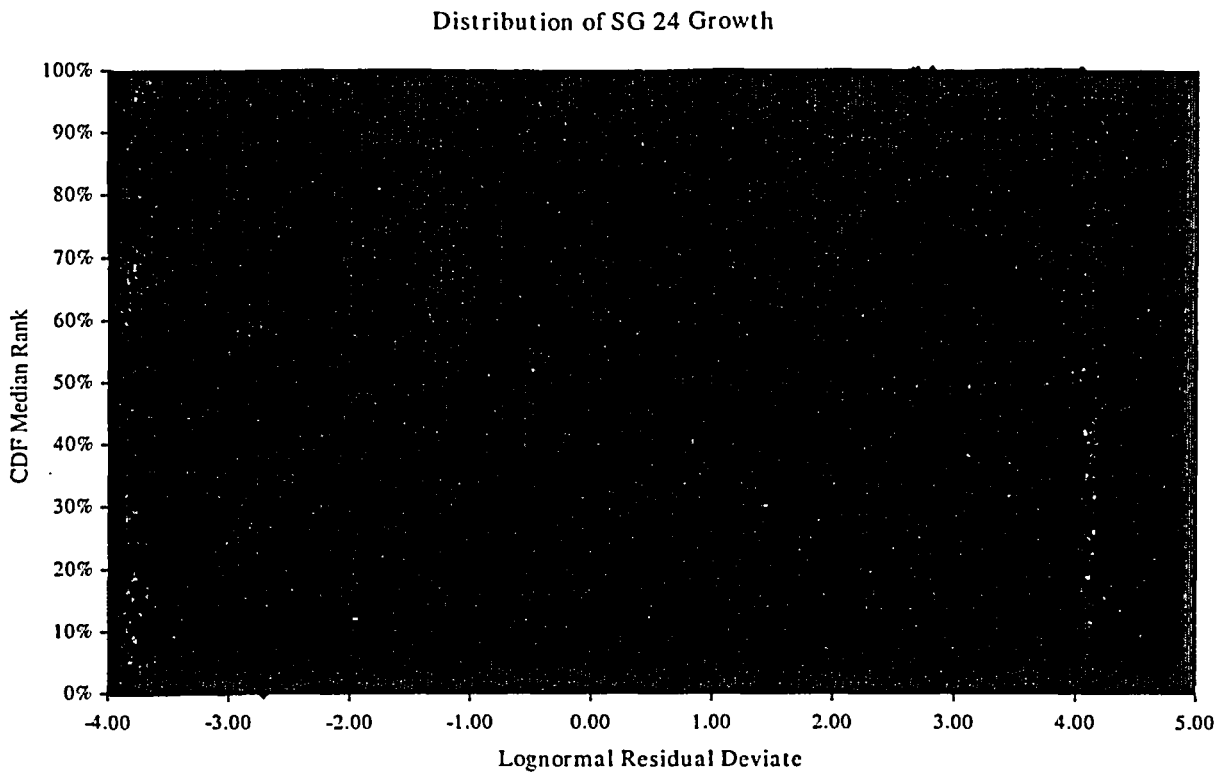

Figure 3: Amplitude Growth CDF vs. Lognormal CDF

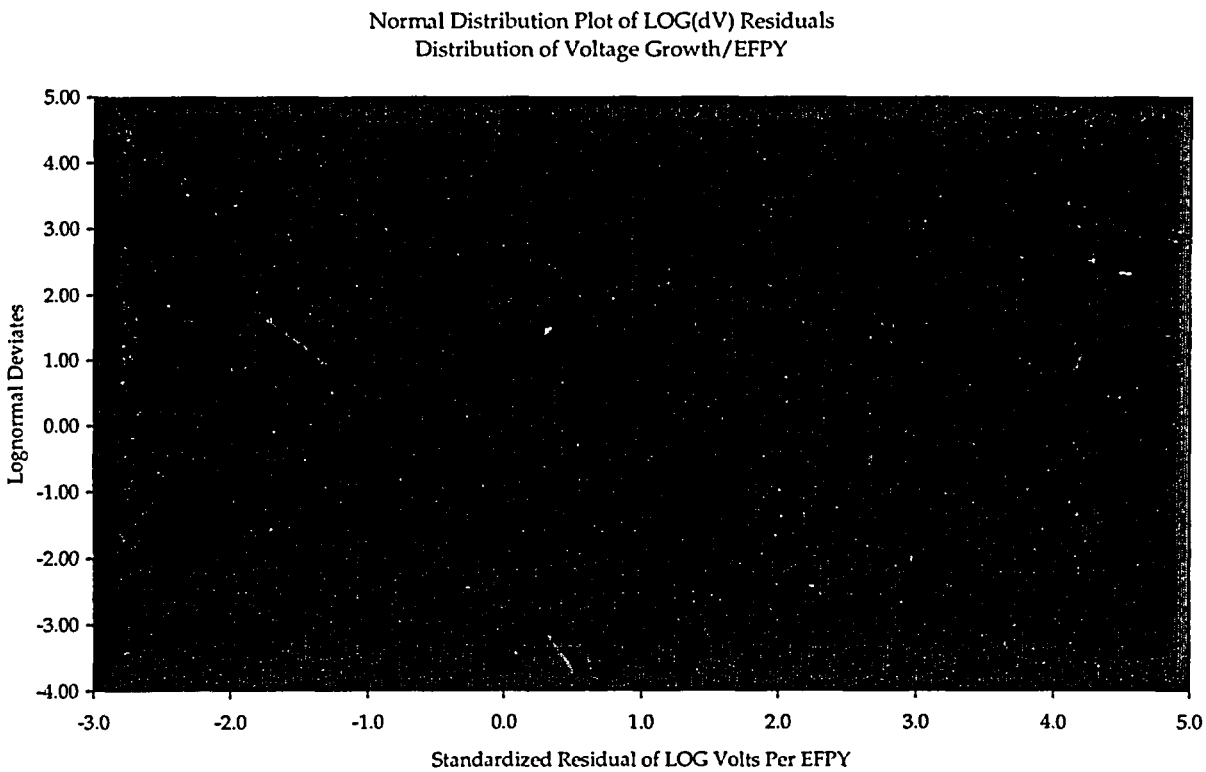

Figure 4: Normal distribution plot of logarithm residuals.

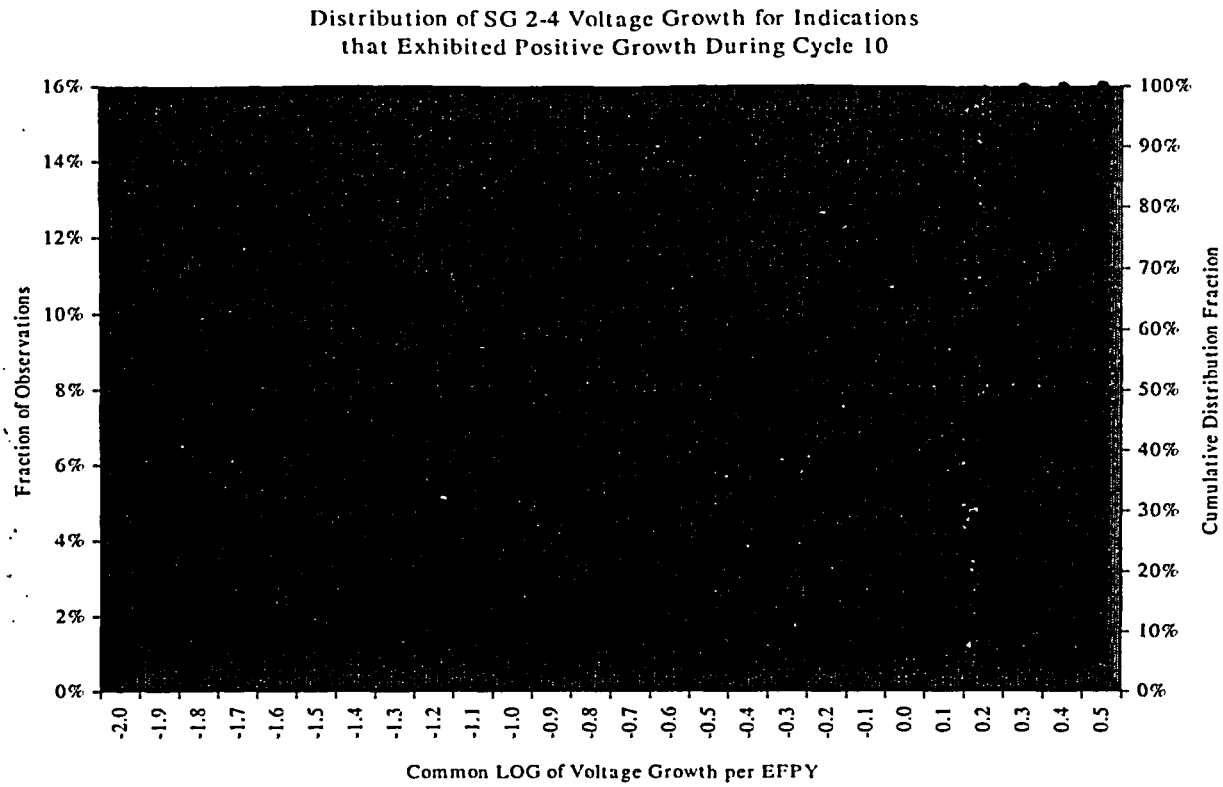

Figure 5: Distribution of Amplitude Growth for Cycle 10

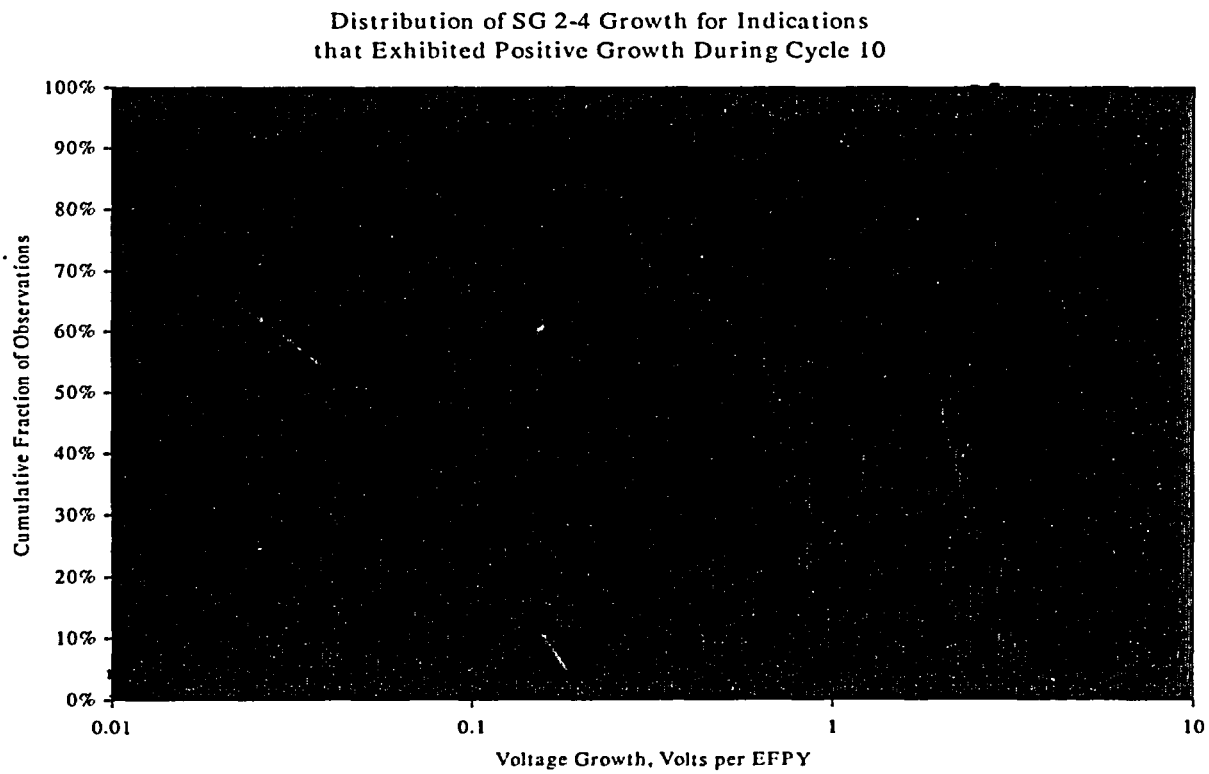

Figure 6: CDF of Amplitude Growth for Cycle 10

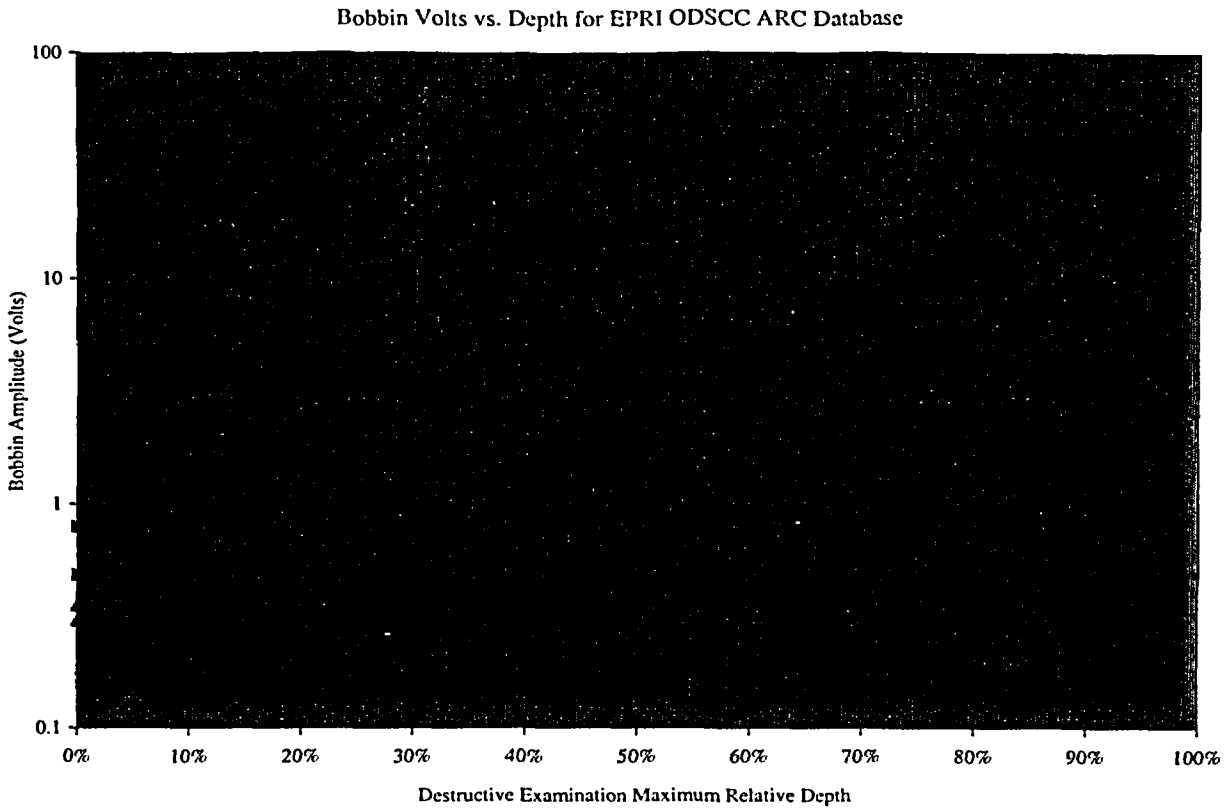

Figure 7: Correlation of bobbin amplitude to maximum depth.

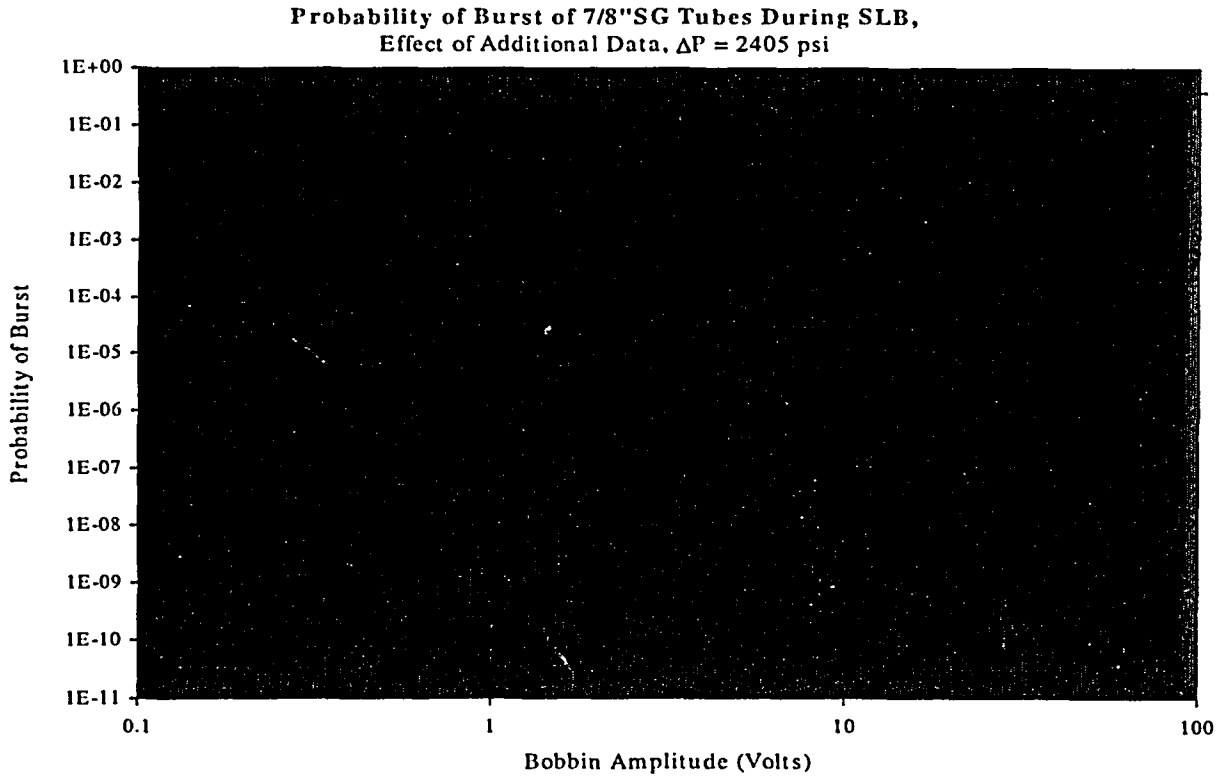

Figure 8: Probability of Burst for 7/8 Inch Diameter Tubes

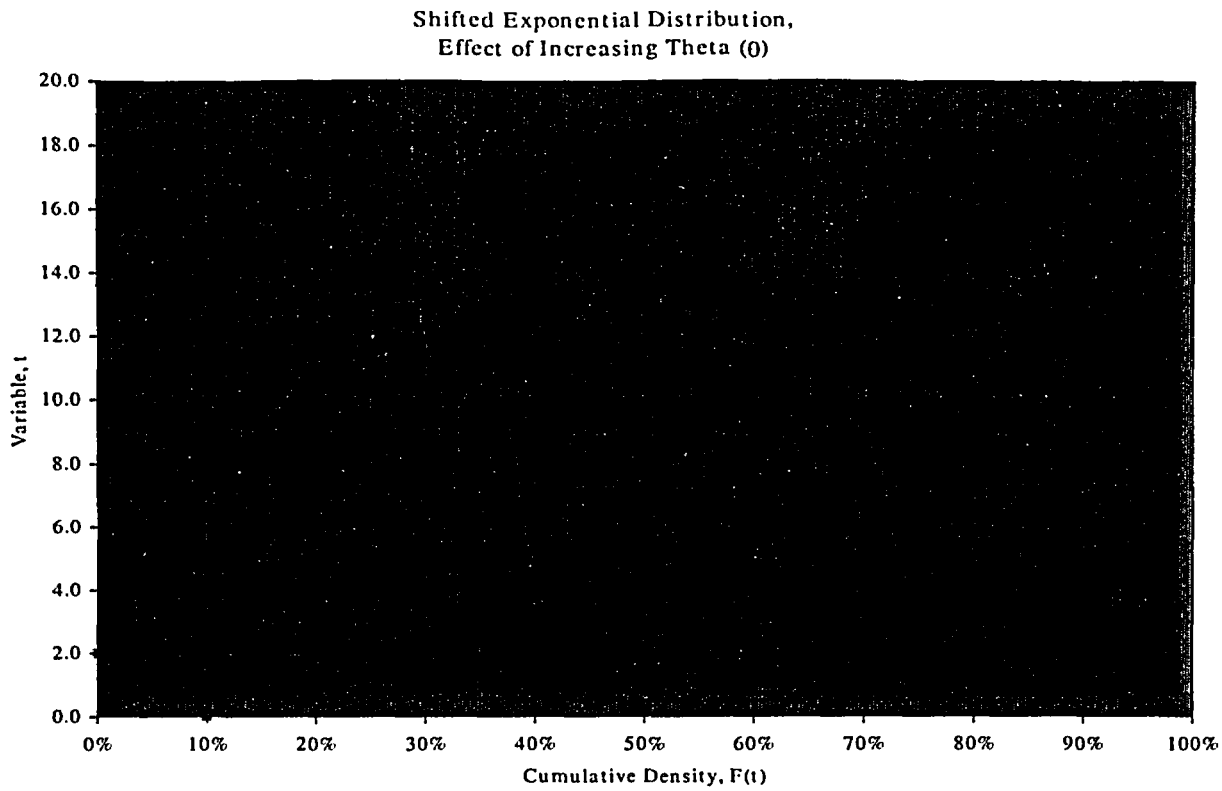

Figure 9: Effect of Theta (θ) on Exponential Distribution

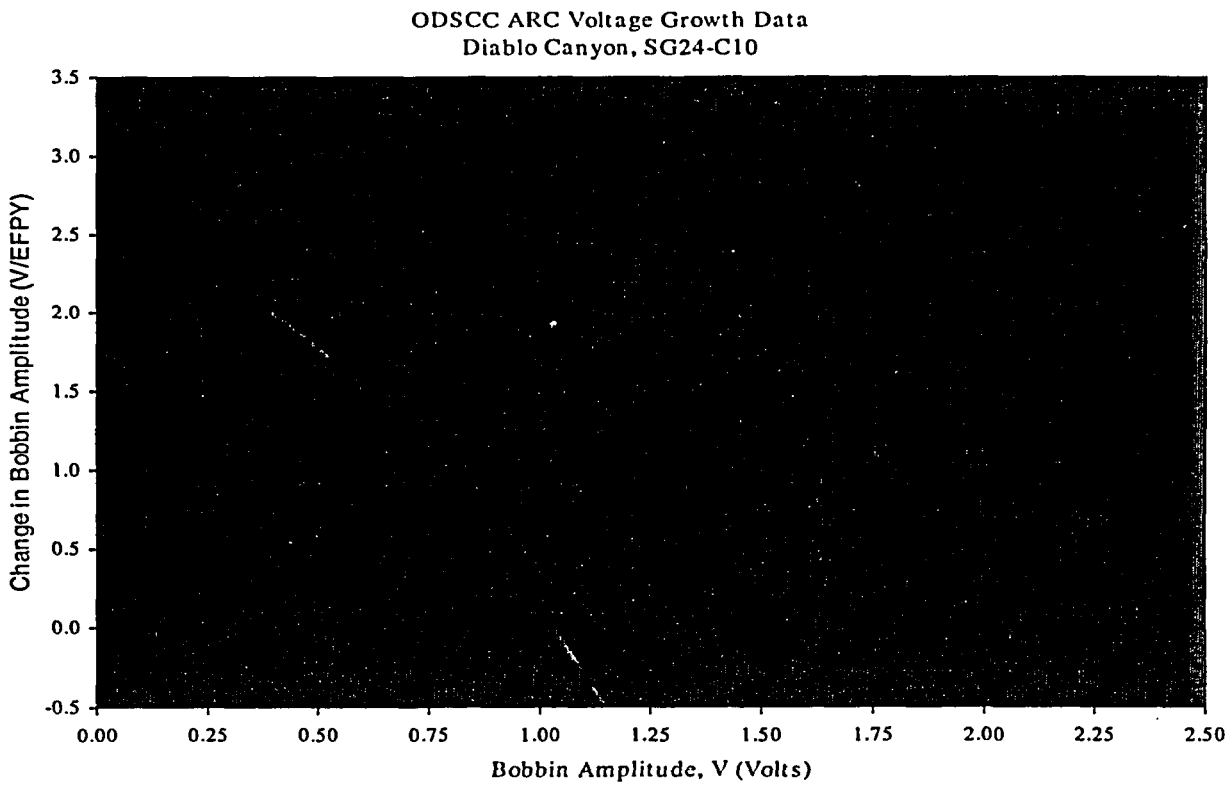

Figure 10: Example Distribution of Growth Data.

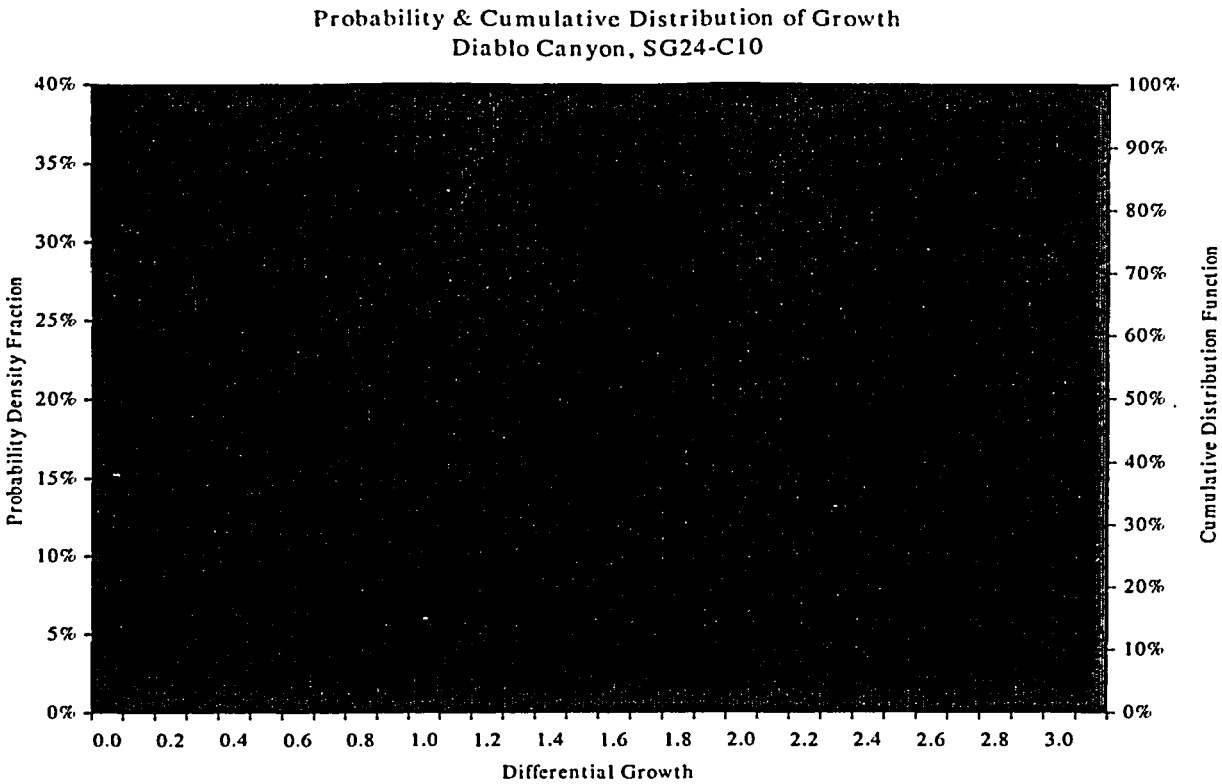

Figure 11: Cumulative Distribution of Growth Data.

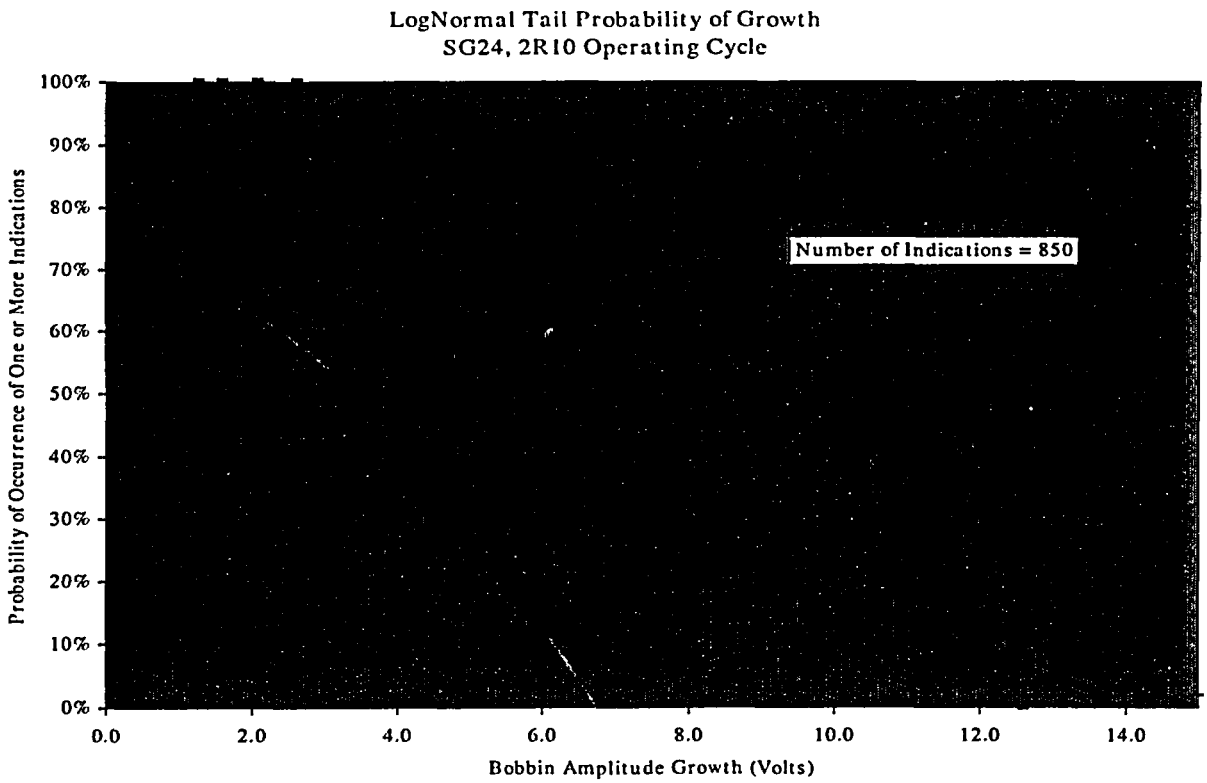

Figure 12: Expected Frequency of SG 24 Large Growth for Cycle 11.

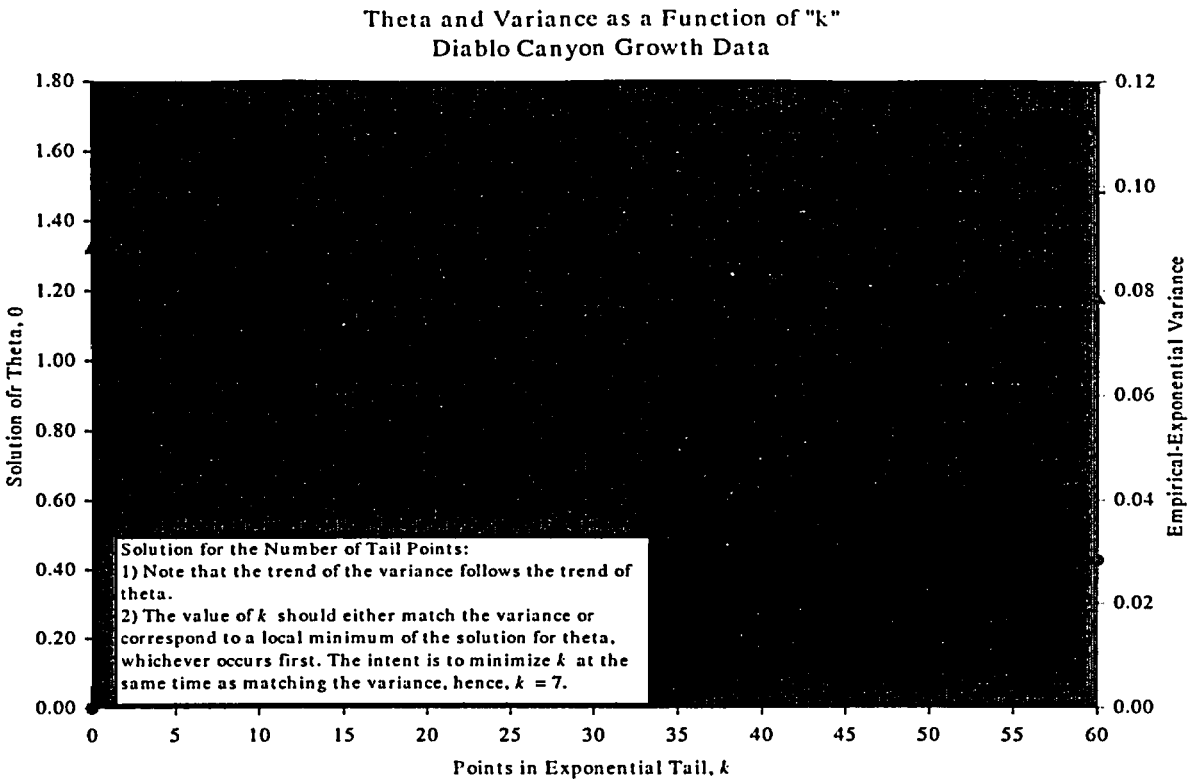

Figure 13: Considerations in the determination of k.

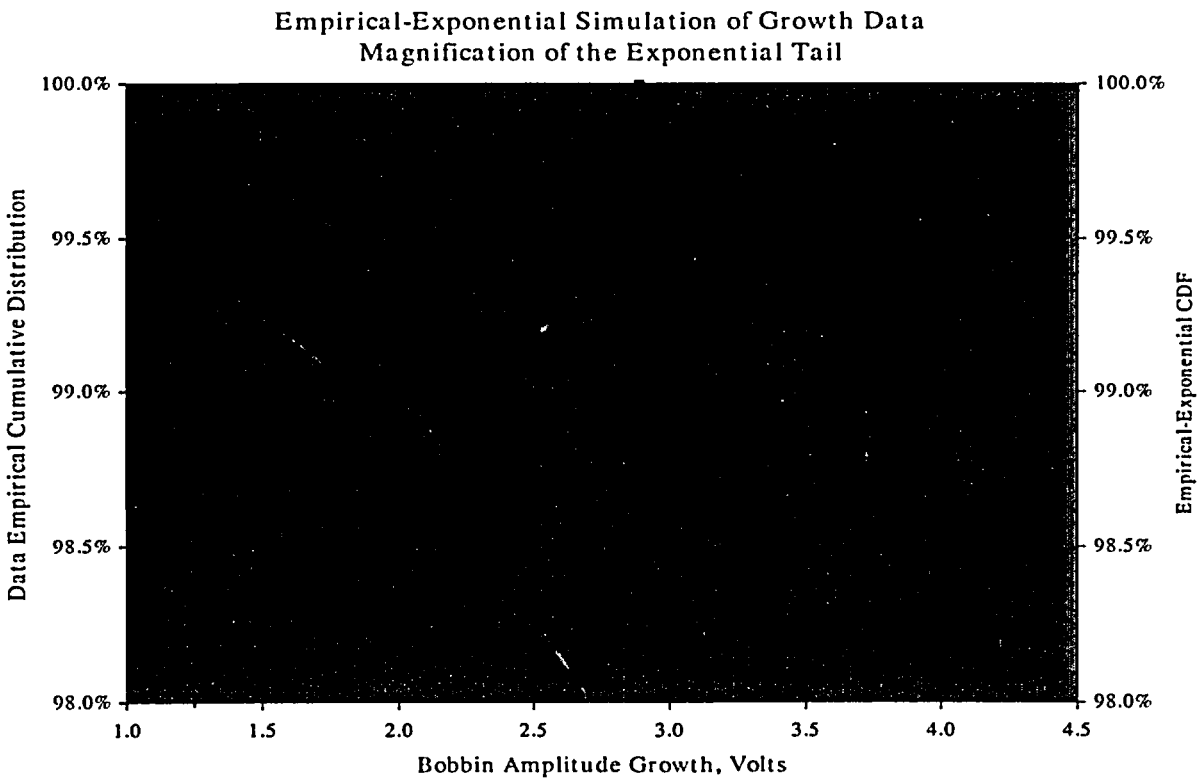

Figure 14: Exponential distribution function for the growth tail.

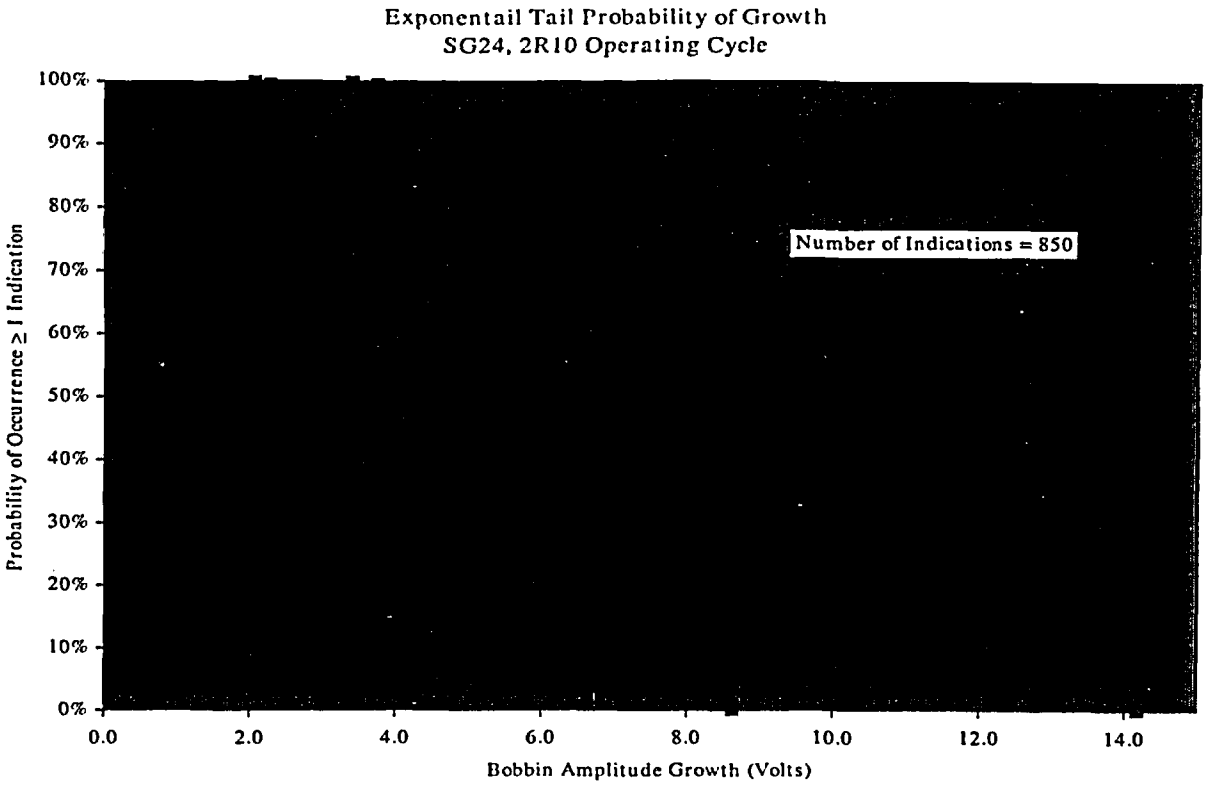

Figure 15: Expected Frequency of SG 24 Large Growth for Cycle 11.

EPRI

VOLTAGE DEPENDENT GROWTH BREAK POINT DETERMINATION

Non-Proprietary Version

Enclosure 7

Voltage Dependent Growth Break Point Determination

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Voltage Dependent Growth Break Points Determination

1.0 INTRODUCTION

The voltage dependent growth (VDG) methods in the previous ARC database addenda were developed from Braidwood and Byron experiences and were assumed to be necessary only with the application of a 3 volt ARC limit. The Diablo Canyon Unit 2 (DCPP2) experience in 2003 demonstrated that voltage dependent growth could become significant for repair limits of 2 volts. As a part of Pacific Gas and Electric's (PG&E) efforts in support of the DCPP2 Operational Assessment (OA), methods were developed for applying VDG based on a statistical analysis to define the number and voltage values for the break points between voltage growth bins. This report provides for incorporation of the methods developed for PG&E in the ARC database.

The information presented in this report was prepared to document the development of a methodology for the determination of break points to be used for the application of voltage dependent growth in performing ODSCC ARC evaluations of SG tube degradation. The results from this effort were presented to the NRC staff on behalf of PG&E regarding the evaluation of indications in the SGs at DCPP2 in 2003. The results of the development are believed to be generically applicable when the use of VDG is appropriate, hence, the inclusion of the information in the EPRI database for ODSCC ARC applications. Although the analysis results can be useful in examining the data for changes that would be indicative of VDG, the development of criteria for making that determination was not within the work scope for the preparation of this report. An Excel™ workbook for performing the VDG analyses was provided to EPRI with this report. Although the workbook was checked for correctness, it was not subjected to the effort necessary to be considered verified and validated to the extent that it could be directly placed under configuration control, nor were built-in safeguards included to prevent its misuse.

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. It can be formally demonstrated that all growth measured in terms of bobbin amplitude must be voltage dependent, however, the level of that dependence has usually been small and could be neglected without introducing meaningful errors in the prediction of end-of-cycle bobbin amplitudes.

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 where guidelines for the analysis are provided in Reference 2. 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 historical practice was for an engineer familiar with the ODSCC ARC analysis to make a judgment from an examination of the data as to where the demarcation or break points should be located to segregate the voltage growth regions. The following information describes a mathematical method that can be applied to determine where the break point locations should be determined based on an evaluation of the data being analyzed. This allows for the growth data to be segregated or separated into bins, "binned," according to a mathematical indicator of where the growth rates are exhibiting meaningful change.

The concept of establishing the break points is based on approximating a curve using linear segments. No break points are needed if the data do not exhibit significant curvature, meaning that VDG is not apparent. Once VDG is apparent in the population, the break points are determined to result in linear segments that best fit the curve. As the size of the population increases and ages, VDG is expected to occur and fitting of the data using a curve would be appropriate if the fitted curve was being simulated in the analysis. Since a curve is not being fitted, i.e., the empirical distribution function (EDF) of the growth data is being used in the SG analysis, it is appropriate to identify break points where separate EDFs would be developed to accommodate changes that are implied by the data exhibiting significant curvature. Thus, the break points would be expected to move according to the strength of the VDG as indicated by the curvature of the instantaneous mean of the data as a function of voltage. The break points are found by minimizing the sum-of-squares of the errors of the data from the predictions from the piecewise linear function fitted to the data. The lowest break point would not be expected to shift significantly since the population curvature in the lower volts range would likely be consistent from one outage to the next. The upper break point or points could be expected to be relatively insensitive with time if the overall shape of the growth data remains constant. A change in the break point values and the number of break points could be expected with an increase in the amplitude of indications being retained in service.

Analyses were performed of tube ODSCC growth data for SG 2-4 at DCPP2 to identify appropriate break points for the performance of the operational assessment for the SG tubes, Reference 3. The analyses resulted in the identification of appropriate break points 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 terminate and another regression line would begin. It is emphasized that the method is not for the purpose of developing voltage growth regression relations for use in operational assessments (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 lines. The relationship is characterized as being bilinear if two linear relations are used to describe the data. The concept can be extended to consider descriptions of data which would be characterized as trilinear and quadrilinear for two and three break points respectively. As previously noted, an Excel™ workbook with the data and formulae used for the analysis accompanies this report; the workbook will analyze data for up to three break points.

2.0 PIECEWISE LINEAR REGRESSION ANALYSIS

3.0 DISCUSSION OF GROWTH PLOTTING

4.0 ANALYSIS

4.1 Upper Range Number of Data

4.2 Bilinear Regression

4.3 Trilinear Regression

4.4 Quadrilinear Regression

5.0 EXAMPLE APPLICATION TO PLANT DCPP DATA

5.1 SG 2-4 Cycle 11 Growth Data

5.2 SG 2-4 Cycle 10 Growth Data

6.0 DISCUSSION

7.0 SUMMARY

8.0 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. WCAP-14277, Revision 1, "SLB Leak Rate and Tube Burst Probability Analyssis Methods for ODSCC at TSP Intersections," Westinghouse Electric Company, LLC, Madison, PA, USA (December 1996).

3. 51-5027557-00, "2R11 DCPP Growth Rates," Framatome ANP, Lynchburg, VA, USA, May 13, 2003.

4. Draper, N. and Smith, H., *Applied Regression Analysis, Second Edition*, John Wiley & Sons, New York, NY, USA (1981).

5. DCL-04-019, "DCPP Unit 1 Voltage-Based Repair Criteria Benchmarking and EOC-12 Projections," L. Womack, Pacific Gas and Electric Company, Diablo Canyon Power Plant, Avila Beach, CA (April 2004).

Table 1
Bilinear Regression Sample Data

Index Number	Previous Voltage	Dummy Variable 1	Volts / EFPY

Table 2
Cycle 10 Data Added to Cycle 11

Index Value	BOC Amplitude (Volts)	Growth (Volts/EFPY)

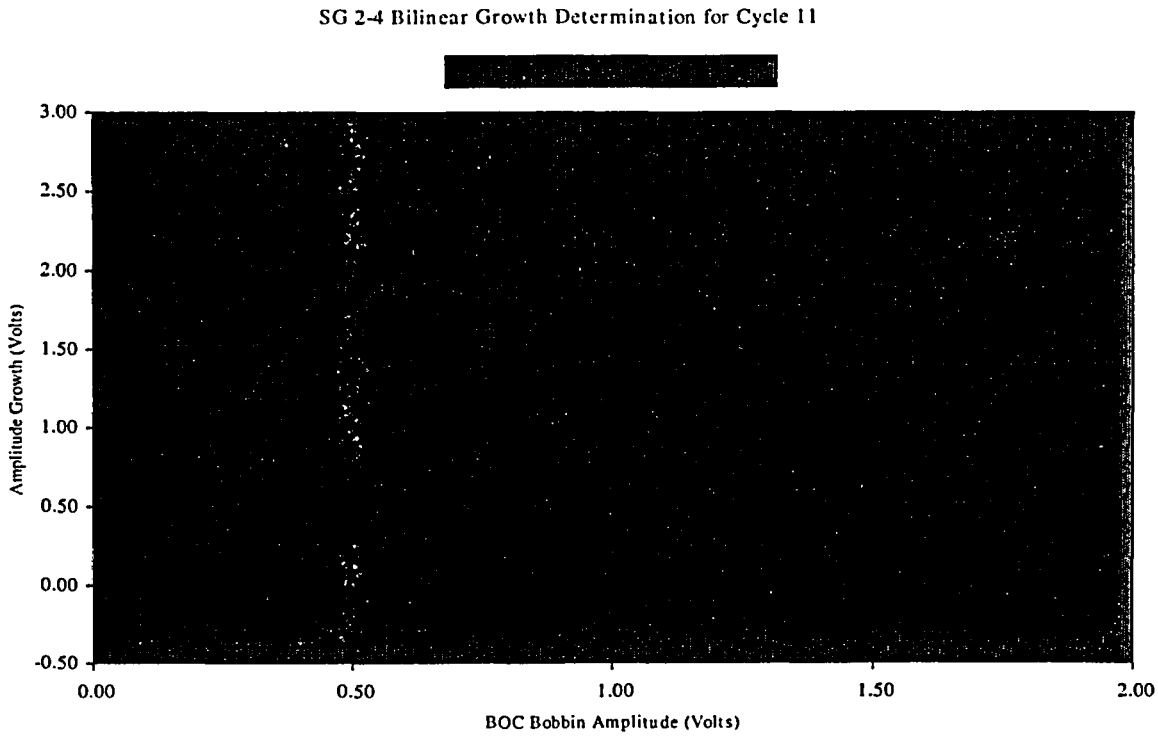

Figure 1
Bilinear Regression Line Illustration

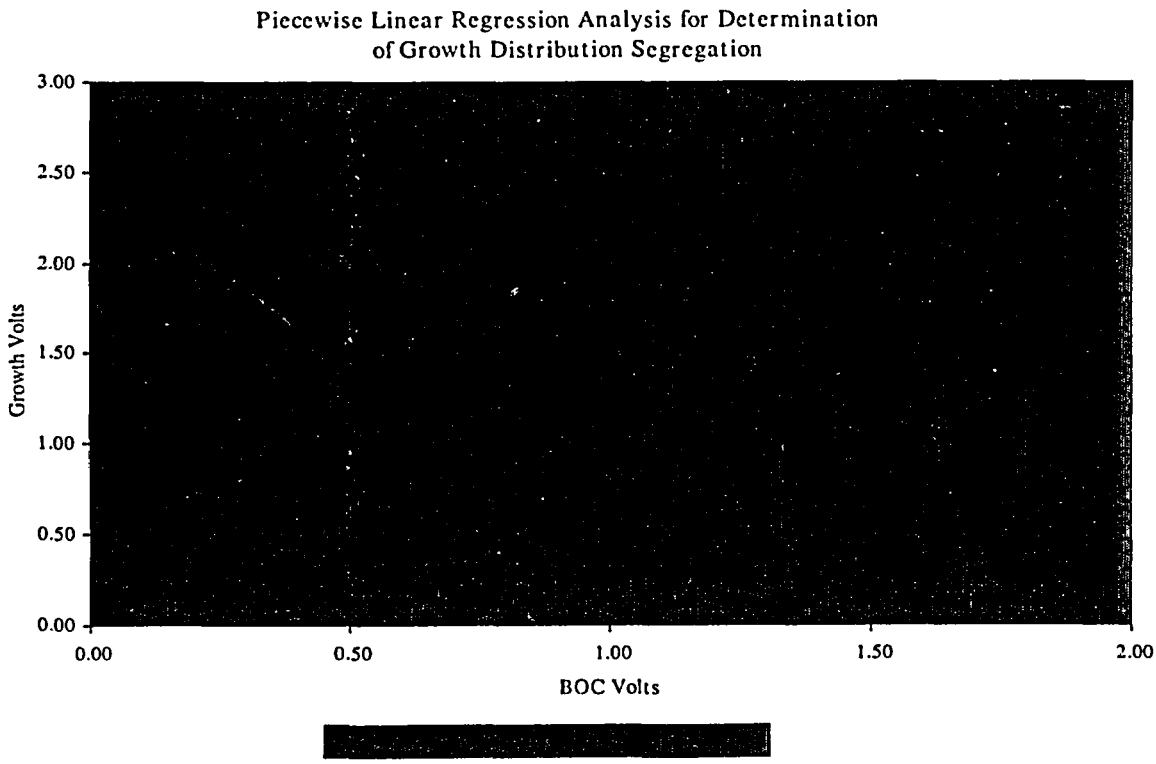

Figure 2
Trilinear regression line illustration

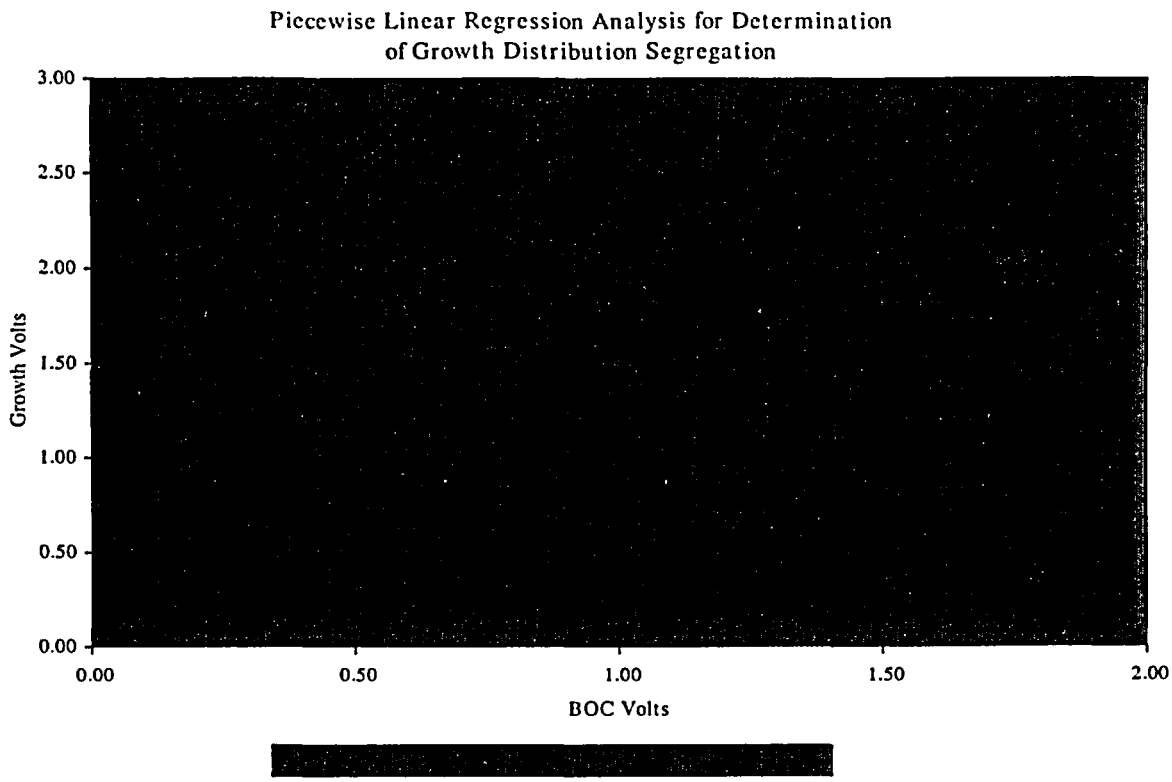

Figure 3
Quadrilinear regression line illustration

Figure 4
Excel screen for bilinear regression analysis

Figure 5
Excel solver screen for bilinear regression analysis

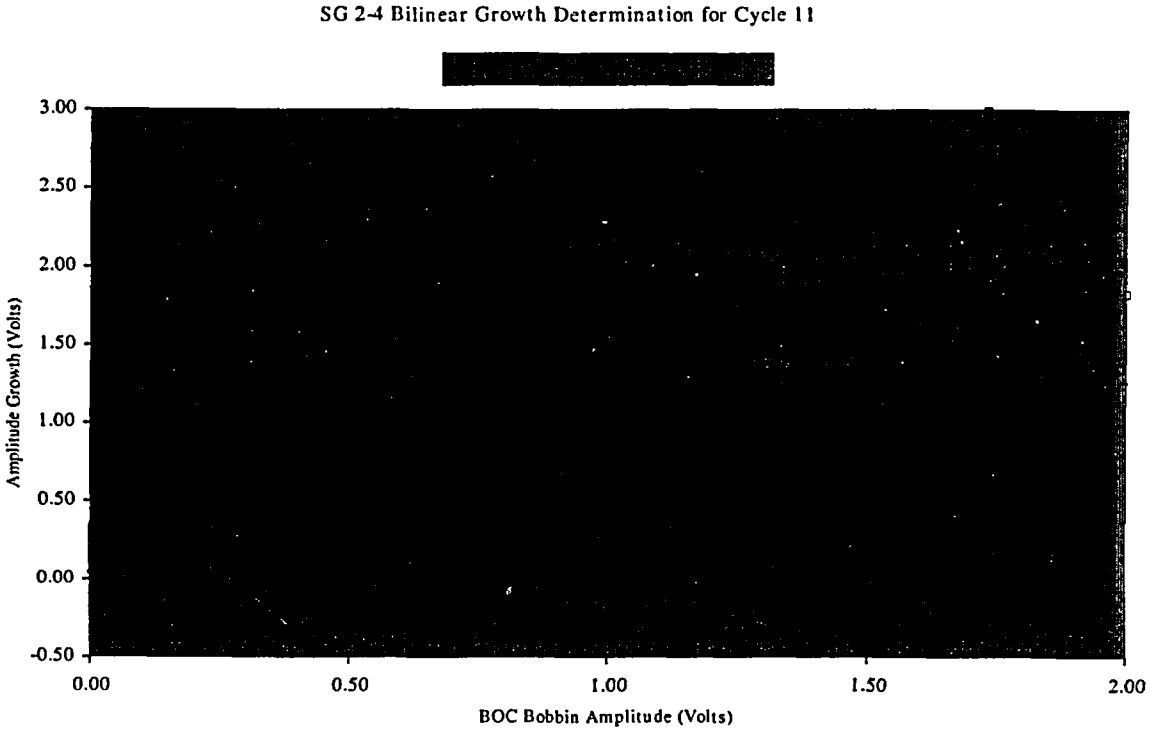

Figure 6
Bilinear regression lines for SG 2-4 Cycle 11 Growth Data

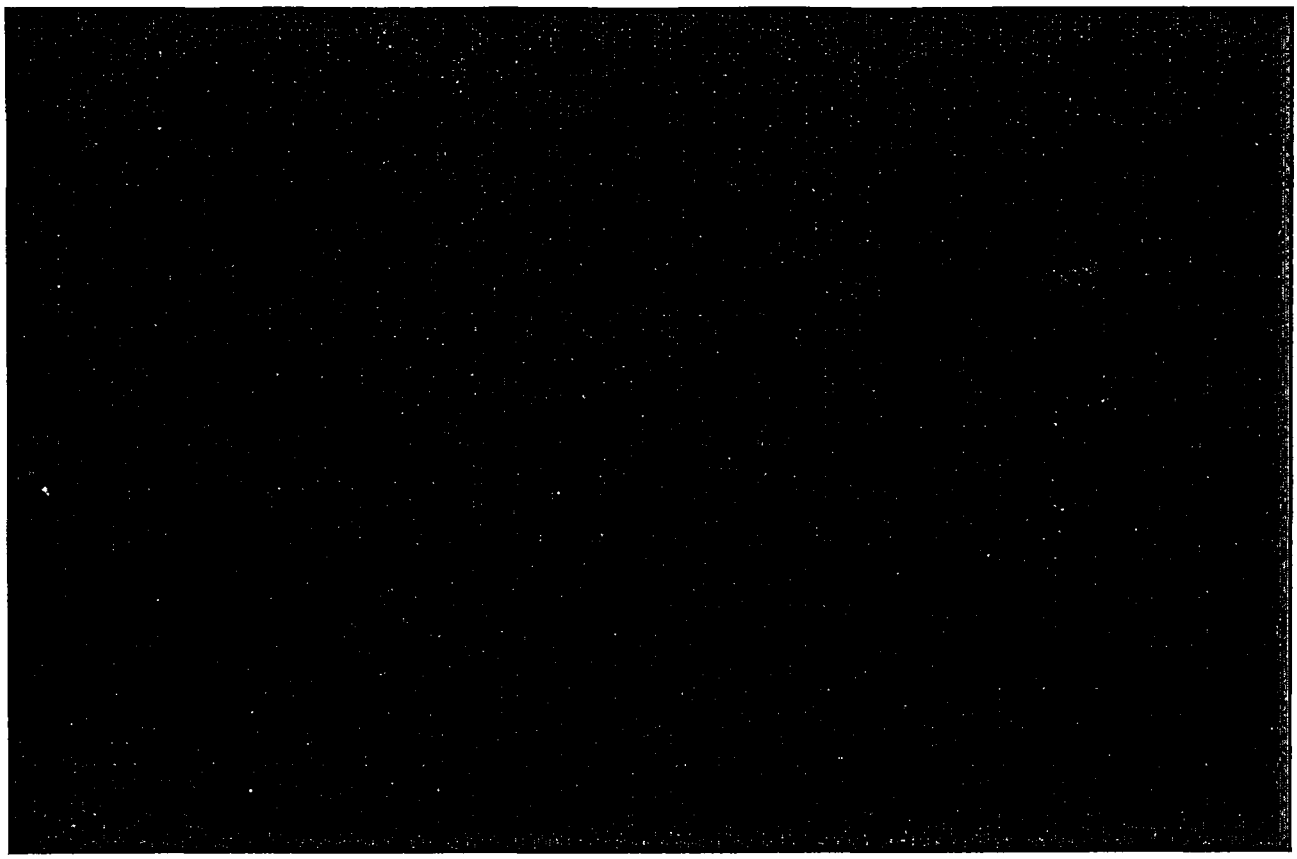

Figure 7
Excel screen for trilinear regression analysis

Figure 8
Excel solver screen for trilinear regression analysis

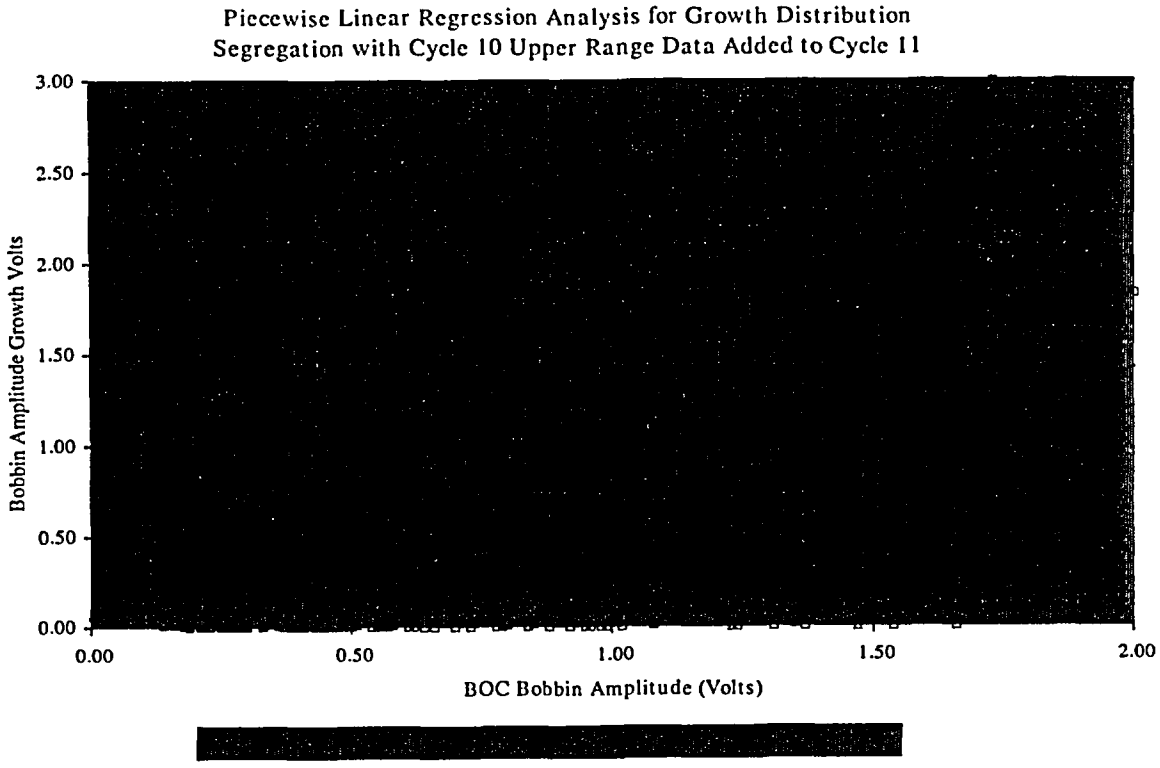

Figure 9
Trilinear regression lines for SG 2-4 Cycle 11 growth data

Figure 10
Excel screen for quadrilinear regression analysis

Figure 11
Excel solver screen for trilinear regression analysis

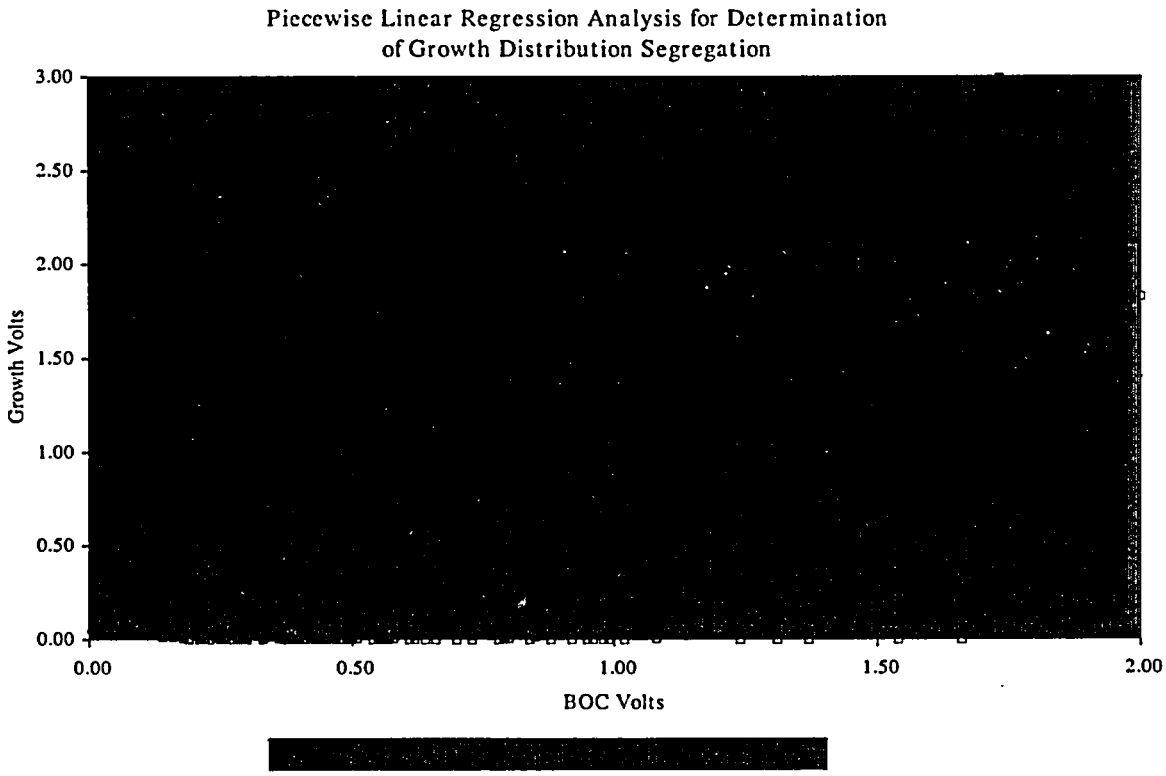

Figure 12
Quadrilinear regression of SG 2-4 Cycle 11 growth data

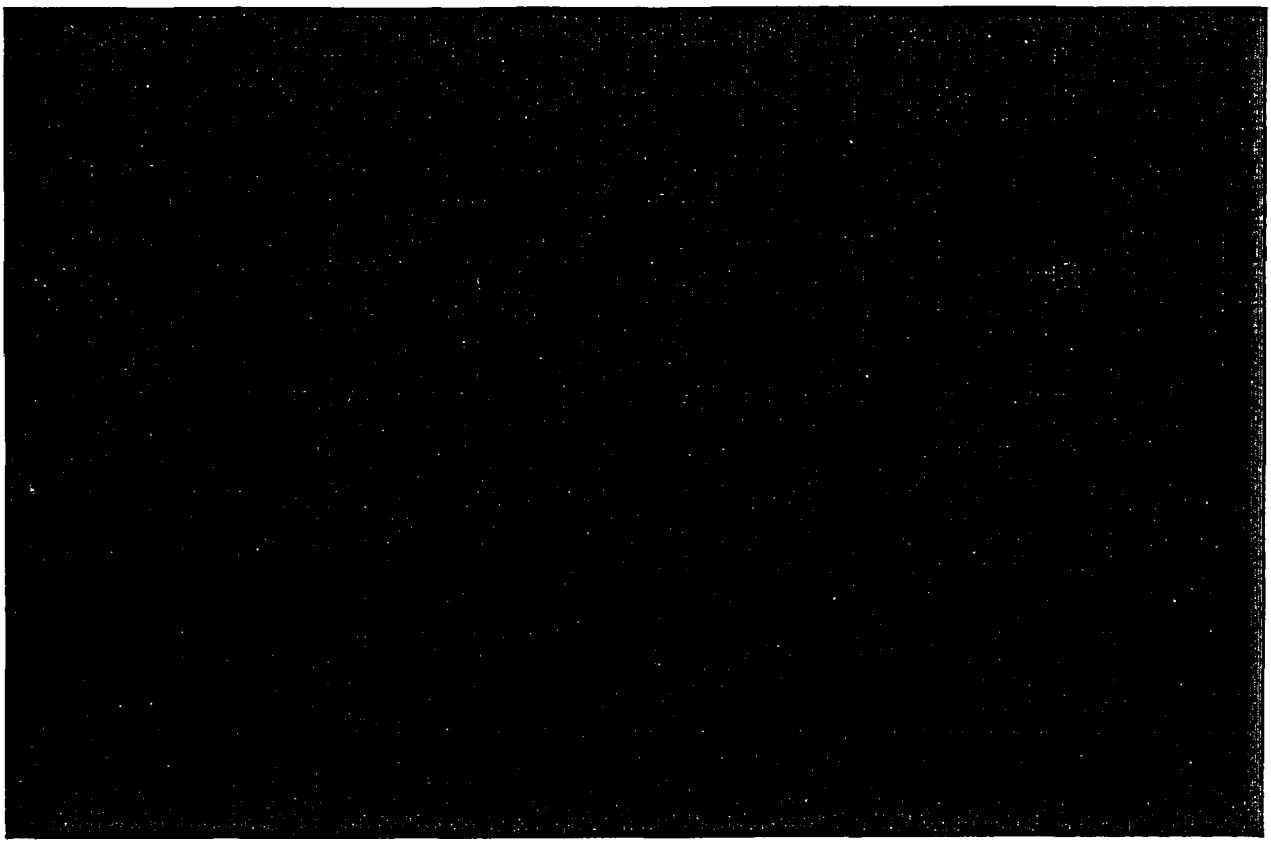

Figure 13
Excel screen for SG 2-4 Cycle 10 growth data

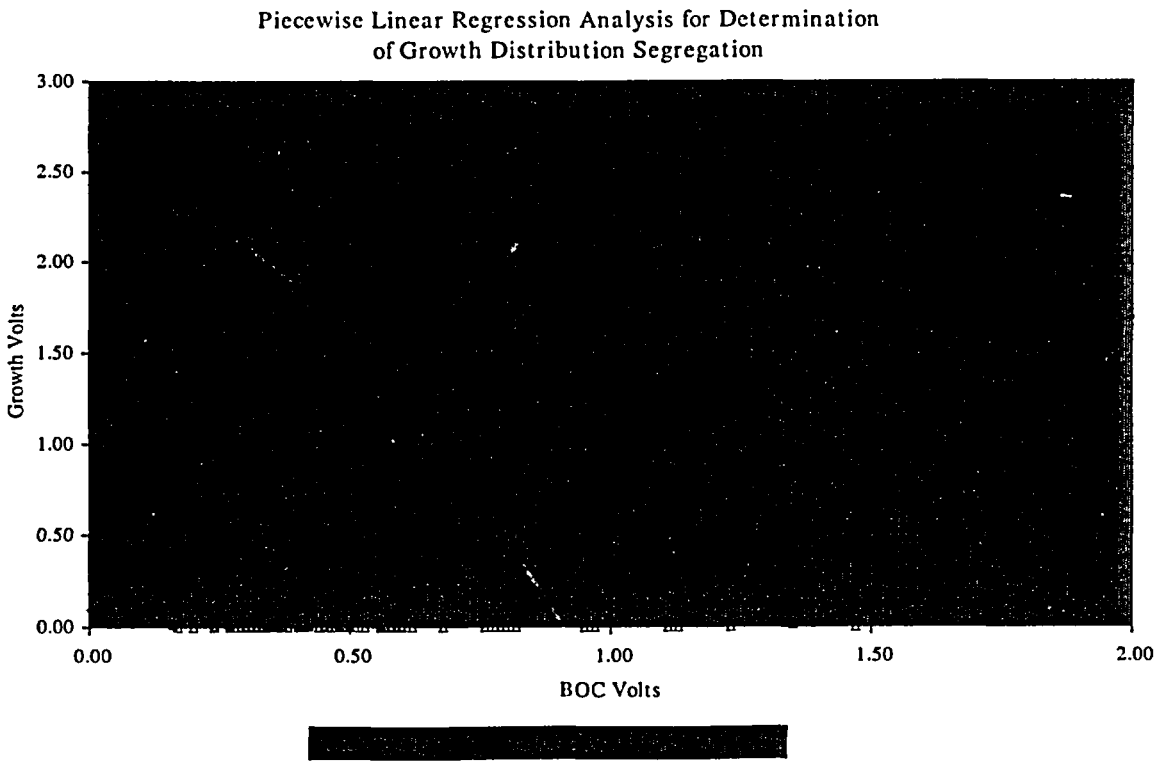

Figure 14: Trilinear regression of SG 2-4 Cycle 10 growth data

Illustration of an unsatisfactory analysis result.

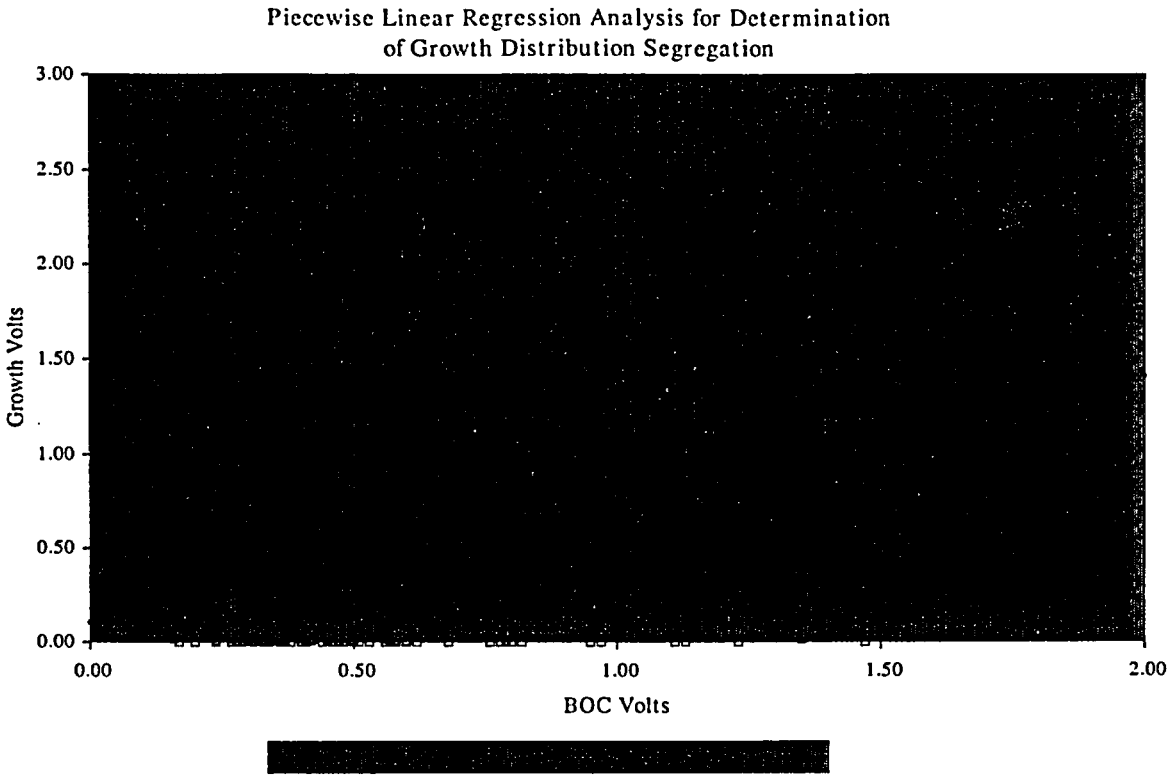

Figure 15
Quadrilinear regression without a data limit on Piece 3

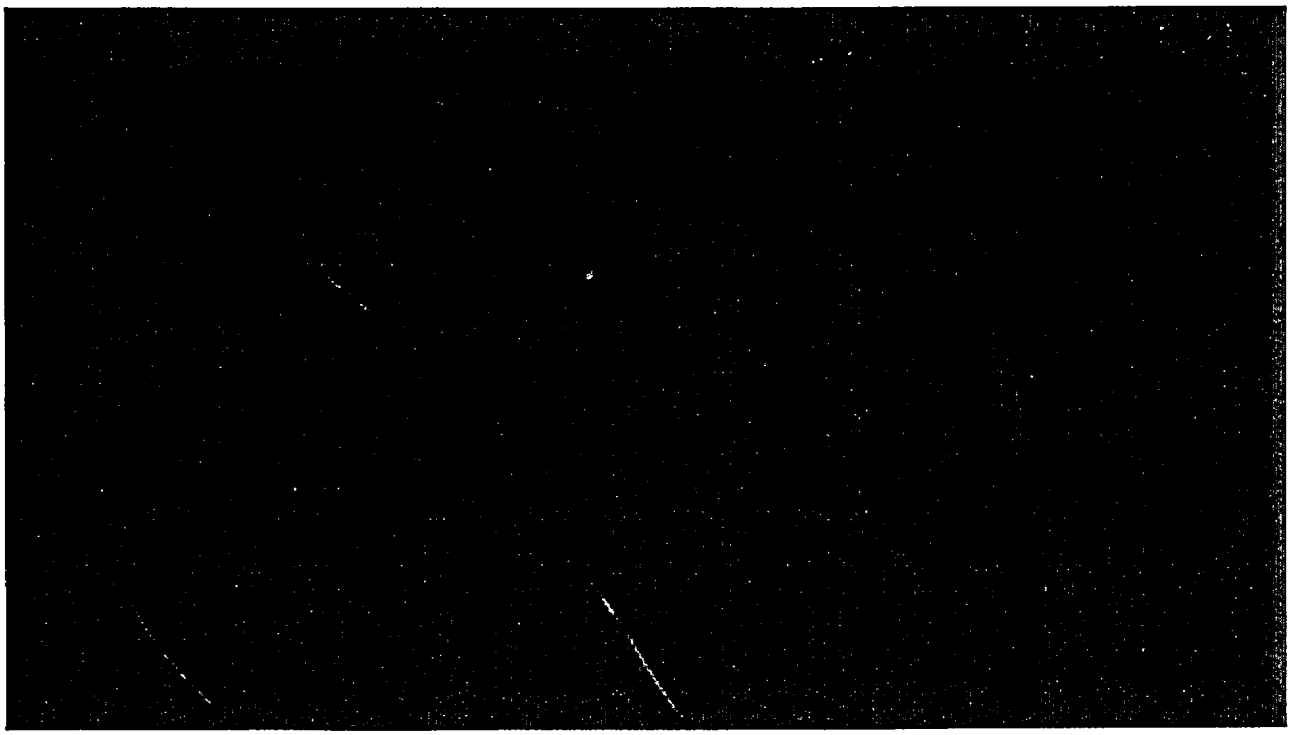

Figure 16
Quadrilinear regression with a data limit on Piece 3

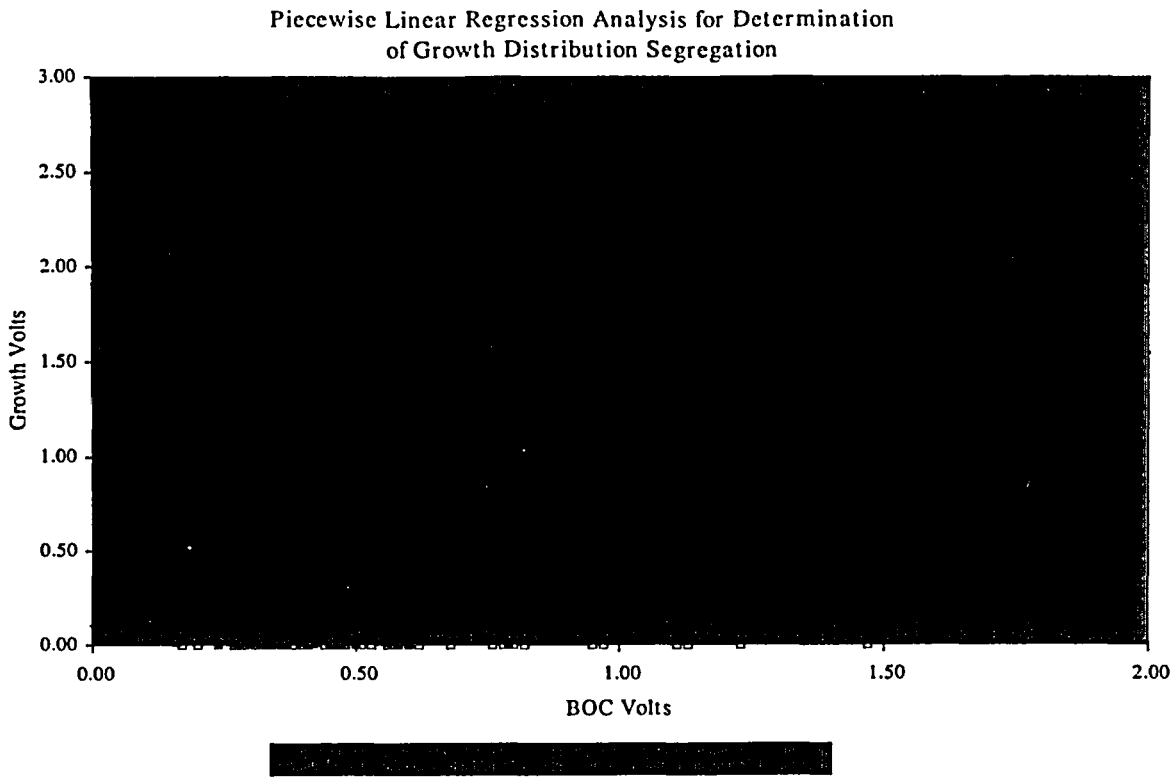

Figure 17
Quadrilinear regression of SG 2-4 Cycle 10 growth data

Proprietary Affidavit

ELECTRIFY THE WORLD

EPRI

June 2, 2004

Mr. Gene Carpenter
Document Control Desk
U.S. Nuclear Regulatory Commission
Washington DC, 20555

Subject: ARC Guidelines for POPCD Updates, Allowance for Large Growth in ARC Analyses and Voltage Dependent Growth Methodology

Gentlemen:

This is a request under 10CFR2.790(a)(4) that the NRC withhold from public disclosure the information identified in the enclosed affidavit consisting of EPRI-owned proprietary information as identified above (the "Information"). A copy of the Information and the affidavit in support of this request are enclosed.

EPRI desires to disclose the Information in confidence to the NRC for informational purposes to assist the NRC. EPRI would welcome any discussions with the NRC related to the Information that the NRC desires to conduct.

The Information is for the NRC's internal use and may be used only for the purposes for which it is disclosed by EPRI. The information should not be otherwise used or disclosed to any person outside the NRC without prior written permission from EPRI.

If you have any questions about the legal aspects of this request for withholding, please do not hesitate to contact me at (704/547-6173). Technical questions on the contents of the Information should be directed to Mr. Edward Blandford at (650) 855-8783.

Sincerely,

David J. Modeen
Vice President & Chief Nuclear Officer

Enclosures

c: Edward Blandford, EPRI
Nichole Edraos, EPRI

EPRI

AFFIDAVIT

RE: ARC Guidelines for POPCD Updates, Allowance for Large Growth in ARC Analyses and Voltage Dependent Growth Methodology

I, DAVID J. MODEEN, being duly sworn, depose and state as follows:

I am a Vice President at the Electric Power Research Institute ("EPRI") and I have been specifically delegated responsibility for the Documentation listed above that is sought under this affidavit to be withheld (the "Documentation") and authorized to apply for their withholding on behalf of EPRI. This affidavit is submitted to the Nuclear Regulatory Commission ("NRC") pursuant to 10 CFR 2.790 (a)(4) based on the fact that the Documentation consists of trade secrets of EPRI and that the NRC will receive the Documentation from EPRI under privilege and in confidence.

The basis for withholding such Documentation from the public is set forth below:

(i) The Documentation has been held in confidence by EPRI, its owner. All those accepting copies of the Documentation must agree to preserve the confidentiality of the Documentation.

(ii) The Documentation is a type customarily held in confidence by EPRI and there is a rational basis thereof. The Documentation is a type, which EPRI considers as a trade secret(s) and is held in confidence by EPRI because to disclose it would prevent EPRI from licensing the Documentation at fees, which would allow EPRI to recover its investment. If consultants and/or other businesses providing services in the electric/nuclear power industry were able to publicly obtain the Documentation, they would be able to use it commercially for profit and avoid spending the large amount of money that EPRI was required to spend in preparation of the Documentation. The rational basis that EPRI has for classifying this/these Documentation(s) as a trade secrets is justified by the Uniform Trade Secrets Act, which California adopted in 1984 and which has been adopted by over twenty states. The Uniform Trade Secrets Act defines a "trade secret" as follows:

> "Trade secret" means information, including a formula, pattern, compilation, program, device, method, technique, or process, that:
>
> (1) Derives independent economic value, actual or potential, from not being generally known to the public or to other persons who can obtain economic value from its disclosure or use; and
>
> (2) Is the subject of efforts that are reasonable under the circumstances to maintain its secrecy.

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(iii) The Documentation will be transmitted to the NRC in confidence.

(iv) The Documentation is not available in public sources. EPRI developed the Documentation only after making a determination that the Documentation was not available from public sources. It required a large expenditure of dollars for EPRI to develop the Documentation. In addition, EPRI was required to use a large amount of time of EPRI employees. The money spent, plus the value of EPRI's staff time in preparing the Documentation, show that the Documentation is highly valuable to EPRI. Finally, the Documentation was developed only after a long period of effort of several years.

(v) A public disclosure of the Documentation would be highly likely to cause substantial harm to EPRI's competitive position and the ability of EPRI to license the Documentation both domestically and internationally. The Documentation can only be acquired and/or duplicated by others using an equivalent investment of time and effort.

I have read the foregoing and the matters stated therein are true and correct to the best of my knowledge, information and belief. I make this affidavit under penalty of perjury under the laws of the United States of America and under the laws of the State of California.

Executed at 3412 Hillview Avenue, Palo Alto, being the premises and place of business of the Electric Power Research Institute:

June 1, 2004

David J. Modeen

Subscribed and sworn before me this day: June 1, 2004

Nichole Alexandra Edraos, Notary Public

NICHOLE ALEXANDRA EDRAOS
Comm. # 1295461
NOTARY PUBLIC - CALIFORNIA
Santa Clara County
My Comm. Expires Feb. 26, 2005

ALL-PURPOSE ACKNOWLEDGEMENT

State of California
County of Santa Clara } ss.

On 6/1/04 (DATE) before me, Nichole Alexandra Edraos, (NOTARY)

personally appeared _____ SIGNER(S)

☐ personally known to me - OR - ☐ proved to me on the basis of satisfactory evidence to be the person(s) whose name(s) is/are subscribed to the within instrument and acknowledged to me that he/she/they executed the same in his/her/their authorized capacity(ies), and that by his/her/their signatures(s) on the instrument the person(s), or the entity upon behalf of which the person(s) acted, executed the instrument.

NICHOLE ALEXANDRA EDRAOS
Comm. # 1295461
NOTARY PUBLIC - CALIFORNIA
Santa Clara County
My Comm. Expires Feb. 26, 2005

WITNESS my hand and official seal.

Nichole Alexandra Edraos
NOTARY'S SIGNATURE

OPTIONAL INFORMATION

The information below is not required by law. However, it could prevent fraudulent attachment of this acknowledgement to an unauthorized document.

CAPACITY CLAIMED BY SIGNER (PRINCIPAL)

☐ INDIVIDUAL
☐ CORPORATE OFFICER

_____ TITLE(S)

☐ PARTNER(S)
☐ ATTORNEY-IN-FACT
☐ TRUSTEE(S)
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DESCRIPTION OF ATTACHED DOCUMENT

NRC affidavit
TITLE OR TYPE OF DOCUMENT

_____ NUMBER OF PAGES

_____ DATE OF DOCUMENT

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SIGNER IS REPRESENTING:
NAME OF PERSON(S) OR ENTITY(IES)

_____

RIGHT THUMBPRINT OF SIGNER

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