Byron Unit 1 Extended Cycle 8 Report

ComEd

October 1996

Byron Unit 1 Extended Cycle 8 Report

Table of Contents

Executive Summary:

On June 20, 1996 at a meeting with NRC staff, ComEd presented and the staff concurred with the technical basis for Byron Unit 1 full cycle operation for a period equivalent to the previous cycle of operation (448.5 days > 500°F). ComEd plans to replace Byron Unit 1 steam generators during the first quarter of 1998. Therefore, this is the last cycle of operation for the Byron Unit 1 original steam generators. The period of operation to shutdown for the replacement outage results in a 600 day operating cycle (June 26, 1996 to February 15, 1998). This evaluation was completed to assure steam generator tube integrity requirements would be met in the unlikely event of a main steam line break (MSLB) at the end of a 600 day operating period.

The conditional probability of burst and leak rate, in the event of a main steam line break are calculated for the Byron Unit 1 end-of-cycle eight (8) voltage distributions for a 600 day (>500°F) operating cycle. The calculations were performed consistent with the methodology outlined in NRC GL 95-05. The calculations incorporate modifications to the inputs, assumptions and methods included in response (References 2c - 2g) to NRC requests for additional information on the Braidwood Unit 1 cycle length assessment (References 5 and 6). A summary of the RAI responses applicable to the Byron Unit 1 assessment is provided in Attachment B and the applicable Byron response is provided in Attachment C and D.

The following elements from the Braidwood cycle length assessment have been incorporated into the Byron Unit 1 analysis:

- analyst uncertainty from a second blind test using voltage integral software,
- updated probe wear uncertainty analysis,
- statistically determined coil size and normalization factors,
- industry LTL material properties,
- statistically determined best fit burst correlation (log burst pressure vs. voltage),
- logistic probability of leak function vs. log maximum voltage, and
- sensitivity of results to Byron Unit 1 short cycle (1995 to 1996) growth rates.

The 1996 inspection at Byron Unit 1 used the best technology available (plus point), at the time of inspection, for steam generator tube top-of-the-tube-sheet (TTS) inspections with acute analyst awareness of the characterization of circumferential indication signals. Therefore, the Byron Unit 1 inspection results are used directly as inputs to the Byron Unit 1 end-of-cycle calculations as follows:

- the beginning of cycle eight distribution, BOC-8, is based upon the Byron Unit 1 end-of-cycle seven (1996) inspection results,
- a POD of 0.8, based upon blind tests from the Byron Unit 1 1996 inspection, is applied to the inspection results to determine the BOC-8 distribution, and
- the BOC-8 distribution is grown 600 days using growth rates from Byron Unit 1 look-backs to determine the end-of-cycle eight, EOC-8, distribution.

The EOC-8 distribution is used to assess the conditional probability of burst and leak rate at MSLB conditions.

The Byron Unit 1 end-of-cycle 8 distributions of indications for the most limiting steam generator were analyzed against the criteria identified in NRC GL 95-05 to assess the conditional probability of burst (10^{-2}) and the leak rate (36.5 gpm) at MSLB conditions. The conditional probability of burst for the limiting parameter (average voltage) is $1x10^{-4}$ and the total predicted EOC leakage from all known degradation mechanisms is 31.4 gpm at MSLB conditions.

Therefore, ComEd has concluded that Byron Unit 1 can operate 600 days and meet the criteria in GL 95-05 for conditional probability of burst (10^{-2}) and leak rate (less than the site allowable limit of 36.5 gpm) for EOC voltage distributions.

1.0 Introduction:

ComEd has completed analysis of the Byron Unit 1 1996 inspection results and has determined the EOC-8 distribution of TTS circumferential indications. The analysis was performed for a cycle length equivalent to 600 days of operation above 500°F (June 26, 1996 to February 15, 1998). The predicted end-of-cycle probability of burst and leakage has been calculated and assessed against NRC Generic Letter, GL 95-05 criteria (Reference 1). The methodology used in the evaluation is consistent with that used to assess the Braidwood Unit 1 EOC-6 distribution of indications as submitted to NRC in Reference 2(a-g).

The following elements from the Braidwood cycle length assessment have been incorporated into the Byron Unit 1 analysis:

- analyst uncertainty from a second blind test using voltage integral software,
- updated probe wear uncertainty analysis,
- statistically determined coil size and normalization factors,
- industry LTL material properties,
- statistically determined best fit burst correlation (log burst pressure vs. voltage),
- log-logistic probability of leak function vs. maximum voltage, and
- sensitivity of results to Byron Unit 1 short cycle (1995 to 1996) growth rates.

The 1996 inspection at Byron Unit 1 used the best technology (plus point) available, at the time of inspection, for steam generator tube TTS inspections with acute analyst awareness of the characterization of circumferential indication signals. Therefore, the Byron Unit 1 inspection results are used directly as inputs to the Byron Unit 1 end-of-cycle calculations as follows:

- the beginning of cycle eight distribution, BOC-8, is based upon the Byron Unit 1 end- of -cycle seven (7) (1996) inspection results,
- a POD of 0.8, based upon blind tests from the Byron Unit 1 1996 inspection, is applied to the inspection results to determine the BOC-8 distribution, and
- the BOC-8 distribution is grown 600 days using growth rates from Byron Unit 1 look-backs to determine the end-of-cycle eight, EOC-8, distribution.

The EOC-8 distribution is used to assess the conditional probability of burst and leak rate at MSLB conditions.

2.0 Methodology and Procedure:

The structural and leakage evaluations of TTS circumferential indications in Byron, Unit 1 were performed by generally applying the guidelines in Generic Letter (GL) 95-05 (Reference 1). Application of the guidelines in GL 95-05 included: (1) defining distributions of maximum and average voltages for OD circumferential indications at TTS for a limiting steam generator based on the indications detected and repaired at Byron, Unit 1 during the 1996 inspection, (2) determining a beginning-of-cycle (BOC) voltage distributions based on a POD adjustment to the distribution of circumferential

indications detected and repaired at Byron, Unit 1 in 1996, (3) projecting the BOC distributions using monte carlo techniques that reflect the EOC voltage distributions using growth rate and eddy current measurement uncertainty, (4) calculating the conditional probability of burst for the EOC maximum and average voltage distributions at postulated MSLB pressure, and (5) calculating the leak rate for the EOC maximum voltage distribution at MSLB pressure and temperature conditions.

3.0 Acceptance Criteria:

Evaluation of the EOC voltage distributions for TTS circumferential indications in a limiting steam generator at Byron, Unit 1 employed the acceptance criteria contained in GL 95-05.

The acceptance criterion used to evaluate the margin against tube burst specified that the conditional probability of burst for the distributions of maximum and average voltage is less than 10^{-2} at MSLB pressure

The acceptance criterion used to evaluate leak rate specified that the calculated leak rate at MSLB pressure from the distribution of maximum voltage from TTS circumferential indications, plus the leak rate at MSLB pressure from the distribution of axial ODSCC indications at tube support plates, plus the leak rate from unfaulted generators was less than the site allowable limit of 36.5 gpm, which is based upon a small fraction of 10CFR100 limits.

4.0 Analysis Input Parameters:

4.1 Cycle Length:

The duration of operation at temperatures greater than 500°F from startup from the last steam generator (SG) tube inspection (June 26, 1996) to the proposed SG replacement outage (February 15, 1998) is 600 days. The projected cycle length used for the assessment is 600 days.

4.2 1996 Indication Distribution:

Results of the Byron Unit 1 1996 TTS inspection for circumferential indications are provided in Table 1 of Reference 3. The look-back data provided in Reference 3 was based upon a look-back performed on-site in April and May of 1996 using the analyst to determine the maximum voltage (i.e. voltage integral software had not yet been developed). Subsequent to this, a look-back of 1996 TTS circumferential indications in SG C using the voltage integral software was performed. Maximum and average voltage were recorded for the four hundred thirty two (432) 0.080" RPC indications reported during this look-back. The 0.080" RPC voltage distribution frequencies were used to scale up the inspection result distributions to account for the indications detected by the plus point coil without 0.080" RPC confirmation.

To develop the distributions for a limiting SG the voltage frequency distributions for 0.080" RPC maximum and average volts in SG C were scaled up such that the total number of indications is equal to the number of plus point indications detected in the most limiting steam generator, SG D (1164). The resulting hybrid distributions used in the EOC analysis are provided in Table 1 and 2 for maximum and average voltage respectively. This hybrid distribution is conservative because the adjustment for the number of plus point indications is applied to all voltage bins. Look-back data has shown that a higher percentage of plus point indications without 0.080" RPC confirmation are at low voltages than at high voltages.

Therefore, a conservative distribution of 1996 indications for the most limiting steam generator is used for input into the beginning of cycle (BOC) distribution.

4.3 Probability of Detection (POD):

A blind test of Byron Unit 1 TTS inspection data was performed at Byron Station to assess the probability of detection of circumferential indications during the inspection. Details of the blind test including the objective, scope and protocol were provided to NRC in Reference 4. A summary and conclusions of the blind test are provided below.

The tubes selected for the blind test came from SG C, 1996 look-back population. The first blind test was made up of 100 tubes and the second was made up of 200 tubes. Three inspection data sets 1994, 1995, and 1996 were included in both blind tests.

A representative range of indication sizes were selected from the Plus Point probe voltages to be included in the blind test. After the tubes were selected, the EPRI "site shell" program built the tests to include the minimum number of flaws and NDD tubes for each data set.

For the 100 tube test, ninety six (96) tubes with indications were chosen from the results of the 1996 look-back. Four tubes that were identified as not having indications, NDD, were included to achieve the 100 tube total. These 96 indications from the 1996 look-back are called "truth flaws." For grading purposes, the truth flaws are the flaws that are required to be reported by the analysts.

The 100 tubes that were selected from the 1996 data were also included in the 1995 and 1994 data sets. The 1996 circumferential indications in some cases were NDD in the 1995 and 1994 data sets, the number of NDD tubes is greatest in the 1994 data set. The 200 tube test was developed with the same method, but was biased with the addition of more NDD tubes.

For the 100 tube test 97% of the 1996 truth flaws were reported correctly by the analysts to achieve a POD of 95% at a CL of 99%. This met the 90% POD at a

95% CL set up in the EPRI site shell program grading scheme. For the 200 tube test 98% of the 1996 truth flaws were reported correctly by the analysts to achieve a POD of 96% at a CL of 98%.

A conservative POD of 0.8, based upon the Byron blind test results, is used in determining the Byron Unit 1 BOC distribution.

4.4 Beginning of Cycle Distribution:

The Byron Unit 1 1996 NDE data binned by voltage from Section 4.2 and the POD from Section 4.3 are used to determine the BOC-8 distribution. This determination is made using the procedure in GL 95-05 (Reference 1), where:

$$N_l = (1/POD)N_d - N_r \qquad (1)$$

and

N_l = BOC distribution,
POD = probability of detection of an indication
N_d = distribution of binned indications detected by NDE, and
N_r = distribution of binned indications repaired

All circumferential indications are repaired upon detection so that $N_r = N_d$ and Eq. 1 becomes

$$N_l = (1/POD - 1)N_d \qquad (2)$$

The BOC distribution by voltage bin is determined from Eq. 2.

4.5 Growth Rates:

From the voltage integral look-back of 1995 and 1996 indications to previous RPC inspections, growth rates were calculated for over 750 indications. The growth rates are normalized to 1 year of operation. Growth rate data was calculated for operating intervals of 344 (1994 to 1995) and 448.5 days (1994 to 1996). A discussion of how the growth rates were calculated and the intervals selected are presented in Attachment C, response to 9/9/96 RAI Question 3 and Attachment D, response to 10/3/96 RAI Question 5. The growth rates for the appropriate intervals are provided in Table 3a and 3b of this report for maximum and average voltage respectively. These growth rates were applied to the BOC distribution for determination of the Byron Unit 1 EOC-8 voltage distributions.

4.6 NDE Uncertainty:

The BOC voltage distributions are adjusted to account for NDE uncertainty associated with analyst uncertainty and probe wear.

Analyst Uncertainty:

In Attachment C response to Questions 25 - 27 ComEd provides the protocol and results of a second blind test performed on circumferential indications. The blind test was performed to assess the uncertainty in analysts TTS circumferential indication voltage measurement. Maximum and average voltage measurements were recorded by nine analysts for the 0.080" RPC data of 141 Byron and Braidwood indications using the voltage integral software with no re-evaluation of recorded results. The second blind test provides the basis for conservative application of analyst uncertainty with a normal distribution and a standard deviation of 30% and 32% in the EOC analysis for 0.080" RPC maximum and average volts, respectively.

Probe Wear:

The results of a study for determination of the amount of rotating pancake probe wear was provided in Reference 2 Section A.2.1 and an updated analysis is provided in Attachment C response to Question 31. This study provides the basis for conservative application of probe wear with a normal distribution and a standard deviation of 7.5%.

4.7 End-of-cycle Distribution:

The BOC distribution, growth rate data, analyst uncertainty and probe wear are used as input to generate the EOC distribution. Any growth rates that were computed from the NDE data to be negative values are set equal to zero in compliance with the guidelines in GL 95-05. A Monte Carlo sampling procedure is used to generate the EOC distribution. The EOC distributions for maximum and average voltage are provided in Table 4.

5.0 Conditional Probability of Burst Analysis:

The conditional probability of burst for the EOC maximum and average voltage distributions in Table 4 are calculated at postulated main steam line break (MSLB) pressure and temperature conditions. The voltage burst correlation developed from industry tube pull test pressure data (Attachment C, Table 5) is used to determine the conditional probability of burst of the EOC distribution. The industry data (from 0.115" and 0.080" pancake coils) was analyzed with a consistent normalization of 10 Volts on a 100% throughwall hole. To make the industry data consistent with Byron Unit 1 look-back data (20 Volts on a 100% TW axial EDM notch, 0.080" RPC), factors for voltage normalization and coil size were applied to the industry data. The factors were determined statistically from analysis of 50 Byron Unit 1 1996 indications to be 0.51 applied to all industry data (normalization factor of 0.51 and 0.68 and coil size factor of

1.0 and 0.75 for the 0.080" RPC and 0.115" RPC, respectively). The normalized industry ECT data and burst pressure data are used to develop a burst correlation.

The burst correlation development was performed consistent with the methodology in GL 95-05 as documented in Reference 7. Burst correlation evaluations examined the scale factors for the coordinate system to be employed, e.g., linear versus logarithmic, the detection and treatment of outliers, the order of the regression equation, the potential influence of measurement errors in the variables, and the evaluation of the residuals following the development of a relation by least squares regression analysis. The results of the analyses indicated that an optimum linear, first order relation could be obtained from the regression of the Log burst pressure on voltage. Examination of the residuals revealed no abnormal scatter or information indicative of non-normal distribution, and no implied outliers. Using the regression relationship, a lower 95% prediction bound for the log burst pressure as a function of 0.080" RPC voltage is then developed. These values are further reduced to account for the lower tolerance bound for the Westinghouse database of tubing material properties at 650°F. The burst correlation's shown in Figures 1 and 2 meet the guidelines of NRC GL 95-05.

Using Monte Carlo sampling techniques to combine uncertainties in material properties and the burst correlation and applying it to the EOC-8 distribution for maximum and average voltage (Table 4) results in an EOC-8 conditional probability of burst of one or more tubes at main steam line break conditions of $7x10^{-5}$ and $1x10^{-4}$ for maximum and average voltages, respectively. These results meet the requirements for the conditional probability of burst in NRC GL 95-05 of 10^{-2}.

6.0 Total Leak Rate During a MSLB:

The total leak rate during a MSLB is calculated for the EOC-8 distribution. The methodology used to calculate the EOC leak rate is provided in Attachment C, response to RAI Question 16. The methodology is summarized in the next two paragraphs.

In order to provide conservatism in the leak rate analysis and to address limited data and uncertainties in the industry leak rate data, a logistic probability of leak vs. log maximum ECT voltage function is used. The function was developed using the same methodology as that used for ODSCC at TSP's consistent with GL 95-05 and documented in Reference 7. The probability of leak is evaluated by segregating the field data into two categories, i.e., specimens that would not leak during a MSLB and those that would leak during a MSLB. These industry data are provided in Attachment C, Table 5. The data were analyzed to fit a sigmoid type equation to establish an algebraic relationship between the 0.080" RPC maximum voltage and the probability of leak. The specific algebraic form used to date has been the logistic function with the common logarithm of the RPC maximum voltage employed as the regressor variable. To add additional conservatism the 95% confidence level of the probability of leak function is applied to the entire EOC distribution. Figure 3 shows the probability of leak function which was applied to the Byron Unit 1 EOC-8 distribution.

The EOC-8 maximum voltage distribution is used to calculate the total probability of leak at each voltage level. Maximum voltage is the ECT voltage parameter which provides the best assessment of through-wall degradation. The maximum voltage is used to

determine which tubes will leak at main steam line break conditions not the rate at which the indications at each voltage level will leak (there is no correlation between leak rate and maximum voltage). Instead, the highest leak rate identified from all tube pull or insitu leak testing is conservatively applied to all voltage bins. The highest leak rate is 0.16 gpm which came from an indication of 1.85 volts (maximum) from an 0.080" RPC probe. This is larger than any indications detected in the Byron Unit 1 1996 inspection. The total EOC-8 TTS circumferential indication leak rate is calculated using the following equation:

$$LR_{cc} = \Sigma_i [POL \times N_i \times 0.16 \text{ gpm}] \qquad (3)$$

Where,

LR_{cc} = total EOC-8 TTS circumferential indication leak rate in gpm
POL = the probability of leak at voltage bin i
N_i = the EOC-8 number of indications in voltage bin i
0.16 gpm = the maximum leak rate from all industry tube pull and insitu leak testing

Applying the Byron Unit 1 EOC-8 TTS circumferential indication maximum voltage distribution (Table 4) and the POL function in Figure 3 to equation (3) results in a total leak rate of 12.1 gpm from the most limiting SG at MSLB conditions. A leak rate of 19.0 gpm is predicted for ODSCC at the TSP for the limiting SG (Reference 8) at the end of the proposed 600 day operating cycle. Combining these two leak rates with 0.3 gpm (Tech Spec maximum allowed leak rate of 0.1 gpm for 3 unfaulted SG's) results in a total leakage at MSLB conditions at EOC-8 of 31.4 gpm which is less than the site allowable leak limit of 36.5 gpm. Byron Unit 1 EOC-8 predicted leak rates from all known degradation mechanisms meets NRC GL 95-05 criteria.

7.0 Conclusions:

The Byron Unit 1 end-of-cycle eight (8) distributions of indications for the most limiting steam generator were analyzed to assess the conditional probability of burst and the leak rate at MSLB conditions against the criteria identified in NRC GL 95-05. The results indicate that Byron Unit 1 can operate for 600 days and maintain considerable margins to the conditional probability of burst of 10^{-2} and the site allowable leak limit of 36.5 gpm. The conditional probability of burst for the limiting parameter (average voltage) is 1×10^{-4} and the total EOC leakage from all known degradation mechanisms is 31.4 gpm. Therefore, Byron Unit 1 can operate for 600 days (>500°F) and maintain safety margins as outlined in NRC GL 95-05.

8.0 References:

1. NRC Generic Letter 95-05, "Voltage Based Repair Criteria for Westinghouse Steam Generator Tubes Affected by Outside Diameter Stress Corrosion Cracking", August 3, 1995, U.S. NRC
2. Braidwood Unit 1 Cycle Length Assessment Report to NRC, 8/2/96

2b. Update to Operating Interval Between Eddy Current Inspections for Circumferential Indications in the Braidwood Unit 1 Steam Generators, Conditional Burst Probability Basis, August 20, 1996

2c. Update to Reference 2, Partial Response to Request for Additional Information (Reference 5) Pertaining to Operating Interval Between Eddy Current Inspections for Circumferential Indications in the Braidwood Unit 1 Steam Generators, September 10, 1996

2d. Update to Reference 2, Partial Response to Request for Additional Information (Reference 5) Pertaining to Operating Interval Between Eddy Current Inspections for Circumferential Indications in the Braidwood Unit 1 Steam Generators, September 17, 1996

2e. Update to Reference 2, Partial Response to Request for Additional Information (Reference 5) Pertaining to Operating Interval Between Eddy Current Inspections for Circumferential Indications in the Braidwood Unit 1 Steam Generators, Update Responses to Questions 19 and 20, September 20, 1996

2f. Update to Reference 2, Complete Updated Response to Request for Additional Information (Reference 5) Pertaining to Operating Interval Between Eddy Current Inspections for Circumferential Indications in the Braidwood Unit 1 Steam Generators, September 24, 1996

2g. Update to Reference 2, Complete Response to Request for Additional Information (Reference 6) Pertaining to Operating Interval Between Eddy Current Inspections for Circumferential Indications in the Braidwood Unit 1 Steam Generators, October 10, 1996

3. Byron Unit 1 1996 Circumferential Indication Summary Report to NRC, September 30, 1996
4. Report to U.S. NRC on Operating Interval Between Eddy Current Inspections for Circumferential Indications in the Braidwood Unit 1 Steam Generators, May 17, 1996
5. NRC Request for Additional Information, dated September 9, 1996
6. NRC Request for Additional Information, dated October 3, 1996
7. WCAP-14277, SLB Leak Rate and Tube Burst Probability Analysis Methods for ODSCC at TSP Intersections, January 1995

Table 1

Byron Unit 1 1996 Max Voltage Distribution Look-Back Results

	Number of Indications		
BINS (volts)	S/G C Actual 0.080" RPC	Additional Ind's to Account for 1164 Plus Point Ind's	Total Dist for 1164 Inds.
0.2	5	8	13
0.3	48	81	129
0.4	128	217	345
0.5	89	151	240
0.6	67	114	181
0.7	43	73	116
0.8	30	51	81
0.9	16	27	43
1	5	8	13
1.1	1	2	3
SUM >>	432	732	1164

Table 2

Byron Unit 1 1996 AVG Voltage Distribution Look-Back Results

	Number of Indications		
BINS (volts)	S/G C Actual 0.080" RPC	Additional Ind's to Account for 1164 Plus Point Ind's	Total Dist for 1164 Inds.
0.05	0	0	0
0.10	17	29	46
0.15	100	169	269
0.20	117	198	315
0.25	77	131	208
0.30	51	86	137
0.35	30	51	81
0.40	21	36	57
0.45	10	17	27
0.50	6	10	16
0.55	1	2	3
0.60	2	3	5
SUM >>	432	732	1164

Table 3a

Byron 1 Growth Rate Bins and Number of Tubes for Maximum Voltage

Bins	94 to 95	94 to 96
ΔV/EFPY	Number of Tubes	
-0.4	4	0
-0.3	3	0
-0.2	12	1
-0.1	33	5
0.0	71	10
0.1	169	20
0.2	177	23
0.3	112	6
0.4	67	5
0.5	25	2
0.6	9	0
0.7	3	0
SUM >>	685	72

Table 3b

Byron 1 Growth Rate Bins and Number of Tubes for Average Voltage

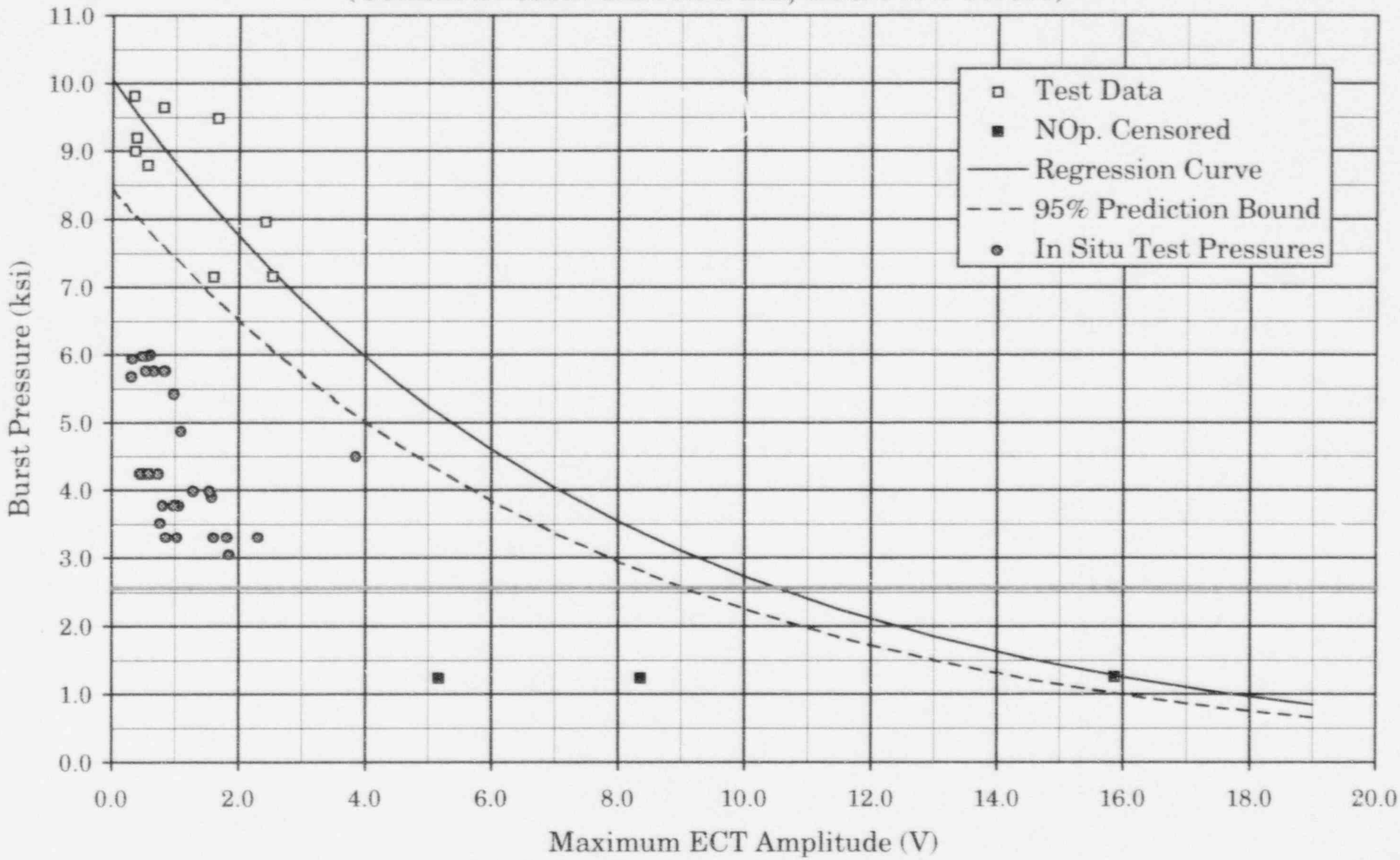
Bins	94 to 95	94 to 96
ΔV/EFPY	Number of Tubes	
-0.25	3	0
-0.20	4	2
-0.15	7	1
-0.10	26	2
-0.05	40	6
0.00	92	7
0.05	185	25
0.10	149	9
0.15	107	14
0.20	41	2
0.25	14	1
0 30	11	3
0.35	3	0
0.40	3	0
SUM >>	685	72

Table 4
Byron Unit 1 End-of-Cycle 8 Distribution
Maximum and Average Voltage

Max Volts		Average Volts	
Top of Bin (volts)	Tubes	Top of Bin (volts)	Tubes
0.10	0.00	0.05	0.02
0.20	1.21	0.10	3.94
0.30	8.49	0.15	17.85
0.40	19.93	0.20	28.95
0.50	27.44	0.25	33.74
0.60	34.54	0.30	34.17
0.70	34.53	0.35	34.44
0.80	33.70	0.40	29.84
0.90	29.25	0.45	26.11
1.00	24.61	0.50	18.92
1.10	19.81	0.55	14.89
1.20	15.53	0.60	10.31
1.30	10.92	0.65	8.59
1.40	7.89	0.70	6.59
1.50	5.67	0.75	4.94
1.60	3.95	0.80	3.43
1.70	2.66	0.85	2.59
1.80	1.90	0.90	1.81
1.90	1.58	0.95	1.44
2.00	0.97	1.00	1.20
2.10	0.67	1.05	0.56
2.20	0.53	1.10	0.65
2.30	0.43	1.15	0.53
2.40	0.31	1.20	0.33
2.50	0.41	1.25	0.27
2.60	0.26	1.30	0.30
2.70	0.12	1.35	0.21
2.80	0.14	1.40	0.19
2.90	0.10	1.45	0.18
3.00	0.09	1.50	0.15
3.10	0.14	1.55	0.10
3.20	0.07	1.60	0.08
3.30	0.12	1.65	0.10
3.40	0.03	1.70	0.05
3.50	0.04	1.75	0.09
3.60	0.07	1.80	0.04
3.70	0.06	1.85	0.06
3.80	0.04	1.90	0.07
3.90	0.06	1.95	0.08
4.00	0.01	2.00	0.07
4.10	0.03	2.05	0.07
4.20	0.02	2.10	0.04
4.30	0.05	2.15	0.03
4.40	0.04	2.20	0.06
4.50	0.01	2.25	0.01
4.60	0.02	2.30	0.01
4.70	0.02	2.35	0.02
4.80	0.02	2.40	0.01
4.90	0.00	2.45	0.01
5.00	0.03	2.50	0.03

Figure 1: Burst Pressure vs. Maximum ECT Amplitude

(Commonwealth Edison Data, LTL Flow Stress)



Conclusions: 1. Log Burst pressure vs. maximum volts provides best fit of burst data

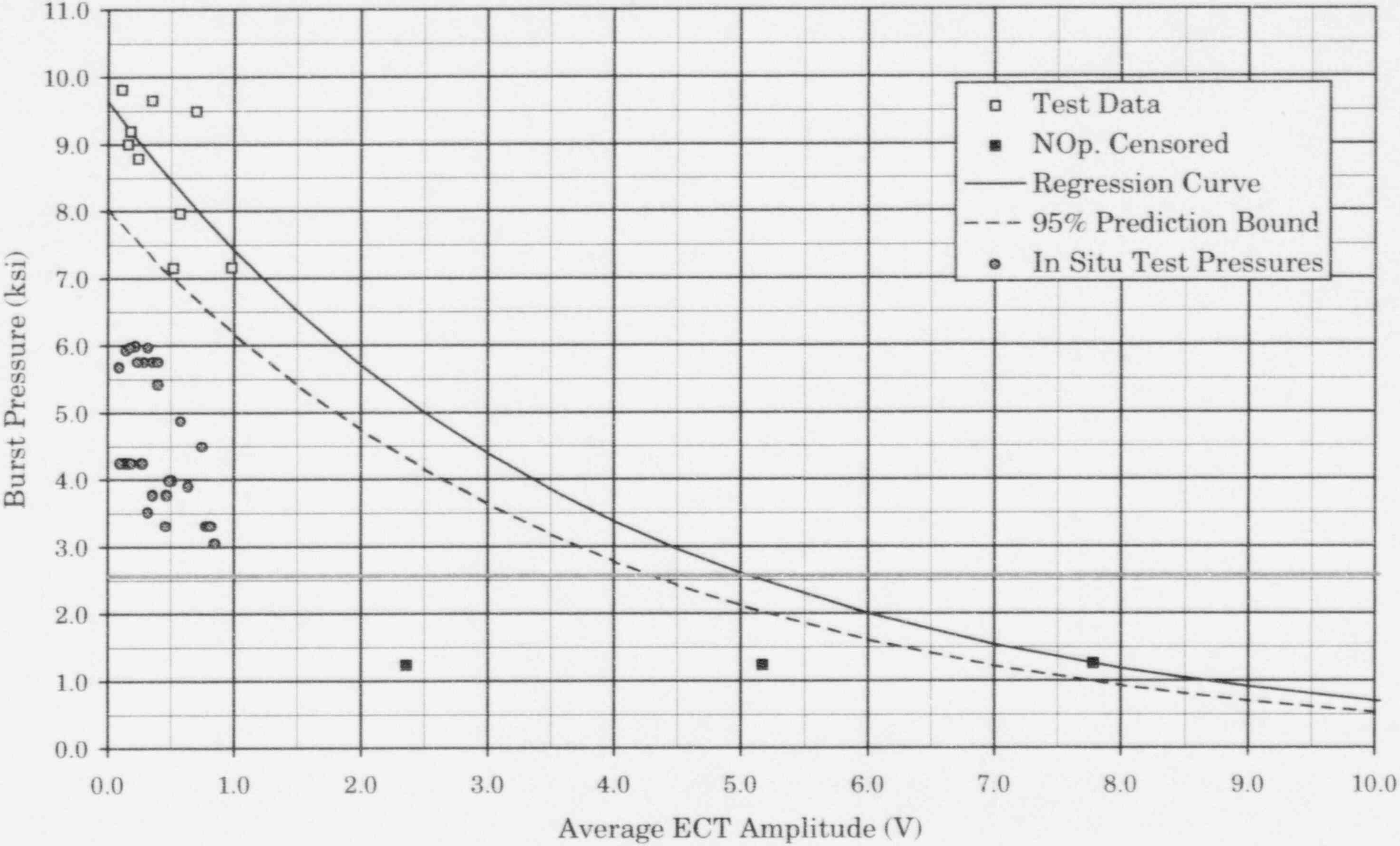
2. Correlation of data satisfies NRC GL 95-05 "p" test 5% requirement

[BURCOMF8.XLS] LogPb.Vmax

HFK. 10/11/96, 10:28 AM

Figure 2: Burst Pressure vs. Average ECT Amplitude

(Commonwealth Edison Data, LTL Flow Stress)



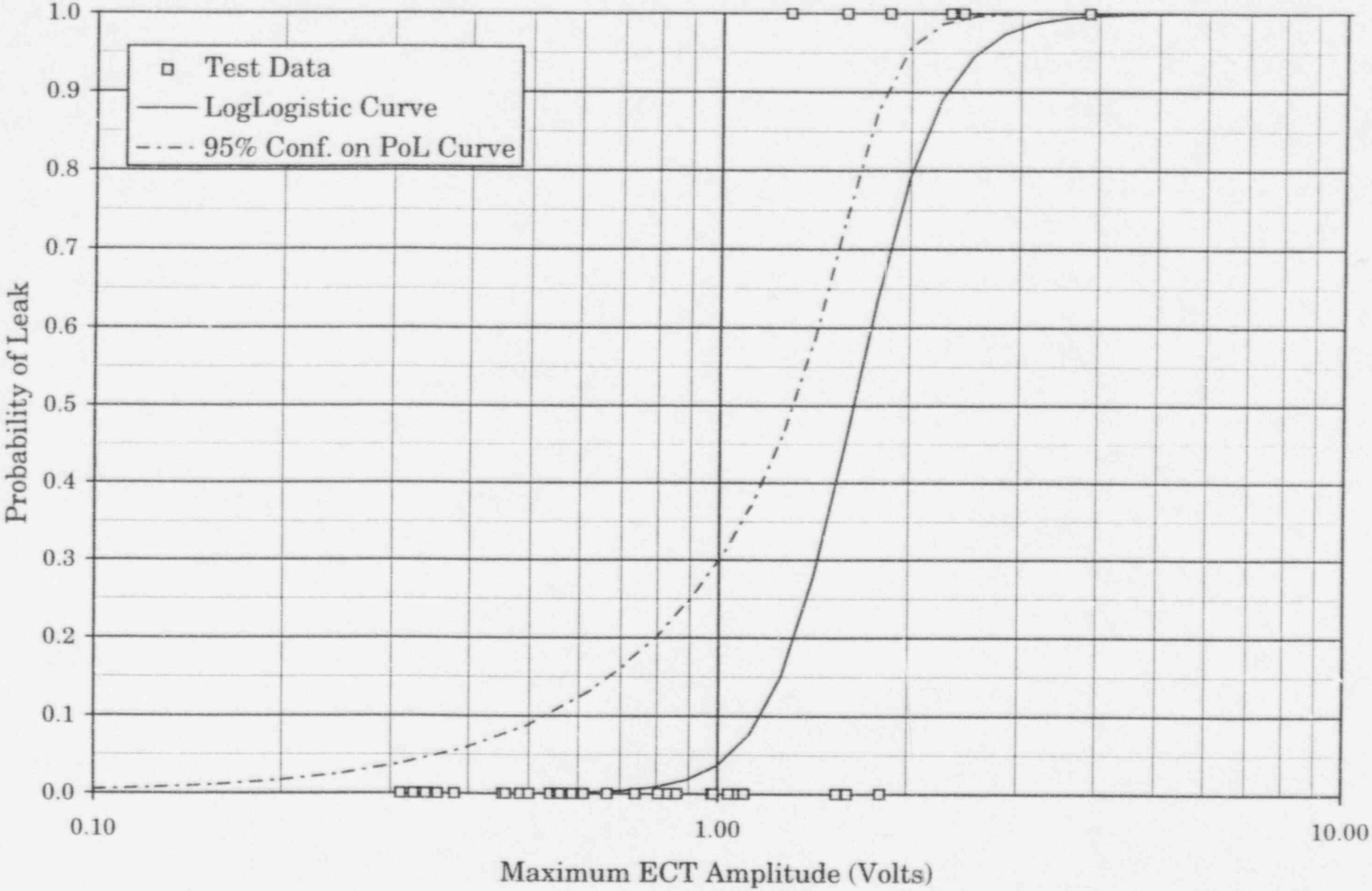
Conclusions: 1. Log Burst pressure vs. average volts provides best fit of burst data

2. Correlation of data satisfies NRC GL 95-05 "p" test 5% requirement

[BURCOMF8.XLS] LogPb.Vavg

RFK: 10/11/96, 9:51 AM

Figure 3: **Probability of Leak vs. Maximum ECT Amplitude**
(Commonwealth Edison Data)



[comeddat.xls] PoL.Vmax

RFK: 9/18/96, 7:59 PM

Attachment A

Sensitivity Studies

A sensitivity study of the Byron Unit 1 EOC-8 conditional probability of burst and leak rate analyses was performed to assess the impact of short interval growth rates (1995 to 1996) on the results. ComEd believes that a sound technical basis exists for the analysis and results presented in the main body of the report. These sensitivity results were performed to provide the NRC staff with additional bases for concurrence with the conclusions that Byron Unit 1 can operate for a 600 day operating cycle and meet tube integrity requirements.

The sensitivity analyses were performed with the same inputs, assumptions and methods as described in the main body of the report with inclusion of the short interval growth rates (1995 to 1996) for maximum and average voltages. The results are provided in the Following Table.

Table A-1. Results of Burst and Leak Analyses Sensitivity Studies

Case	POB (avg. volts)	POB (max. volts)	Leak Rate (max. volts)
Base No 1995 to 1996 Growth Rates	1E-4	7E-5	12.1 (gpm)
1995 to 1996 Growth Rates Included	1E-4	6E-5	13 (gpm)

Note 1: Leak rate is from TTS circumferential indications only

Conclusions:

Inclusion of the short interval growth rates (1995 to 1996) results in minor changes in the results of the end-of-cycle analysis for Byron Unit 1.

Attachment B

RAI Question Applicability to Byron

RAI Question Number	Description	Applicability to Byron	Basis
9-Sep-96			
1	Brd. 1 morphology based upon ECT max and avg volts	not applicable	Not applicable to Byron, from 12 tube pulls morphology is well understood
2	Brd. 1 growth rates	not applicable	Byron growth rate data sufficient to meet GL 95-05
3	Byron 1 growth rates	applicable	1994 to 1995 and 1994 to 1996 growth rates used in analysis
4	Brd. 1 report clarification	not applicable	Clarification provided
5	Industry burst data	applicable	Data for burst and leak correlations
6	Deterministic burst limit	not applicable	Probabilistic analysis method used for Byron
7	Frequency > S.L. Criteria $2x10^{2}$	not applicable	Criteria not used in Byron analysis GL 95-05, 10^{2} criterion applied
8	Burst correlation statistical fit	applicable	Basis for best fit burst correlation
9	Brd. 1, morphology, applicability of deterministic lower bound limit	not applicable	Byron 1 morphology understood, new burst correlation is used in analysis
10	Brd. 1 LTL for Burst Limit	not applicable	Byron 1 analysis uses industry LTL
11	Fatigue affects on burst limit	applicable	Brd. 1 response applicable for Byron 1
12	Multiple tube failures due to whip/impingement	applicable	Brd. 1 response applicable for Byron 1
13	Use of single scan line vs multiple	applicable	Brd. 1 response applicable for Byron 1
14	Avg. Volts for leak rate analysis, method for leak rate temp. and press. correction	applicable	Brd. 1 response applicable for Byron 1
15	Leakage from other than max. voltage location	applicable	Brd. 1 response applicable for Byron 1
16	Leakage cut-off and max. leak rate	applicable	Brd. 1 response applicable for Byron 1
17	ECT inspection data	not applicable	Data already submitted with Brd. 1 response
18	Brd. inspection guidelines	not applicable	Applicable to Brd. inspection
19	Normalization correction factor	applicable	Brd. 1 response applicable for Byron 1
20	Coil size correction factor	applicable	Brd. 1 response applicable for Byron 1
21	Provide review of industry ACTS/ANTS	not applicable	Data already submitted with Brd. 1 response
22	Account for liftoff	applicable	Brd. 1 response applicable for Byron 1
23	Brd. inspection POD for 0.080" RPC	not applicable	Byron Unit 1 Blind test results used for determination of POD
24	Noise and deposit signals	applicable	Brd. 1 response applicable for Byron 1
25	Analyst uncertainty based on plus point	applicable	Byron analysis uses results of VIR blind test
26	Blind test assumes normal distribution	applicable	Brd. 1 response applicable for Byron 1
27	Blind test re-evaluation of data	applicable	Byron analysis uses results of blind test with no re-evaluation
28	Analyst Uncertainty with trigger offset	applicable	Byron analysis uses results of VIR blind test
29	Analyst Uncertainty for Max vs. Avg. Volts	applicable	Byron analysis uses results of VIR blind test
30	Use of filters, trigger offset, on 360 deg flaws	applicable	Brd. 1 response applicable for Byron 1
31	Probe wear study	applicable	Brd. 1 response applicable for Byron 1, probe wear of 7.5% applied
3-Oct-96			
1	Applicability of Industry axial failures in burst correlation	applicable	Brd. 1 response applicable for Byron 1
2	Normalization correction factor data scatter	applicable	Brd. 1 response applicable for Byron 1
3	Coil size correction factor uncertainty	applicable	Brd. 1 response applicable for Byron 1
4	Clarify normalization voltage data	not applicable	clarification provided
5	Update analysis for changes including 1995 to 1996 growth rates	applicable	Sensitivity of 1995 to 1996 growth rates included in Byron 1 analysis

Attachment C

BYRON UNIT 1 RESPONSE TO

REQUEST FOR ADDITIONAL INFORMATION DATED SEPTEMBER 9, 1996 (REFERENCE 5)

RELATED TO THE BRAIDWOOD, UNIT 1 CYCLE LENGTH ASSESSMENT

Reference: Braidwood Response (Reference 2c - 2f)

1. **In the license's submittal dated August 2, 1996, a morphology assessment was provided which attempts to demonstrate the similarity between circumferential crack indications in Braidwood, Unit 1 to Byron, Unit 1 based on the relationship between the maximum and the average eddy current (EC) voltages. However, the licensee did not provide a sufficient basis for assuming an eddy current voltage assessment is indicative of degradation morphology. Accordingly, provide data supporting the assumption that circumferential flaws (either real and/or simulated) with morphologies different from that found at Byron Unit 1 demonstrate a different and clearly distinct relationship between the average and the maximum EC voltage such that differing morphologies could be distinguished.**

Response (10/17/96):

Twleve Byron Unit 1 tubes with top-of-the-tube-sheet (TTS) circumferential indications have been pulled and metallographically examined during two successive inspections (1994 and 1995). The morphology of these indications have been the same and consistent with other industry tube pull TTS OD circumferential cracks as outlined in the Braidwood Unit 1 Cycle Length Assessment Report dated February 23, 1996. Morphology of Byron Unit 1 TTS circumferential indications is well understood, therefore this question does not apply to Byron Unit 1.

2. **In Section 4.3 of the licensee's submittal dated August 2, 1996, it is stated that Braidwood Unit 1 growth rates had not been determined at the time of the submittal due to difficulty in converting the EC test data. State when this work will be completed and submitted to the NRC. If this conversion has been completed, submit the results of the assessment.**

Response (10/17/96):

This question is specific to Braidwood Unit 1 growth rates and therefore is not applicable to Byron Unit 1. Byron Unit 1 growth rates have been calculated and provided to NRC in response to RAI's on the Braidwood Unit 1 cycle length assessment (Reference 2f, 2g). See RAI Question 3 below.

3. **The licensee's assessment of Byron Unit 1 growth rates considered inspection data from three inspection outages. Supply the growth rate data for each of the three intervals between these outages; i.e., the interval between the first and second SG tube inspections, the interval between the second and third inspection outages and the interval between the first and third inspection outages. Indicate which of the intervals exhibited the largest growth rate on an effective full power year (EFPY) basis. Provide these data in tabular form separated into the voltage bins shown in Figures 4.3 and 4.4 of your August 2, 1996, submittal. Explain how the indications were: placed in a particular bin. That is, state whether EC voltage values were truncated or rounded up to the higher voltage bin (e.g., 0.45 volts would be raised to 0.5 volts).**

Response (10/17/96):

Byron Unit 1 growth rate data for the three operating intervals is provided in Tables 3a and 3b. The growth rate data is calculated by subtracting the voltage at the beginning of the inspection interval from the voltage at the end of the inspection interval. The difference is then divided by the operating period (342, 448 and 104 days for the three intervals) and multiplied by 365 to provide the growth rate per year. The growth rate data is then put into 0.1 and 0.05 interval voltage growth rate bins, for maximum and average voltage growth, respectively (e.g. 0.44 would be placed in the 0.5 maximum voltage growth rate bin and in the 0.45 average voltage growth rate bin).

Growth rates for the three intervals (1994 to 1995, 1994 to 1996 and 1995 to 1996) are presented in Table 3a and Table 3b of Attachment C for maximum voltage and average voltage, respectively. Growth rate data from 1994 to 1995 comes from the results of the 1995 (SG B) and 1996 (SG C) look-backs, the remaining growth rates come from the 1996 indication look-backs.

The interval showing the greatest variation in growth rates normalized to a year is the shortest interval between the 1995 and 1996 tube inspections. This variation in growth rate for the 1995 to 1996 interval is considered to be a result of inaccuracies that occur when changes in degradation levels are measured for relatively short time intervals. Because corrosion cracks do not grow uniformly, measurement over short time intervals results in scatter that is not representative of the average growth rate over the interval of interest. This can easily be seen by comparing the data from the three intervals. If the

short interval growth rates are actually representative, the variation seen in the 1995 to 1996 interval would also be seen in the 1994 to 1996 interval.

A contributing factor of the scatter in the growth rates is the multiplication of any ECT sizing error for the short interval by a factor greater than three to normalize the data to one year. Byron Unit 1 growth data for the intervals 1994 to 1995 and 1994 to 1996 are used in assessment of Byron Unit 1 end-of-cycle eight, EOC-8, distributions because the Byron data is a statistically significant number of data points (over 750), meets the requirements of GL 95-05 and the growth rates span an entire operating cycle. Byron data for the two periods for which it was calculated (1994 to 1995 and 1994 to 1996) span long periods of operation (342 and 448 days > 500°F) minimizing the uncertainty in extrapolating the data to the proposed operating interval for Byron Unit 1 of 600 days.

Further discussion of the calculation of Byron Unit 1 growth rates is provided in response to Question 5 of NRC RAI dated October 3, 1996.

4. **Clarify the language in Section 4.2.2 of the text which states: "...one hundred three (103) indications identified during the 1994 EC inspection were re-analyzed with the 0.080 inch RPC probe."**

Response (10/17/96):

Because this question pertains to a clarification in the Braidwood Unit 1 cycle length assessment report this question is not applicable to Byron Unit 1.

5. **Supply in tabular form, the data used in the burst pressure and leakage correlations in the submittal dated August 2, 1996, including the following information: (1) the metallographic results (i.e., the percent degraded area, the maximum depth circumferential extent), if available; (2) the SG tube material properties; (3) the EC voltage measurements (maximum and average voltages) Indicating which inspection probe was used; (4) the maximum test pressure; and (5) the burst pressure and/or leak rate. As stated by the staff during the meeting held on August 26, 1996, some of the SG tube burst data in the correlations relating EC voltage values to burst pressure may have come from SG tubes which burst axially rather than circumferentially. Identify in this table which data points in the correlations burst axially as well as those that exhibited mixed mode cracking as determined from the destructive metallurgical examinations. Also, identify any indications that leaked during in-situ pressure testing at a rate beyond the pump capacity.**

Response (10/17/96):

Table 5 provides a summary of the tube pull burst and insitu pressure test data requested in RAI Question 5. All the data are for top-of-the-tubesheet OD circumferential indications. This data is used in the burst and leak correlations for the Byron Unit 1 EOC analysis. A description of each of the columns is provided below:

Test Method: This column identifies whether the test was a burst test, whether the tube was taken to failure, insitu pressure tested or, whether the tube is taken to a target pressure to confirm structural integrity. Additionally, as discussed in response to Question 6 three large voltage indications maintained structural integrity at normal operating pressure. In no cases did a tube with a TTS circumferential indication burst during insitu pressure or under normal operating conditions.

Metallographic Results: For tubes pulled from steam generators, metallographic sizing of the defects have been performed. The results are documented for percent degraded area (PDA), Maximum depth (deepest crack penetration into the tube wall), and circumferential extent of the degradation.

Coil Size: The coil size used to acquire ECT data corresponding to the recorded voltages. All burst data was acquired with the 0.080" RPC. Insitu pressure test data has been acquired with the 0.080" and 0.115" RPC.

10V on 100% TW Hole: Maximum and average voltage results for the indication obtained by normalizing to 10 volts on a 100% throughwall hole. No corrections are applied to this data. For one tube, this flaw did not exist on the calibration standard and therefore the data is not included.

20V on 100% EDM Notch (normalized): The data in column "10V on 100% TW hole", is corrected in this field to the normalization procedure used in Byron and Braidwood look-backs. A correction factor of 0.51 and 0.68 (September 20, 1996 submittal) is used to correct the analysis data to 20V on a 100% TW EDM notch for 0.080" and 0.115" RPC, respectively. The data in column "10V on 100% TW hole" is also corrected where the 0.115" RPC probe is used. The correction factor applied to the 0.115" RPC data is 0.75 (September 20, 1996).

Insitu Pressure: Maximum pressure, in ksi, achieved during insitu pressure testing. No corrections are applied to this data.

Burst Pressure: Maximum pressure, in ksi, achieved prior to burst of the tube or EDM simulant specimen.

Operating Pressure: Normal operating differential pressure in ksi for tubes which were not burst tested or insitu pressure tested.

Leak Rate: Actual measured leak rate during tube pull or insitu leak testing in gpm.

Adjusted Leak Rate: Actual measured leak rate corrected to Braidwood Unit 1 main steam line break conditions (2560 psi, 600°F)

Insitu Leak Rate > Make-up at Maximum Pressure: In some cases during insitu pressure testing the target test pressure could not be achieved due to excessive leakage through the crack for which the test pump could not adequately make-up the necessary flow. This column indicates if this were the case during testing. Leak rate testing is performed at pressures which the test pump had adequate capacity to maintain leakage flow.

Yield Strength: Where tube pull data is available, the yield strength is reported in ksi.

Ultimate Strength: Where tube pull data is available, the ultimate strength is reported in ksi.

Axial or Circumferential Failure: During burst testing, the mode of failure is defined as axial or circumferential. In one case the burst test was terminated after high pressures were achieved (>10 ksi) due to the failure of a test rig weld.

Mixed Mode: Tube pull burst tests for which metallographic examination identified mixed mode cracking is identified in this column.

6. **Analytical predictions of circumferential burst pressure as a function of the percent of degraded SG tube area (PDA) are generally two-part correlations. Specifically, a constant upper bound value dictates the axial burst pressure for SG tube with limited degradation; However, more severely degraded tubes are governed by a relationship indicating lower circumferential burst pressures with increasing values of PDA. Since EC voltage may be related to PDA, it is possible that an empirical relationship between voltage and burst pressure may follow a trend similar to that predicted by analytical correlations. The voltage-burst pressure relationship included in the submittal dated August 2, 1996, is a monotonically decreasing function over all voltages. Discuss the basis for such a relationship in light of current analytical models for circumferential burst pressure.**

Response (10/17/96):

The Byron Unit 1 EOC-8 analysis uses a burst correlation statistically developed to the guidelines of GL 95-05 from industry tube pull data as discussed in response to Question 8. The deterministic structural limit was not used in the Byron Unit 1 EOC analysis and therefore this question is not applicable to the Byron Unit 1 analysis.

7. **In Section 5.3 of the submittal dated August 2, 1996, it is stated that the assessment provided follows the methodology in NRC Generic Letter (GL) 95-05. However, a $2x10^{-2}$ frequency of indications greater than the structural limit is the proposed acceptance criteria as stated in Section 5.4. This latter value is twice the value given in GL 95-05. Accordingly, clarify the discussion on the basis for using this proposed acceptance criteria. In addition, provide a detailed discussion on the technical basis underlying the assumptions in the analysis which is intended to demonstrate that the conditional probability of burst for the SG tubes with voltage beyond the structural limit is less than about 10^{-4} when the frequency of indications is less than $2x10^{-2}$.**

Response (10/17/96):

The Byron Unit 1 EOC-8 analysis assesses the end-of-cycle voltage distributions conditional probability of burst against the criteria of 10^{-2} from NRC GL 95-05 and therefore this question is not applicable to the Byron Unit 1 analysis.

8. **Provide the basis for the shape of the curve used to determine the lower bound SG tube burst pressure. Determine whether a statistical fit to the data can be established using the available data set; i.e., the statistical fit should be valid at the 5% level consistent with GL 95-05. The guidance provided in GL 95-05 with respect to empirical models should be addressed; e.g., provide the order of the regression equation. If a statistical fit to the data can be established, provide a detailed probabilistic analysis of the conditional burst probability which is consistent with the intent of GL 95-05.**

Response (10/17/96):

The burst correlation development was performed consistent with the methodology in GL 95-05 as documented in Reference 7. Burst correlation evaluations examined the scale factors for the coordinate system to be employed, e.g., linear versus logarithmic, the detection and treatment of outliers, the order of the regression equation, the potential influence of measurement errors in the variables, and the evaluation of the residuals following the development of a relation by least squares regression analysis. The results of the analyses indicated that an optimum linear, first order relation could be obtained from the regression of the Log burst pressure on voltage. Examination of the residuals revealed no abnormal scatter or information indicative of non-normal distribution, and no implied outliers. The statistical fit is valid at the 5% level consistent with GL 95-05. Using the regression relationship, a lower 95% prediction bound for the log burst pressure as a function of 0.080" RPC voltage is then developed. These values are further reduced to account for the lower tolerance bound for the Westinghouse database of tubing material properties at 650°F. The burst correlations are shown in Figures 1 and 2 of the main body

of the report and the results of the probabilistic analysis of the conditional burst probability, which is consistent with the intent of GL 95-05, is provided in Section 5.0.

9. For any given EC voltage, a variety of flaw morphologies is possible. Since the staff believes that it has not been demonstrated that EC voltage can accurately predict the morphology of degradation as stated in Item 1 above, discuss the possibility that more structurally significant morphologies may exist than those used to determine the lower bound fit. For example, discuss the possibility that a very tight coplanar flaw with a 360°, 95-percent throughwall defect exhibits the same maximum EC voltage as one of the two data points connecting the lower bound curve but which may exhibit a lower burst pressure. Provide the supporting data. If different and/or lower burst pressures are possible for the same EC voltage, discuss how the proposed probabilistic analysis accounts for this uncertainty.

Response (10/17/96):

Twelve Byron Unit 1 tubes with top-of-the-tube-sheet (TTS) circumferential indications have been pulled and metallographically examined during two successive inspections (1994 and 1995). The morphology of these indications have been the same and consistent with other industry tube pull TTS OD circumferential cracks as outlined in the Braidwood Unit 1 Cycle Length Assessment Report dated February 23, 1996. Morphology of Byron Unit 1 TTS circumferential indications is well understood, therefore this question does not apply to Byron Unit 1.

10. The burst pressure data were corrected for Braidwood lower tolerance limit (LTL) properties using information from certified material test reports. To remain consistent with the methodology in GL 95-05, burst pressure data should be normalized using material property data from the industry database used for alternate plugging criteria applications for axial cracking at SG tube support plate intersections. Accordingly, adjust the data in Figures 5.5 and 5.6 of the August 2, 1996, submittal using the industry database and determine the resulting structural limits for the average and maximum EC voltage correlations.

Response (10/17/96):

Byron Unit 1 EOC-8 conditional probability of burst calculations were performed using the Westinghouse database of tubing LTL material properties at 650°F. These are the same properties used in analysis of ODSCC TSP conditional probability of burst calculations. Therefore this question is not applicable to Byron Unit 1 analysis.

11. As discussed in Regulatory Guide 1.121. "Bases for Plugging Degraded PWR Steam Generator Tubes," SG tube repair criteria should consider the fatigue affects from cyclic loading forces. Discuss how these effects (e.g., fatigue, vibration, and flow-induced loadings) have been accounted for in the analysis of the proposed operating interval. Provide supporting test data.

Response (10/17/96):

Current operating experience and data from pulled tubes indicate there are no discernible fatigue, vibration, or flow-induced loading effects on tubes with circumferential ODSCC indications at the TTS. The effect of any subcritical low-cycle fatigue loading that may have occurred in service is captured in the growth rate described in the response to Question 3. For high cycle vibratory fatigue loading, rapid crack growth and subsequent failure would occur in much less than an operating cycle once the crack growth threshold was exceeded. Significant industry operating experience, including operating experience at Byron Unit 1, show there are no tube failures from high cycle vibratory or fatigue loads over the operating cycle length of interest at Byron Unit 1. Based on this experience there is no need to include explicit fatigue, vibratory, or flow-induced loading in the Byron Unit 1 evaluation.

12. If a SG tube were to separate or burst, discuss the possibility that multiple failures could occur as a result of SG tube whipping or impingement. Provide the supporting data and analysis.

Response (10/17/ 9):

The effects of jet impingement on adjacent tubes from axial cracks has been provided to the NRC in WCAP-13494, Revision 1, "Catawba Unit-1 Technical Support for Steam Generator Interim Tube Plugging Criteria for Indications at Tube Support Plates," March 1993. This report includes the test data for impingement wear coefficients and the supporting analysis model.

The analyses given in WCAP-13494 show that at a crack exit velocity of 200 ft/sec and direct impingement on the adjacent tube, it takes > 170 hours to penetrate the wall thickness for pure water and close to 890 hours for a steam void fraction of about 0.8 which is the range expected for leakage under SLB conditions. These times are very long compared to the time required to reduce pressure differentials to negligible values in a SLB event and propagation of damage to adjacent tubes due to jet impingement is not expected.

The second part of the question relates to the potential for damage propagation to adjacent tubes as a consequence of whipping of a severed tube end. This potential propagation mechanism requires the whipping tube end to cause penetration of the wall by progressive impact wear. Whipping of a severed tube end would be most significant if

caused by secondary side flow induced vibration leading to fluidelastic instability of the severed tube end. The mass and energy of the whipping tube is not large enough to cause significant damage to the adjacent tube by massive deformation. In addition, the severed tube end is weaker for distortion due to impact than the adjacent, intact tube and most of the distortion would occur at the severed tube end.

Thus, adjacent tube impact wear due to flow induced, fluidelastic tube vibration of the severed tube end is the principal; mechanism to be evaluated for potential damage propagation. In a steam line break event, the time of significant secondary flow is the first few seconds of the event during blowdown of the SG. A few seconds is too short of a time interval to cause substantial wear on an adjacent tube. In addition, the primary to secondary pressure differential is smaller during the first few seconds of a SLB since the larger pressure differentials result from pressure buildup due to safety injection. Thus, the likelihood of impact wear causing penetration of an adjacent tube in a SLB event is negligible.

The potential for impact wear from a whipping tube under normal operating conditions is conceptually higher than under accident conditions due to potentially longer times at significant secondary side velocities that could cause fluidelastic instability of the severed tube end. However, the time following a tube rupture to shut the plant down with low secondary side flow is also measured in seconds. Again, the time periods with a whipping tube end are too short to cause penetration of an adjacent tube.

13. Because of the non-coplanar nature of stress corrosion cracking in SG tube expansion transitions, EC signals from circumferential indications may exhibit both axial and circumferential degradation. Accordingly, discuss whether an assessment of SG tube degradation using voltage measurements from several scan lines (i.e., a volumetric assessment) is necessary as opposed to selecting a single scan line.

Response (10/17/96):

Tube failure and rupture occurs at the weakest location of the degraded tube area. The most degraded area of the tube can be assessed by the use of a single scan line for maximum and average voltage. The analysis of Byron Unit 1 data uses the same analysis methods (a single scan line) as that used to define the burst limits for maximum and average voltage. This provides a consistent analysis of the Byron Unit 1 tubes against known tube failures. A volumetric approach using more than one scan line can average undegraded areas of the tube with degraded areas to provide a non-conservative voltage signal which may not be representative of the structural integrity of the tube. Results of tube pull conclude that the area of degradation away from the crack face do not contribute to the failure of the tube. The 0.080" RPC does perform a volumetric assessment of the degraded area of a circumferential band equivalent to the size of the coil (i.e. 0.080").

Therefore, the use of a single scan line is adequate to assess the structural integrity of SG tubes.

14. The correlation of leak rate versus maximum EC voltage applies only to the end-of-cycle (EOC) EC voltage distributions derived from maximum EC voltages. Provide a similar relationship based on EC voltage integral measurements of circumferential indications. Describe, or reference if previously submitted, the procedure used to normalize the SG tube leak rates to the operating temperature and the main steam line break (MSLB) pressure of 2560 pounds per square inch (psi).

Response (10/17/96):

Maximum voltage was selected as the parameter to assess whether or not a tube will leak because it provides the best available ECT measurement of the crack's depth especially when the crack is asymmetric and a segment of the crack is either through wall or substantially deeper than the remainder of the crack front. Average voltage provides a measure of the integrated degradation over the entire tube circumference and there may not be segments where the crack is either through wall or nearly through wall.

The industry leak rate data from insitu pressure tests and tube pull leak tests is provided in the response to Question 5 and is plotted in Figure 14a against average voltage. The average voltage is normalized as discussed in response to Questions 19 and 20.

Analysis of circumferential indication distribution leak rate will continue to use maximum voltage, since it is the best available ECT parameter which provides indication of the depth of degradation and the potential for a tube to leak. Byron Unit 1 1995 tube pulls have confirmed that tubes with significant throughwall degradation have high maximum voltages.

Byron Unit 1 EOC leak rates are based upon leak rate testing performed at temperatures and pressures different from MSLB conditions. The test leak rates are corrected by the following procedure. Leak rate input data which are available and used to calculate a corrected leak rate at Byron MSLB conditions are: observed leak rate (room temperature), leak rate temperature and pressure, MSLB temperature and pressure, PICEP regression equations relating leak rate to pressure in terms of a ratio of the crack opening area to crack length. The most limiting ratio of the leak rate at MSLB temperature to room temperature is calculated using the most limiting (largest leak rate) crack opening to length ratio at MSLB pressure. From this ratio the leak rate at MSLB temperature is determined given the leak rate at test temperature. The PICEP computer code has been used by the industry for calculating MSLB leak rates in SG tubes.

15. Assuming that the maximum EC voltage is a more accurate parameter for predicting SG tube leakage, discuss the need to assess the leakage from other portions of a circumferential SG tube indication which may have voltages that are less than the maximum EC voltage recorded for a given SG tube but that may nevertheless leak. Specifically, address the possibility that several locations in the circumferential crack pattern of a SG tube at the expansion transition may contribute to the overall leakage from the SG tube since it is possible that the individual cracks in a non-coplanar pattern could be separated by a sufficient distance such that separate EC voltages for these indications could be recorded.

Response (10/17/96):

No correlation of leak rate to an ECT parameter has yet been identified. Therefore, the leak rate used to assess the end-of-cycle leak rate for Byron Unit 1 is based upon the maximum leakage recorded during testing of service induced cracks. The testing of these cracks were performed under pressurized conditions and leakage was measured from the entire area of degradation. Any leakage from degradation not detected by the ECT analysis is included in the leak rate assessment. Indications which have a probability of leaking as determined from the 0.080" RPC maximum voltage POL function are assigned the maximum leakage (from the entire area of degradation). Therefore the present methodology for assessing the leak rate from circumferential indications includes all leakage from the area of degradation. Because the flaw with the largest maximum voltage in the area of degradation is used to determine the probability that the tube may leak, indications with smaller maximum voltages would yield a lower probability of leaking and therefore are not considered in the analysis.

16. Given that for any EC voltage, a variety of morphologies can exist as discussed in Items 1 and 9 above, discuss the basis for assuming that there is an EC voltage cutoff for determining when a SG tube is susceptible to leaking. Discuss how the proposed methodology would account for the uncertainty in the potential for a SG tube to leak and the uncertainty in the leak rate itself. Further, given the limited amount of SG tube leakage data for circumferential indications, discuss why the bounding value of SG tube leakage which is assumed, is conservative.

Response (10/17/96):

In order to provide additional conservatism in the leak rate analysis, to address limited data and uncertainties in the industry leak rate data, a logistic probability of leak vs. log maximum ECT amplitude function was developed. The probability of leak function is based upon the data presented in Table 5. A 95% confidence level of the probability of leak function is used to assess the Byron Unit 1 EOC leak rate. Figure 3 in the main body

of the report shows the function and its lower 95% confidence level. Because a correlation between voltage and leak rate does not exist a maximum leak rate of 0.16 gpm is assumed for each voltage bin. Operating experience has demonstrated that circumferential cracks, even those with significant degradation, do not leak significantly under normal operating conditions. This is most likely due to the presence of ligaments observed from tube pull metallographic results. The leakage assumed in the analysis is the largest leakage (corrected to Byron MSLB conditions) measured during tube pull or insitu pressure leak testing and provides more realistic results than the calculation approaches. The 0.16 gpm leak rate is applied to all voltage bins where leakage has been identified to occur. This conservatively applies the highest observed leak rate, corrected to MSLB conditions, to a distribution of indications which have been observed through testing to have significantly lower leak rates.

The EOC-8 leak rate was calculated by summing the leak rate at each bin which is calculated as follows: obtain the product of the number of tubes in each bin and the probability of leak of tubes at the bin voltage then multiply by the bounding leak rate (from tube pull leak rate testing and insitu pressure testing).

17. Provide the EC inspection data and the calibration setup files used in the burst and leakage correlation's. In addition, provide EC data for a representative range of circumferential indications and their corresponding EC voltage integral and maximum EC voltage measurements. The EC data should be provided in a format compatible with Eddynet95 software.

Response (10/17/96):

The ECT data was supplied in the Braidwood RAI response (Reference 2d) and therefore this question is not applicable to the Byron Unit 1 analysis.

18. Provide a copy of the EC data analysis guidelines used during the Braidwood Unit 1 SG tube inspections in fall 1995.

Response (10/17/96):

A copy of the eddy current data analysis guidelines that were used for the Braidwood Unit 1 steam generator tube inspections in the fall of 1995 was provided with the Braidwood Unit 1 RAI response (Reference 2d), therefore this question is not applicable to Byron Unit 1. Byron Unit 1 look-back analysis guidelines were provided in Reference 2f.

19. In Section 6.2.1 of the submittal dated August 2, 1996 the EC voltage normalization procedure for adjusting the SG tube burst and leakage data is described. This EC voltage adjustment was made to obtain consistent EC voltages for circumferential indications where the calibration standard did not contain an axial EDM notch. Discuss how the EC voltages for other reflectors in the calibration standard compare with the 0.58 correction factor applied to the data. Provide a statistical analysis based on field data which supports the use of the 0.58 correction factor.

Response (10/17/96):

An assessment to determine the appropriate normalization factor has been performed on 50 field data points, of varying voltages, using the voltage integral software. The results of this field data assessment are presented in Table 19b for maximum and average volts. The data is provided for analysis of both the 0.115" and 0.080" RPC data normalized to 10 volts on the 100% throughwall hole (TWH) and 20 volts on the 100% axial EDM notch. Because industry data was acquired with the both the 0.080" and 0.115" RPC, it is necessary to have a normalization correction factor established for each coil size. Normalization correction factors can be determined for both the 0.115" and 0.080" RPC using the data in Table 19b. A statistical analysis of the field data (maximum and average voltage combined) has been performed using a linear regression analysis. The results from the statistical analysis indicate that the normalization correction factor is 0.51 and 0.68 for the 0.080" and 0.115" RPC, respectively, as determined from the slopes of the mean regression lines (see Figure 19).

Normalization correction factors are provided for the 0.115" and 0.080" pancake coils for assessment of industry tube pull and insitu pressure test ECT data. Further discussion of this topic is provided in response to October 3, 1996 RAI Question 2 and 3.

20. A 0.76 correction factor was applied to adjust 0.115-inch probe coil EC voltages to equivalent 0.080-inch probe coil EC voltages. Describe in detail the development of this correction factor, including a discussion on the number of samples reviewed, the types of defects analyzed, and the mean and standard deviation of the study sample. Additionally, provide the recorded EC voltages, if practical, or the range of circumferential indication EC voltages included in the sample. Provide a statistical analysis based on field data which supports the use of the 0.76 correction factor.

Response (10/17/96):

Assessment of the appropriate coil size factor has been performed on 50 Byron Unit 1 field data points with varying voltages using the voltage integral software. The results are presented in Table 19b for maximum and average volts. The data in Table 19b can be used to determine a coil size correction factor normalizing the data in two ways (10 volts

on the 100% TWH and 20 volts on a 100% EDM notch). Because the industry tube pull and insitu pressure test data was normalized to 10 volts on the 100% TWH, this normalization is appropriate to use in determining a coil size factor. A statistical analysis of the field data (maximum and average combined) has been performed using a linear regression analysis. The results from the statistical analysis indicate that the coil size factor for the field data is 0.75 (for normalization to 10 volts on a 100% throughwall hole) as determined from the ratio of the slope of the 0.080" and 0.115" RPC mean regression lines from Figure 19. Figure 20 shows the 0.115" RPC data adjusted using the 0.75 factor and the 0.080" RPC data in the same plot. The two data sets are now consistent as determined by the overlay of the 2 data sets linear regression lines. Therefore, a 0.75 coil size factor is appropriate.

Further discussion of this topic is provided in response to October 3, 1996 RAI Question 2 and 3.

21. Provide a summary of the essential variables of the inspection techniques as documented in the EC acquisition technique sheets (ACTS) and the analysis technique sheets (ANTS) for the Byron Unit 1 SG EC inspections in 1994, 1995, and 1996 and for the 1995 Braidwood Unit 1 SG EC inspections. Additionally, provide the ACTS and ANTS associated with the SG EC inspections conducted at other plants where data were obtained for use in the SG tube burst and leakage correlation's presented in the August 2, 1996, submittal. Identify and discuss how the differences in the acquisition and analysis of EC data will affect the EC voltage measurements used in the analysis.

Response (10/17/96):

A summary of the essential variables of the inspection techniques used for the industry data used in the burst and leak correlations were provided in the Braidwood Unit 1 RAI response (Reference 2f), therefore this question is not applicable to Byron Unit 1.

22. Some studies have identified a lift-off effect in SG tube expansion transitions for gimbaled probes due to SG tube geometry changes. This lift-off can decrease a probe coil's response to SG tube indications. If gimbaled probes were used in any of the inspections where data is used to support the Braidwood Unit 1 cycle length assessment, explain the basis for not accounting for this affect for EC voltage measurements in expansion transitions. Some of the data in the SG tube burst and leakage correlations were obtained from 56 tubes which had been explosively expanded into the SG tubesheet. Describe any differences between the transition geometry, particularly with respect to the length of the expansion of the explosively expanded tubes and that for roll- expanded SG tubes. Discuss the effects of the SG tube transition geometry on the recorded EC voltages. Discuss the need to account for liftoff in the EC voltage measurements for both the data used in the proposed correlations and the data obtained for the field indications.

Response (10/17/96):

Gimbaled probe data was not used for measuring the eddy current voltages in the expansion transitions for supporting the Byron Unit 1 EOC analysis.

The explosive expansion transition signals are typically more uniform in their geometry than the mechanically hard roll transitions. The roll transition signals do affect the eddy current signals. The orientation of these signals is mainly horizontal while the flaw response is vertical. The voltage integral software looks at the eddy current data in a 360° scan, any affects from the flaws or roll transitions would be included in the voltage measurements. If the roll transition signal contained any vertical component, it would be included as part of the flaw voltage measurement, which means the voltage measurement would be conservative.

Liftoff is minimized since the probe is spring loaded and surface riding. With the liftoff minimized, liftoff becomes an issue of data quality and cannot be factored into the eddy current voltage measurements.

23. In Figure 3.1 of the submittal dated August 2, 1996, the number of circumferential indications detected with the plus point coil is related to those detected with the 0.080-inch rotating pancake coil (RPC) probe. The results are presented as the number of indications as a function of EC voltages as measured with the plus point probe. Explain the relationship between the circumferential indication EC voltages as measured with the 0.080-inch coil to those measured using the plus point coil. Describe the data set used in the comparison study between the two coils. Explain the differences in the analysis guidelines for the coil study to those used during the Braidwood Unit 1 A1R05 SG tube EC inspections. In addition, the EC voltages in this figure are the maximum indication EC voltages. State whether a similar relationship has been developed using average EC voltage (i.e., voltage Integral) measurements. If so, supply the results. If not, discuss the usefulness of performing such an assessment in light of the present analysis based on EC voltage integral measurements.

Response (10/17/96):

A POD analysis of the Byron Unit 1 1996 TTS inspections was performed by analysis of blind test data. A detailed discussion of the blind test is provided in Section 4.3 in the main body of the report. Because a direct POD could be determined from blind test results this question is not applicable to Byron Unit 1 EOC analysis.

24. **Data to support the assessment of the probability of detection (POD) and the SG tube burst and leakage correlations in the August 2, 1996 submittal were taken from various sources. Since the noise levels inherent in the data and SG tube wall deposits may affect the resulting EC voltage measurements, provide an assessment comparing the influence of noise and deposits on the EC signals for the SG tube burst and leakage data. Additionally, provide a discussion as to how the noise levels were determined (i.e., SG tube location, coils, and frequencies). Given that these factors may affect EC voltage measurements, provide the basis for selecting the lowest point in the scan line as the null point for EC voltage measurements.**

Response (10/17/96):

Noise and deposits will affect the eddy current signal by increasing the overall voltage response. Probe noise and deposits were monitored through the "C" scan, strip charts and lissajous signals for signals inherent to noise and deposits during the voltage measurements for the steam generator burst and leak data for overall acceptability and quality of the data. It was found that the overall quality of the data was acceptable qualitatively and no signal to noise correction factors were applied to any voltage measurements for the industry leak and burst data. Due to the top of the tube sheet location of the indications there was no presence of indications in the vicinity of the flaw which could influence the voltage measurement.

Since the Voltage Integral software selects the lowest point in the scan line to establish a 'zero' threshold, any increase in the signal amplitude will increase not only the 'zero' threshold, but also the scan line and the resultant output, again being a more conservative measurement. Letting the Voltage Integral software select the lowest point in the scan line as the null point produces a more consistent result for the voltage measurements.

25. **In the Braidwood Unit 1 cycle length assessment, analyst uncertainty values of 0. 19 and 0.22 were utilized. Given that a signal for a specific type of degradation may be better defined by one coil rather than another, provide an assessment of the analyst variability based on the coil of interest (e.g., the 0.080-inch probe). Additionally, state the units associated with these values. If the values are in volts, state the corresponding analyst uncertainty as a percentage value.**

Response (10/17/96):

The initial Byron Unit 1 blind test (Reference 4), was developed to assess detection, recorded voltage measurements were used to assess analyst error for that test. A second blind test has been performed to assess sizing. The second blind test provides a more

appropriate evaluation of analyst error in voltages measured from 0.080" RPC data, by testing the following areas:

1. the analyst must select the circumferential scan line with the maximum indication peak,

2. from the selected scan line the analyst must select the maximum voltage,

3. data normalization,

4. the use of filters,

5. the effects of inconsistent use of trigger offset, and

6. the ability of the voltage integral software to consistently calculate the maximum and average voltage.

The second blind test was performed using the voltage integral software to analyze and measure the maximum and average 0.080" RPC voltages. The blind test included 9 analysts and 141 indications. The indications ranged in size and were selected from the following inspection data: Braidwood Unit 1 October 1995 indications from all SG's, Byron Unit 1 1996 SG C, Byron Unit 1 1996 tubes which were insitu pressure tested from SG A, Byron Unit 1 1994 and 1995 tube pulls. The response to this question refers to the additional blind test and not the blind test submitted in Reference 4.

<u>Blind Test Protocol:</u>

- A total of nine analysts participated in and completed the blind test of 141 indications.

- To be consistent in measuring and reporting circumferential indication voltages during the testing, analysis guidelines were written. Zetec voltage integral EddyNet 95 analysis software was used.

- Voltage was normalized to 10 Volts on a 100% throughwall hole. Analysts were allowed to used other coils to locate the indications. Voltage was recorded based upon the 0.080" pancake coil. Both maximum and average voltage was measured.

- A detailed discussion is presented in response to Question 28 of how the average and maximum voltages were determined during the blind test.

- The testing was proctored by the ComEd eddy current Level III to insure all data was analyzed using the appropriate guidelines and to observe that no indication results were being discussed between the analysts.

- The probe that was used in the 1995 Braidwood Unit 1 and 1994 Byron Unit 1 tube pull data set was a 3-Coil motorized rotating pancake coil (MRPC) which included a .080" pancake coil, axial wound coil and a circumferentially wound coil. The rotating probe used for the 1995 Byron Unit 1 tube pull and 1996 data sets consisted of a 0.080" pancake coil, a 0.115" pancake coil and a plus point coil. The analysts used all coils to aid in their analysis of detecting the circumferential indications.

Blind Test Results:

The blind test results were analyzed to determine analyst error and the standard deviation of the percent analyst error. The following procedure was used in the calculation for maximum and average voltage:

- The mean of the nine analysts measured indication voltages is considered the indication reference voltage.

- The percent error from the reference voltage of each analysts' call for the 141 indications is determined. This is calculated by subtracting the analysts' call from the reference voltage and dividing by the reference voltage.

- The standard deviation of the percent error for the entire population of calls from the 9 analysts for the 141 indications is determined.

- The standard deviation was calculated to be 32% and 30% for average and maximum voltage, respectively. No resolution of data was performed. The units for the percent analyst error are volts/volts.

The 30% and 32% analyst error for average and maximum voltage, respectively, are used in analysis of the Byron Unit 1 EOC analysis.

2[illegible]. **Discuss the basis for keeping the data from the 100 SG tube and 200 SG tube tests separate for the analyst variability study. Provide and discuss the mean, standard deviation, and shape of the distribution used for the model of analyst uncertainty (e.g., a normal distribution with a mean of x and standard deviation of y). Discuss the technical basis for the distribution which was used.**

Response (10/17/96):

The additional blind test was comprised of a single population of tubes (141) with a single result for average and maximum voltage being determined. The results of this blind test will be used for end-of-cycle analyses which are based upon results from look-backs. The distribution of percent analyst error is assumed to be normal with a mean of zero and a standard deviation of 32% and 30% for average and maximum volts, respectively. Figure

26a and 26b show the distribution of analyst deviation for average and maximum voltages, respectively including the cumulative frequency distribution for the percent analyst error and the cumulative normal distribution. The cumulative frequency distribution of percent analyst error closely approximates the cumulative normal distribution particularly at the high end tail of the distribution. The percent analyst error distribution is more peaked than a normal distribution; therefore, would predict higher analyst uncertainty just above the mean than assuming a normal distribution. A normal distribution for percent analyst error provides conservative results for larger uncertainties.

27. Discuss the basis for reevaluating the EC voltages measured in the analyst variability study based on a resolution process. Discuss whether this practice was used in the blind tests. The staff believes that this method of analyzing analyst variability is inconsistent with the methodology used in GL 95-05 (i.e., reevaluating the EC voltages). Clarify what is meant by the statement that observation EC voltages from different coils for the same indications were excluded.

Response (10/17/96):

As stated in response to Question 25, there was no resolution in the second blind test. End-of-cycle analysis has been performed using the updated analyst error. It is believed that this provides a conservative result for the following reasons.

- The distributions to which the analyst variability are applied are obtained from look-back of the indications. During the look-back process any reported indications which appear to be inconsistent with the indication distribution are evaluated to ensure that the data was correctly analyzed. A similar methodology should be applied in the blind tests. A resolution process should occur after completion of the blind test to identify results which do not fit the distribution. The results presented in Question 25 do not incorporate any resolution of the data recorded by the analysts during the blind test however, analysis of the data identified that a large contribution of the overall analyst error is attributed to a small number of calls. Evaluation of these calls identified several root causes not associated with the interpretation of the indication.

- In order to evaluate the affects of resolution of blind test results, voltages with a percent error greater than -100% (these represent conservative calls with voltages recorded greater than the mean voltage) is applied to the data to provide a realistic assessment of the analysis results. Application of this resolution process results in a standard deviation of percent analyst error of 0.23 for average volts and 0.24 for maximum volts. The resulting distribution after resolution is shown in Figures 27a and 27b for average and maximum voltage, respectively. The figures show that the distribution is more normal after the resolution.

Therefore, use of a normal distribution with a mean of 0 and a standard deviation of 0.32 for average and 0.30 for maximum is conservative. Additionally, the tail of the distribution is quite long in the negative direction which represents overcalls (voltages greater than the mean). This indicates that the largest uncertainty is associated with conservative overcalls and further justifies resolution of calls with a percent error eater than 100% in the negative direction.

28. Describe the measures included in the blind test protocol which would have prevented an analyst from using information from one coil to locate and size the maximum EC voltage signal as seen by another coil. As discussed by the staff in the meeting held on August 26, 1996, the rotational slewing of the data via such mechanisms as the trigger offset feature in Eddynet95 could lead to additional variability in an analyst's ability to accurately size circumferential indications with an EC voltage integral measurement. Describe how this variability was accounted for in the assessment of analyst uncertainty.

Response (10/17/96):

During the blind test discussed in response to Question 25 the analysts were instructed to use all coils (i.e. pancake, circumferential, and plus point), for identifying flaw location. The blind test protocol permitted the analysts to use information from one coil to another coil to locate the indication. In order to obtain the best analysis for detection and measurements of any given flaw, guidelines are structured for the analysts to use all available "tools" (i.e. coils, frequencies, channels, mixes etc,) for assisting in measurements made from one coil to another.

The objective of the blind test is to assess the variability of the voltage measurement. Using different coils to aid in location of the indication does not affect the variability of the voltage measurement. The analyst variability is used to assess the end-of-cycle voltage distribution based upon look-back data. During the look-backs, the analysts were allowed, and did use other coils as necessary to locate the indications. Therefore, the methodology of using different coils to locate the indications is consistent between the two blind tests, the look-backs and the guidelines for field inspection.

The voltage measurements were measured and recorded during the blind test using the Zetec Voltage Integral Software. Voltage measurements are recorded as described below:

- A C-Scan plot is generated for the expansion region of interest.
- Using the Axial and Circumferential strip chart cursors, the C-Scan line associated with the maximum vertical displacement for the indication is selected.
- The Voltage Integral software plots the circumferential scan line that is selected in the main C-Scan plot.
- The average voltage is automatically calculated by the Voltage Integral software.

- The cursor is then positioned by the analyst in the Voltage Integral Software at the maximum vertical "Vert. Max"scan line displacement. The circumferential scan lines maximum and average voltage is then recorded.

The appropriate slewing (rotate data) for each coil was used for the blind test. The rotational slewing of the coils will not introduce variability for the maximum and average voltage measurements. The rotational slewing of the coils eliminates the offset in the eddy current data caused by the physical separation of the coils.

The trigger off-et is discussed in the look-back and blind test analysis guidelines. The guidelines require the trigger offset to place the start and stop point of the indication in the center of the C-Scan plot minimizing the variability of the voltage integral measurement.

The blind test uncertainties discussed in detail in response to Question 25 include any uncertainty associated with the trigger offset feature in Eddynet95.

29. If the measured EC voltages in the "look back" analysis of the Byron Unit 1 EC measurements were maximum EC voltages, explain the basis for applying these results of the analyst uncertainty measurement to the EC voltage integral measurements. If circumferential indications were sized using, the lissajous signal, explain the basis for applying a variability in sizing with the lissajous signal to measurements of maximum EC voltage determined by positioning the signal cursor in the voltage integral scan.

Response (10/17/96):

The second blind test uncertainties discussed in detail in response to Question 25 include the uncertainties associated with the voltage integral software for determination of maximum and average voltage.

The eddy current maximum voltages were sized during the "look-back" analysis using the lissajous signal from the RPC Cir. Liz. window. The lissasjous signal displayed in the Circ Liz window represents the maximum scan line plotted in the C-Scan plot. The cursor was then positioned at the maximum displacement of the scan line in the Voltage Integral window and the vertical maximum voltage is displayed. The vertical maximum voltages are the same due to the normalization process used for these windows which is included in the "look-back" analysis guidelines. Measuring the maximum voltage from either the Circ. Liz. window or positioning the cursor at the maximum displacement in the Voltage Integral window will produce the same voltage measurements. Therefore, no voltage variability adjustment is necessary.

30. Provide a copy of the EC sizing procedures used in the assessments of the analyst uncertainty, the growth rate, the burst and leakage data, and the POD. Discuss the extent of use and the influence of the following on any EC voltage measurements: (1) the use of Eddynet95 data filters; (2) the trigger offset feature and (3) the presence of 360m circumferential flaws. Address both the EC voltage integral and the EC maximum voltage measurements.

Response (10/17/96):

Filters were used in the analyst uncertainty, growth rates, and POD assessment but not the burst and leak data. As part of the ECT analysis the following filters were used in the assessment for the uncertainty and growth rates:

- Axial average filter was used to remove the effects caused by tube wall variations and data offsets.
- Circ. Line filter was used to remove the effects caused by unwanted signals such as deposits and geometry changes.

The axial average filter helps to smooth the data offsets visually represented down the axial scan lines in the C-Scan plot. The filter averages all of the data point values on a given circumferential scan line and subtracts the average value from every data point on that line. This process repeats for every circumferential scan line in the C-Scan plot. The output reduces the data offsets in the axial direction. When the axial average filter is enabled the software automatically calculates and smoothes the data that is visually produced on the C-Scan plot.

The circumferential scan line filter lets the analyst choose a circumferential scan line to be used as a filter. The chosen scan line is subtracted from every circumferential scan line in the C-Scan plot. It acts as a nulling function for all of the circumferential scans and removes unwanted signals (i.e. tube wall variations, deposits, geometry changes, etc.), that occur consistently in each scan line. Analysts were trained to select a non-flawed scan line to be used as a filter for the ECT sizing used for growth rate studies and analyst uncertainty. No filters were used in the ECT analysis of the burst and leak database.

To evaluate the impact of these filters and results, ComEd performed an evaluation on voltage measurements with the use of filters. Figure 30A represents voltage measurements for non-filtered data. Figure 30B represents voltage measurements with the use of the Axial Average filter. Figure 30C represents voltage measurements with the use of the Circ. Line filter. Figure 30D represents voltage measurements with the use of the Axial Average and Circ. Line filter.

Conclusions:

- The maximum and average voltage does not change with an Axial Average filter.

- The maximum and average voltage does change with a Circ. Line filter. The resultant output of the voltage measurements is reduced. Selecting a non-degraded circ line to be used as a filter does not reduce the flaw signal.
- The maximum and average voltage remains the same as the Circ. Line filter, when using the Axial Average and Circ. Line filters in combination.

Therefore, ComEd analysis is correct because the use of filters does not affect the voltage signal corresponding to the flaw.

The affects of the trigger offset feature is discussed in response to Question 28.

An evaluation of the affects of 360 degree flaws on the Byron 1 end-of-cycle assessment has been performed. Guidelines for the voltage integral look-back of Byron 1 1996 and 1995 indications required the analysts to identify indications which had 360 degree ECT signals. Of the over 400 1996 0.080" RPC indications evaluated, 8 had 360 degree ECT signals. Of the over 700 1995 0.080" RPC indications evaluated, 21 had 360 degree ECT signals. Three of the 23 Braidwood Unit 1 indications were determined by ECT to be 360 degrees. Because of the small number of indications reported with 360 degree flaws the number of tubes affected by this question is small.

The effect of 360 degree flaws on voltage integral results was evaluated using Byron Unit 1 1995 tube pull voltage and metallographic (MET) results. The maximum voltage determined by the voltage integral software, where the null point is selected by the software as the lowest point of the scan line, is compared to the maximum voltage determined by the analyst, with a user balanced null point (without the use of the voltage integral software). The comparison is shown in Table 30 for the 10 Byron Unit 1 1995 tube pulls. The results indicate that for 360 degree flaws there is no trend of the maximum voltage from the voltage integral software, where the null point is selected by the software as the lowest point of the scan line, being reduced due to the affects of 360 degree flaw when compared to the maximum voltage with a user defined balanced null point. Significant effects on voltage only occur when there is uniform degradation for 360 degrees. Tube pull results from Byron Unit 1 indicate that this type of degradation does not exist.

A comparison of the maximum voltages obtained during the voltage integral look-back (where the software selects the null point based upon the lowest point in the scan line) to previous look-back results (where a user defined balanced null point is used) for indications determined by ECT to be 360 degrees was performed. The results are documented in Table 30. Similar to the tube pull data the results indicate that for 360 degree flaws there is no trend of the maximum voltage from the voltage integral software being reduced due to the affects of 360 degree flaw when compared to the maximum voltage with a user defined balanced null point.

Indications, analyzed with the voltage integral software, used to establish the burst and leak limits with 360 degree degradation would provide a conservative result. The voltage

of these indications would be reduced if the 360 degree affect described in the question ("null" line set for a scan line with no undegraded area) affected the data. A reduced voltage correlated to the test pressure or leak rate would therefore provide conservative limits. The tube pull and insitu pressure test data represents some of the most degraded tubes and therefore the burst limits are conservative.

31. The probe wear allowance that was developed in the August 20, 1996, submittal was based on a small sample of the total SG tubes inspected. Provide an assessment of probe wear based on all available data. The staff believes that the methodology used to determine the probe wear allowance is significantly different from that used to determine the probe wear allowance in GL 95-05. Discuss the basis for not determining the probe wear allowance in accordance with the methodology used to support the GL 95-05 probe wear allowance given that different SG tube roughness can change the amount of probe wear observed between calibration runs.

Response (10/17/96):

No practice has been defined for measuring and tracking MRPC probe wear for circumferential indications at the top of the tubesheet. An assessment to quantify the effects of MRPC probe wear on indication voltages was performed. The assessment was structured to evaluate MRPC wear using the Bobbin probe wear method documented in GL 95-05.

The probe wear was determined from the trends of the measured calibration standard voltages from the first calibration standard to the last calibration standard measured for each calibration group.

Identified below are the similarities and differences to GL 95-05 for implementing the IPC criteria.

Similarities:

- Bobbin probe design must incorporate centering features that provide for minimum probe wobble and offset; the centering features must maintain constant probe center to tube ID offset for nominal tubing.
- MRPC probe designed as a surface riding coil and the centering features provide constant probe center to tube ID offset for nominal tubing.
- GL 95-05, probe wear should be controlled by either an inline measurement device or through the use of a (wear standard) for periodic wear measurement.
- MRPC probe wear assessment was controlled by the ASME calibration standard as the measurement device for periodic wear measurements.
- Bobbin wear standard contains four through wall holes, spaced 90 degrees apart around the tube circumference.
- ASME standard contains one through wall hole.

Differences:

- Initial Bobbin (new probe) amplitude response from each of the four holes is determined and compared on an individual basis with subsequent measurements. Signal amplitudes or voltages from the individual holes, compared with their initial amplitudes, must remain within 15% of their initial amplitude for an acceptable probe wear condition.
- Initial MRPC (new probe) amplitude response from the single hole is compared on an individual basis with subsequent measurements. Signal amplitudes or voltages from the individual hole, compared with their initial amplitudes.

GL 95-05 describes a specific probe wear standard to be used for ODSCC at the TSP's. This standard is inappropriate for any MRPC because of the coil geometry differences. However, a single 100% TW hole or 100% TW EDM notch are the MRCP equivalent of the bobbin coil standard.

ComEd has adequately accounted for the effects of RPC probe wear in assessment of Byron Unit 1 end-of-cycle distribution.

Probe wear evaluation was performed on an additional 14 calibration groups representing over eleven hundred tubes. The results of the additional calibration groups do not significantly change the results of the probe wear assessment. The probe wear, including the additional calibration groups, are 7.0% and 7.5% for the 100% TW drilled hole and the 100% TW EDM notch, respectively. A probe wear of 7.5% is considered in calculation of the Byron Unit 1 EOC voltage distribution.

Table 3a. Byron 1 Growth Rate Bins and Number of Tubes for Maximum Voltage

Maximum Voltage Growth Rate Bins and Number of Tubes			
Bins ΔV/EFPY	94 to 95	94 to 96	95 to 96
-1.8			1
-1.7			1
-1.6			0
-1.5			0
-1.4			2
-1.3			2
-1.2			0
-1.1			0
-1.0			2
-0.9			1
-0.8			3
-0.7			4
-0.6			1[illegible]
-0.5			3
-0.4	4	0	11
-0.3	3	0	7
-0.2	12	1	11
-0.1	33	5	5
0.0	71	10	21
0.1	169	20	10
0.2	177	23	17
0.3	112	6	19
0.4	67	5	8
0.5	25	2	6
0.6	9	0	8
0.7	3	0	7
0.8			5
0.9			1
1.0			2
1.1			1
1.2			1
1.3			5
1.4			3
1.5			1
1.6			2
1.7			0
1.8			0
1.9			1
SUM >>	685	72	181

Table 3b Byron 1 Growth Rate Bins and Number of Tubes for Average Voltage

Average VoltageGrowth Rate Bins and Number of Tubes			
Bins ΔV/EFPY	94 to 95	94 to 96	95 to 96
-1.20			1
-1.15			0
-1.10			1
-1.05			0
-1.00			0
-0.95			0
-0.90			0
-0.85			0
-0.80			0
-0.75			1
-0.70			0
-0.65			2
-0.60			1
-0.55			3
-0.50			3
-0.45			3
-0.40			2
-0.35			6
-0.30			7
-0.25	3	0	10
-0.20	4	2	3
-0.15	7	1	4
-0.10	26	2	16
-0.05	40	6	9
0.00	92	7	17
0.05	185	25	8
0.10	149	9	10
0.15	107	14	20
0.20	41	2	7
0.25	14	1	12
0.30	11	3	2
0.35	3	0	6
0.40	3	0	4
0.45			0
0.50			6
0.55			3
0.60			2
0.65			0
0.70			5
0.75			0
0.80			2
0.85			1
0.90			0
0.95			2
1.00			0
1.05			0
1.10			0
1.15			0
1.20			1
1.25			0
1.30			1
SUM >>	685	72	181

Table 5

Test Method	Metallographic Results PDA (%)	Max Depth (%)	Circ. Extent (degrees)	COIL SIZE	10 V on 100% TW Hole Max Volts	Avg Volts	20 V on 100% EDM Notch (Normalized) Max Volts	Avg Volts	Insitu Press. (ksi)	Burst Press. (ksi)	Operating Press. (ksi)	Leak Rate (gpm)	Leak Rate Test Press. (ksi)	Adj. Leak Rate (gpm)	Insitu Leak Rate > Make-up at Max Pressure	Yld. Strength (ksi)	Ultimate Strength (ksi)	Axial or Circ. Failure	Mixed Mode
Insitu	-	-	-	0.115	1.51	0.63	0.77	0.32	4.15	-	-	n	-	n	-	-	-	-	-
Burst	65	100	360	0.08	3.13	1.02	1.60	0.52	x	8.44	-	n	-	n	-	-	-	Circ.	No
Insitu	-	-	-	0.115	3.09	1.26	1.58	0.64	4.60	-	-	0.050	2.000	0.054	yes	-	-	-	-
Insitu	-	-	-	0.115	3.62	1.66	1.85	0.85	3.60	-	-	0.150	2.000	0.161	yes	-	-	-	-
Insitu	-	-	-	0.115	2.52	1.00	1.29	0.51	4.70	-	-	0.040	4.700	0.011	-	-	-	-	-
Insitu	-	-	-	0.115	2.08	0.93	1.06	0.47	4.45	-	-	0.000	-	0.000	-	-	-	-	-
Insitu	-	-	-	0.115	1.58	0.71	0.81	0.36	4.45	-	-	0.000	-	0.000	-	-	-	-	-
Insitu	-	-	-	0.115	1.67	0.71	0.85	0.36	6.80	-	-	0.000	-	0.000	-	-	-	-	-
Insitu	-	-	-	0.115	1.63	0.79	0.83	0.40	6.80	-	-	0.000	-	0.000	-	-	-	-	-
Insitu	-	-	-	0.115	1.31	0.57	0.67	0.29	6.80	-	-	0.000	-	0.000	-	-	-	-	-
Insitu	-	-	-	0.115	1.06	0.48	0.54	0.24	6.80	-	-	0.000	-	0.000	-	-	-	-	-
Insitu	-	-	-	0.115	1.92	0.71	0.98	0.36	4.45	-	-	0.000	-	0.000	-	-	-	-	-
Insitu	-	-	-	0.08	3.03	0.97	1.55	0.49	4.70	-	-	0.000	-	0.000	-	-	-	-	-
Burst	49	100	360	0.08	4.75	1.12	2.42	0.57	-	9.40	-	0.139	2.650	0.090	-	-	-	Circ	Yes
Burst	49	71	350	0.08	3.25	1.38	1.66	0.70	-	11.20	-	n	-	n	-	-	-	Axial	No
Burst	47	91	280	0.08	4.96	1.92	2.53	0.98	-	8.45	-	n	-	n	-	-	-	Axial	No
Insitu	-	-	-	0.115	4.53	1.53	2.31	0.78	3.90	-	-	0.011	3.000	0.0064 (4)	-	-	-	-	-
Insitu	-	-	-	0.115	3.15	1.59	1.61	0.81	3.90	-	-	0.000	-	0.000	-	-	-	-	-
Insitu	-	-	-	0.115	1.69	0.90	0.86	0.46	3.90	-	-	0.000	-	0.000	-	-	-	-	-
Insitu	-	-	-	0.115	3.56	1.61	1.82	0.82	3.90	-	-	0.000	-	0.000	-	-	-	-	-
Insitu	-	-	-	0.115	2.04	0.90	1.04	0.46	3.90	-	-	0.000	-	0.000	-	-	-	-	-
Insitu	-	-	-	0.115	1.19	0.43	0.61	0.22	7.08	-	-	0.000	-	0.000	-	-	-	-	-
Insitu	-	-	-	0.115	0.61	0.17	0.31	0.09	6.70	-	-	0.000	-	0.000	-	-	-	-	-
Insitu	-	-	-	0.115	1.93	0.78	0.98	0.40	6.40	-	-	0.000	-	0.000	-	-	-	-	-
Insitu	-	-	-	0.115	0.64	0.29	0.33	0.15	7.00	-	-	0.000	-	0.000	-	-	-	-	-
Insitu	-	-	-	0.115	1.09	0.63	0.56	0.32	7.05	-	-	0.000	-	0.000	-	-	-	-	-
Insitu	-	-	-	0.115	0.95	0.36	0.48	0.18	7.05	-	-	0.000	-	0.000	-	-	-	-	-
Insitu	-	-	-	0.08	7.56	1.47	3.86	0.75	5.30	-	-	0.029	4.200	0.010	-	-	-	-	-
Insitu	-	-	-	0.08	2.16	1.14	1.10	0.58	5.75	-	-	0.000	-	0.000	-	-	-	-	-
Burst (1)	78	100	360	0.08	-	-	4.14	1.02	-	4.35 (1)	-	n	-	n	-	65.45 (1)	113.95	Circ	No
Burst	35	51	360	0.08	-	-	0.38	0.18	-	10.950	-	0.000	-	0.000	-	54.00	101.60	Axial	Yes
Burst	35	83	310	0.08	1.10	0.47	0.56	0.24	-	10.300	-	0.000	-	0.000	-	55.80	97.40	(2)	No
Burst	54	79	360	0.08	0.67	0.21	0.34	0.11	-	11.400	-	0.000	-	0.000	-	50.90	100.90	Axial	Yes
Burst	48	77	360	0.08	1.58	0.68	0.81	0.35	-	12.100	-	0.000	-	0.000	-	56.10	107.80	Axial	No
Burst (1)	65	100	359	0.08	1.94	0.56	0.99	0.29	-	7.424 (1)	-	n	-	n	-	58 (1)	106.40	Circ.	Yes
Burst	56	98	360	0.08	0.70	0.31	0.36	0.16	-	10.600	-	0.000	-	0.000	-	51.60	102.30	Axial	No
Insitu	-	-	-	0.115	1.14	0.27	0.58	0.14	5.00	-	-	0.000	-	0.000	-	-	-	-	-
Insitu	-	-	-	0.08	1.20	0.28	0.61	0.14	5.00	-	-	0.000	-	0.000	-	-	-	-	-
Insitu	-	-	-	0.08	0.98	0.52	0.50	0.27	5.00	-	-	0.000	-	0.000	-	-	-	-	-
Insitu	-	-	-	0.08	1.45	0.54	0.74	0.28	5.00	-	-	0.000	-	0.000	-	-	-	-	-
Insitu	-	-	-	0.08	0.89	0.54	0.45	0.28	5.00	-	-	0.000	-	0.000	-	-	-	-	-
Insitu	-	-	-	0.08	1.15	0.36	0.59	0.18	5.00	-	-	0.000	-	0.000	-	-	-	-	-
Insitu	-	-	-	0.08	0.90	0.20	0.46	0.10	5.00	-	-	0.000	-	0.000	-	-	-	-	-
Insitu	-	-	-	0.08	1.15	0.38	0.59	0.19	5.00	-	-	0.000	-	0.000	-	-	-	-	-
Operating	73	100	330	0.08	31.12	15.25	15.87	7.78	-	-	1.375	-	-	-	-	-	-	-	No
Operating	94	100	360	0.08	16.39	11.19	8.36	5.71	-	-	1.350	-	-	-	-	-	-	-	No
Operating	86	100	360	0.08	10.13	4.63	5.17	2.36	-	-	1.350	-	-	-	-	-	-	-	No

(1) Based upon EDM simulant of actual tube degradation level, corrected for material properties of tube pull
(2) Test rig connection failure before tube burst
(3) Data Reported in 9/10/96 Submittal as 0.88 and 0.37 Volts for max. and avg. volts respectively
the data was acquired with 0.115" RPC and correction factor not applied, this does not change conclusions of submittals
(4) Data reported in 8/2/96 and 9/10/96 submittals as 0.00352 gpm at 3.9 ksi, actual leakage is recorded at 3.0 ksi

Table 19b
Field Data for Statistical Analysis of Industry ECT Correction Factors

		Voltage Normalized @ 10 volts on the 100% TWH				Voltage Normalized @ 20 volts on the 100% AXIAL EDM NOTCH			
		.080 PANCAKE COIL		.115 PANCAKE COIL		.080 PANCAKE COIL		.115 PANCAKE COIL	
Row	Col	Volts VM Max	Volts VM Avg	Volts VM Max	Volts VM Avg	Volts VM Max	Volts VM Avg	Volts VM Max	Volts VM Avg
1	10	0.88	0.37	1.01	0.36	0.45	0.19	0.47	0.16
18	20	1.23	0.54	1.56	0.69	0.65	0.29	0.75	0.34
25	22	1.29	0.81	1.75	0.81	0.72	0.46	1.14	0.38
5	24	1.05	0.50	0.96	0.46	0.49	0.24	0.42	0.20
40	32	1.00	0.42	1.01	0.48	0.55	0.23	0.57	0.27
47	31	0.39	0.24	0.58	0.23	0.31	0.14	0.36	0.35
42	31	0.49	0.29	0.67	0.34	0.30	0.15	0.39	0.19
41	31	0.94	0.39	1.11	0.52	0.52	0.21	0.63	0.29
13	34	0.75	0.42	0.77	0.39	0.43	0.24	0.63	0.32
45	35	0.85	0.21	0.95	0.28	0.49	0.12	0.78	0.23
35	38	0.35	0.19	0.34	0.19	0.20	0.11	0.28	0.16
14	41	0.92	0.34	0.80	0.25	0.40	0.14	0.50	0.15
21	42	2.62	1.11	2.21	0.87	1.20	0.51	1.43	0.56
38	43	2.10	1.00	1.85	0.84	0.97	0.46	1.21	0.56
39	43	1.22	0.88	1.08	0.68	0.55	0.37	0.70	0.44
17	45	1.35	0.68	1.26	0.71	0.62	0.31	0.81	0.47
26	45	1.22	0.52	1.17	0.55	0.55	0.24	0.75	0.36
42	59	0.43	0.27	0.56	0.33	0.21	0.12	0.57	0.27
17	59	0.58	0.19	0.53	0.18	0.32	0.16	0.44	0.18
16	60	0.63	0.33	0.65	0.28	0.33	0.18	0.52	0.23
18	61	0.51	0.19	0.68	0.25	0.29	0.10	0.59	0.22
14	60	1.00	0.43	1.17	0.47	0.53	0.22	0.96	0.37
13	59	1.24	0.55	1.23	0.53	0.65	0.28	1.00	0.43
8	61	1.40	0.55	1.59	0.52	0.73	0.29	1.27	0.43
8	60	0.80	0.41	0.76	0.35	0.42	0.21	0.61	0.28
4	59	0.52	0.26	0.70	0.37	0.31	0.16	0.52	0.26
[illegible]	63	0.52	0.19	0.71	0.32	0.26	0.11	0.57	0.25
13	62	1.00	0.49	0.80	0.23	0.52	0.26	0.66	0.18
16	63	0.75	0.29	0.99	0.40	0.47	0.18	0.87	0.36
19	62	0.69	0.31	0.52	0.23	0.35	0.16	0.22	0.11
20	61	1.15	0.57	1.19	0.41	0.61	0.30	1.06	0.45
25	62	1.11	0.49	0.87	0.33	0.57	0.26	0.71	0.26
28	64	0.79	0.31	0.72	0.21	0.38	0.14	0.92	0.39
37	64	1.29	0.57	1.30	0.57	0.67	0.30	1.04	0.46
45	66	1.22	0.59	1.31	0.58	0.64	0.31	1.06	0.47
41	65	1.37	0.58	1.24	0.55	0.67	0.27	0.99	0.44
38	46	1.13	0.27	1.20	0.35	0.69	0.17	0.88	0.26
24	47	1.30	0.61	1.11	0.52	0.79	0.37	0.81	0.38
26	49	0.73	0.34	1.01	0.47	0.43	0.20	0.75	0.35
38	49	1.43	0.58	1.49	0.64	0.86	0.35	1.09	0.47
41	49	1.16	0.50	1.18	0.58	0.71	0.30	0.87	0.43
36	66	0.42	0.20	0.60	0.36	0.24	0.11	0.34	0.21
25	65	0.73	0.46	0.61	0.47	0.38	0.24	0.37	0.28
20	66	0.55	0.28	0.46	0.21	0.26	0.12	0.34	0.15
21	65	0.95	0.61	0.89	0.73	0.50	0.32	0.53	0.44
13	64	1.54	0.41	1.68	0.51	0.80	0.21	1.00	0.30
7	65	0.74	0.30	0.54	0.23	0.38	0.15	0.32	0.14
6	66	0.70	0.30	0.69	0.24	0.45	0.20	0.37	0.14
16	67	1.80	0.90	1.83	0.87	0.90	0.45	1.03	0.48
21	69	1.46	0.70	1.69	0.84	0.75	0.36	1.02	0.50

Table 30
Assessment of 360 Degree Flaws on Voltage Integral Software

Row	Col.	MET Arc Length (degrees)	June 96 Look-back VIR Max Voltage (volts)	Previous Look-Backs Max Voltage (volts)	Ratio of Max/Vir Max Look-Back Voltages
Byron Tube Pull Data					
38	55	310	0.64	0.78	1.22
27	48	360	0.39	0.18	0.46
14	93	360	0.92	0.46	0.50
24	42	340	1.24	1.17	0.95
23	43	359	1.13	1.25	1.11
36	44	279	0.37	0.18	0.48
20	85	360	0.41	0.33	0.81
28	68	319	0.32	0.1	0.31
24	91	343	0.41	NDD	n/a
14	37	360	0.31	0.59	1.92
Braidwood ECT Inspection 360 Flaws					
46	45	-	0.38	0.4	1.05
21	54	-	1.36	1.07	0.79
13	102	-	1.06	0.8	0.75
Byron 1996 SG C ECT Inspection 360 Flaws					
3	99	-	0.32	0.16	0.50
4	97	-	0.4	0.12	0.30
7	99	-	0.31	0.1	0.32
8	95	-	0.56	NDD	-
12	97	-	0.37	0.17	0.46
13	97	-	0.31	0.15	0.48
18	99	-	0.41	0.26	0.63
19	37	-	0.43	NDD	-
Byron 1995 SG B ECT Inspection 360 Flaws					
1	93	-	0.79	0.7	0.89
1	104	-	0.61	0.28	0.46
5	96	-	0.42	0.56	1.33
6	107	-	0.44	0.52	1.18
9	68	-	0.27	0.26	0.96
13	77	-	0.36	0.73	2.03
13	82	-	0.44	0.39	0.89
13	93	-	0.44	0.5	1.14
14	79	-	0.47	0.47	1.00
15	60	-	0.37	0.21	0.57
17	46	-	0.7	0.68	0.97
20	89	-	0.49	0.44	0.90
20	90	-	0.75	0.7	0.93
21	96	-	0.34	0.32	0.94
24	74	-	0.75	0.81	1.08
26	44	-	0.67	0.45	0.67
27	50	-	0.53	0.45	0.85
28	49	-	0.44	0.4	0.91
30	94	-	0.64	0.61	0.95
37	72	-	0.54	0.5	0.93
39	47	-	0.43	0.17	0.40

Average Voltage vs. Corrected Leak Rate at MSLB Conditions
Figure 14a

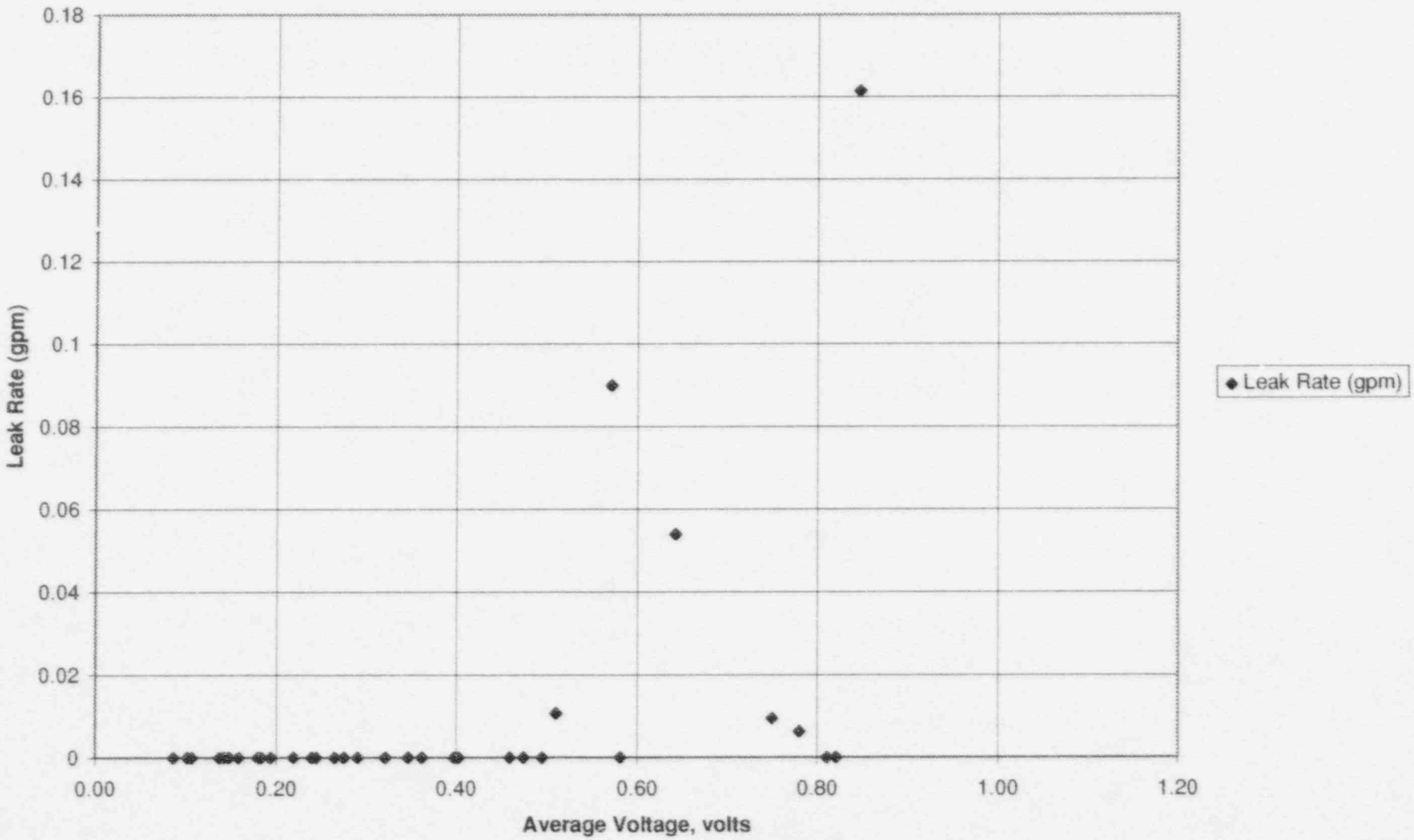


Figure 19. Voltage Normalization Regression Analysis, 0.080 and 0.115 inch Coils, Maximum and Average Voltage

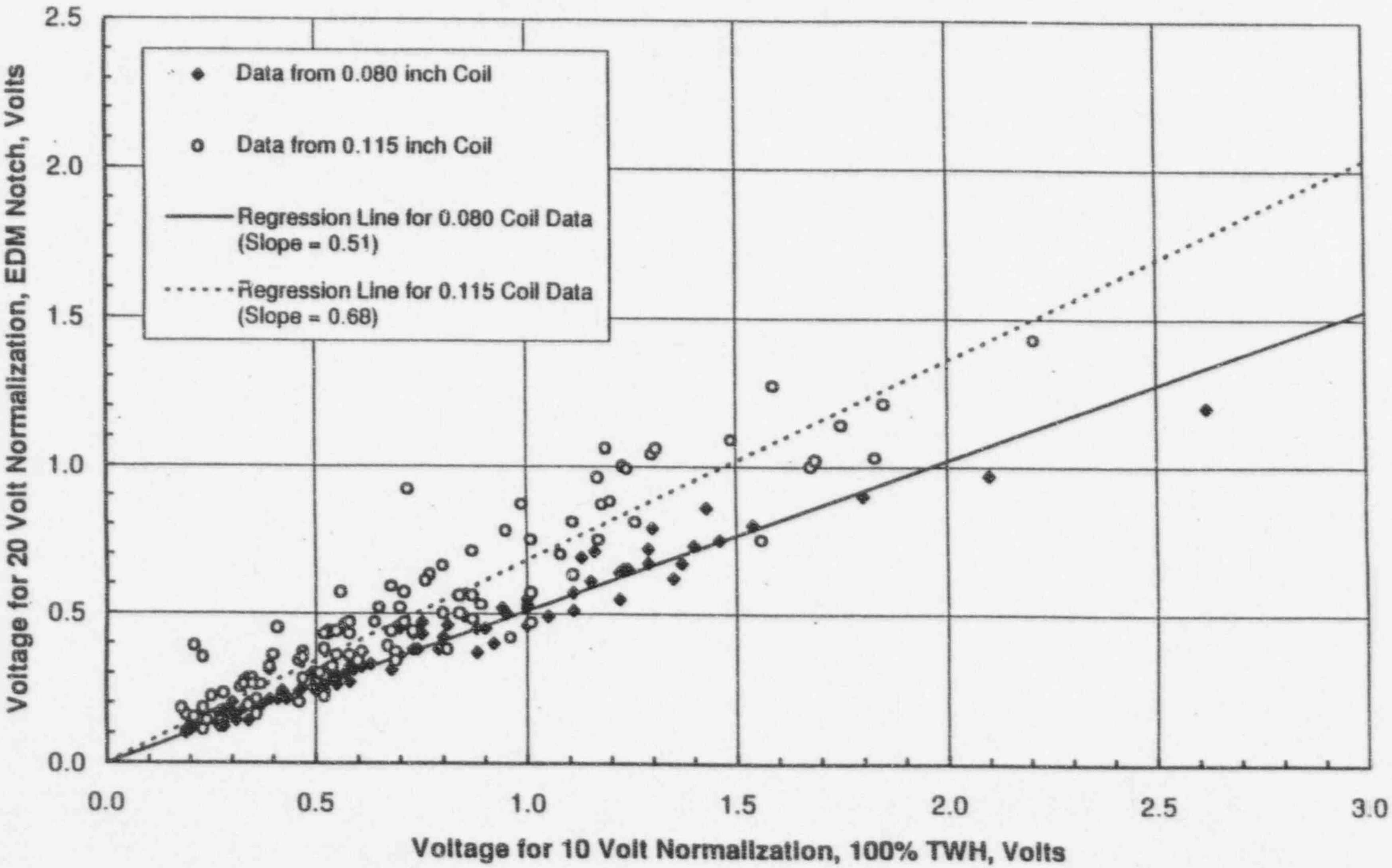
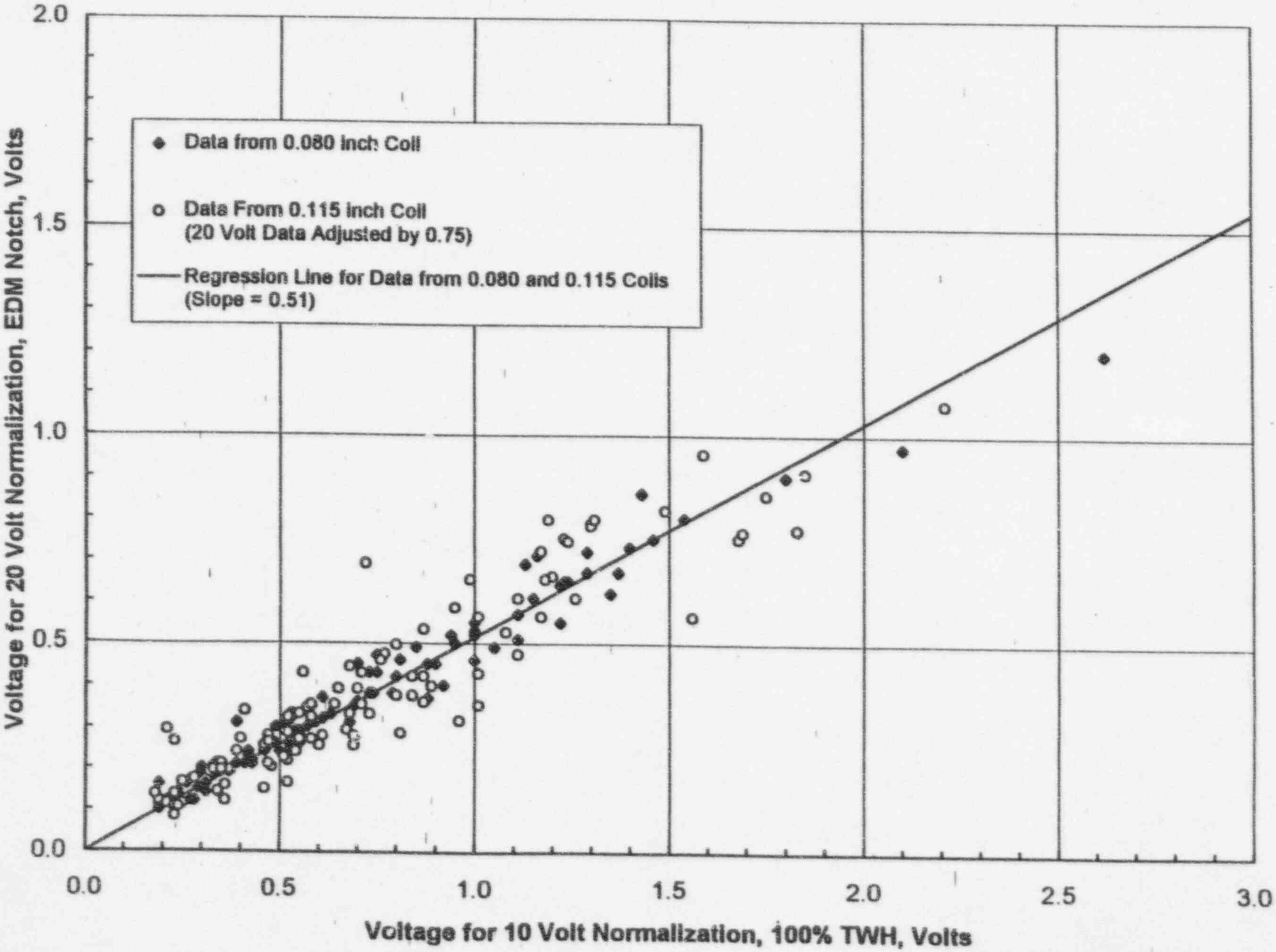


Figure 20. Correlation of 20 Volt to 10 Volt Normalization Data, 0.115 inch/20V Coil Data Adjustified by 0.75 Factor, Average & Maximum Voltage



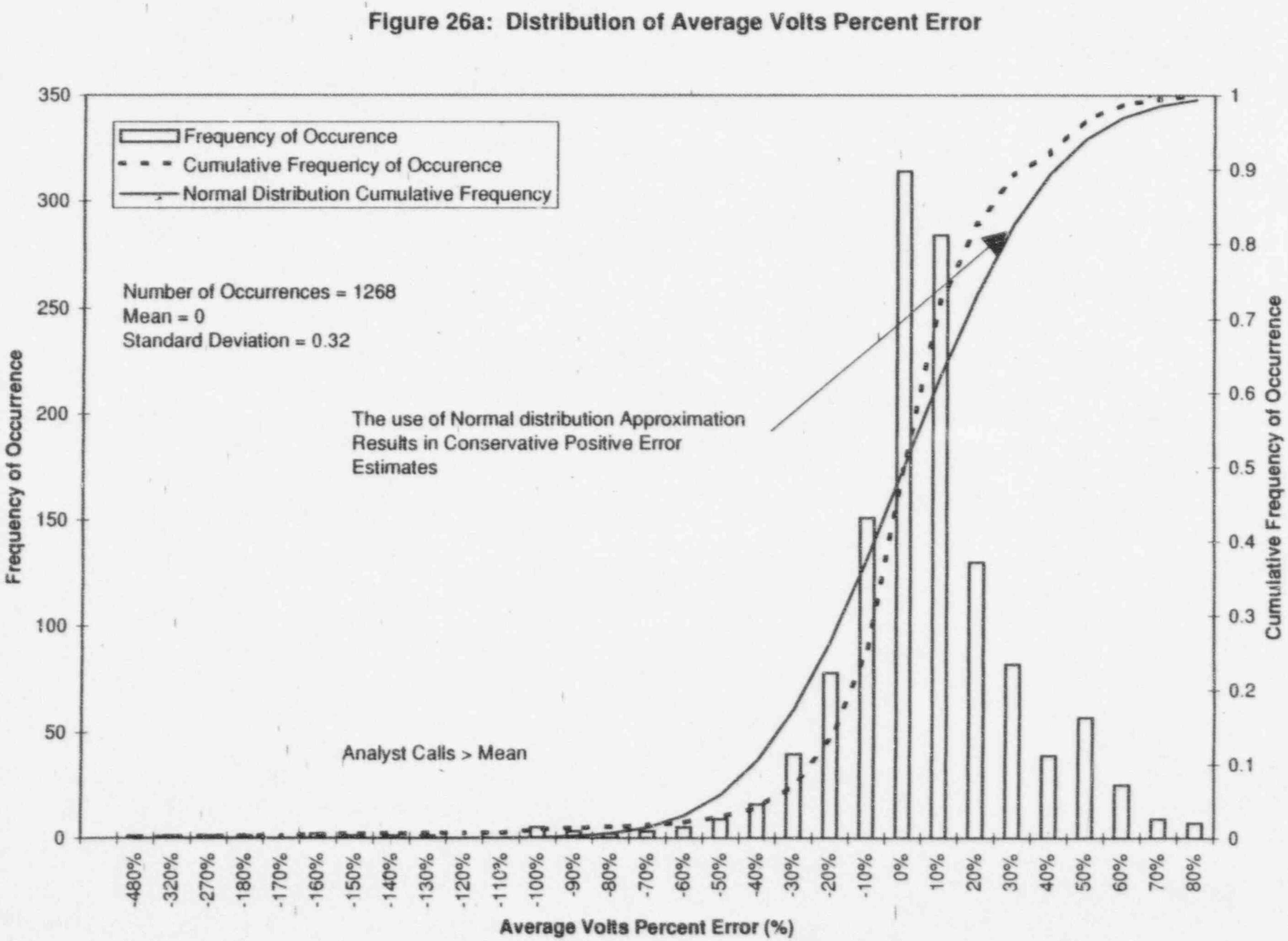


Figure 26a: Distribution of Average Volts Percent Error
Frequency of Occurence
Cumulative Frequency of Occurence
Normal Distribution Cumulative Frequency
Number of Occurrences = 1268
Mean = 0
Standard Deviation = 0.32
The use of Normal distribution Approximation Results in Conservative Positive Error Estimates
Analyst Calls > Mean
Frequency of Occurrence
Cumulative Frequency of Occurrence
Average Volts Percent Error (%)
350
300
250
200
150
100
50
0
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-480% -320% -270% -180% -170% -160% -150% -140% -130% -120% -110% -100% -90% -80% -70% -60% -50% -40% -30% -20% -10% 0% 10% 20% 30% 40% 50% 60% 70% 80%

Figure 26b: Distribution of Maximum Volts Percent Error

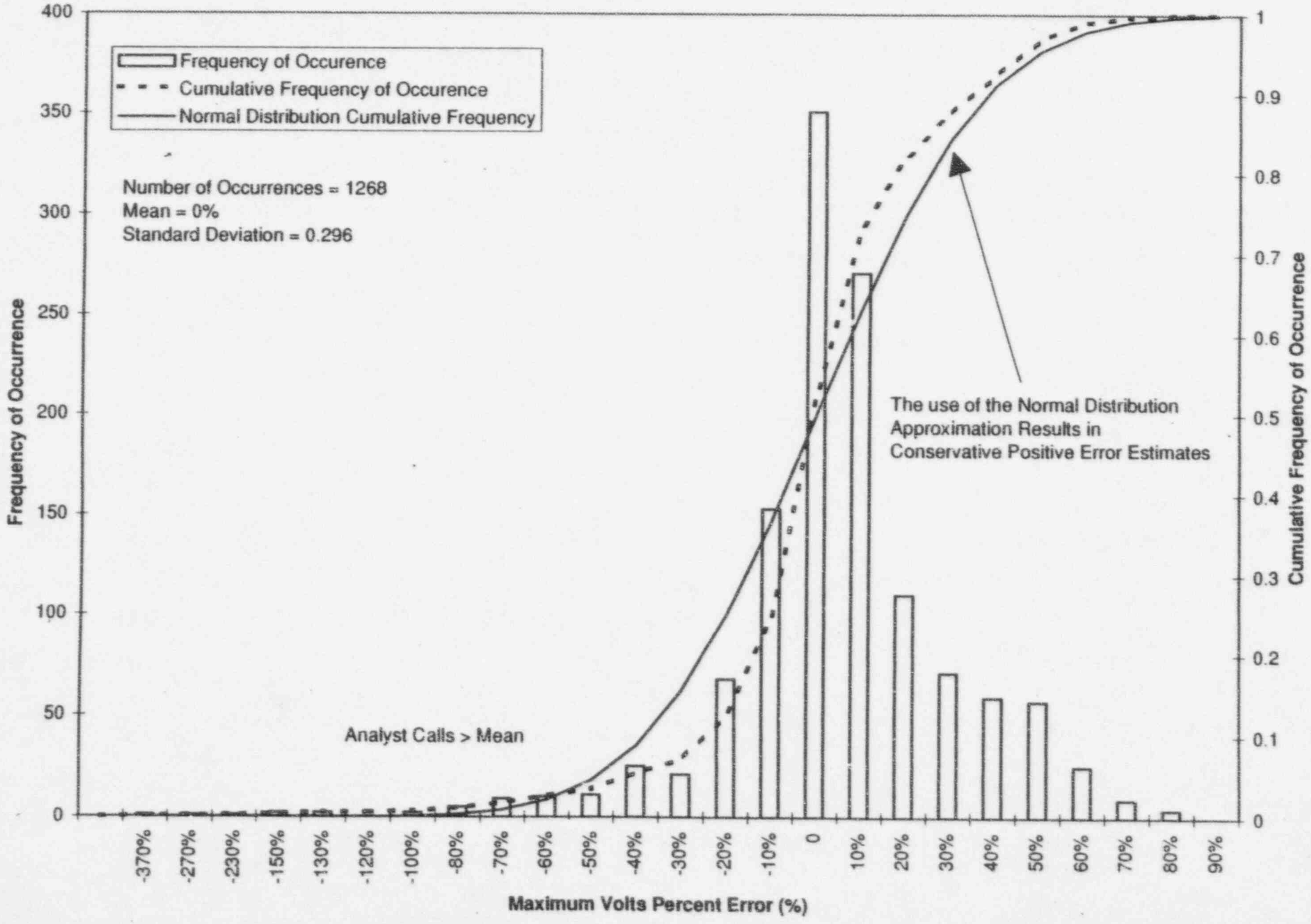


Figure 27a: Distribution of Average Volts Percent Error, Calls with > 100% Error Removed

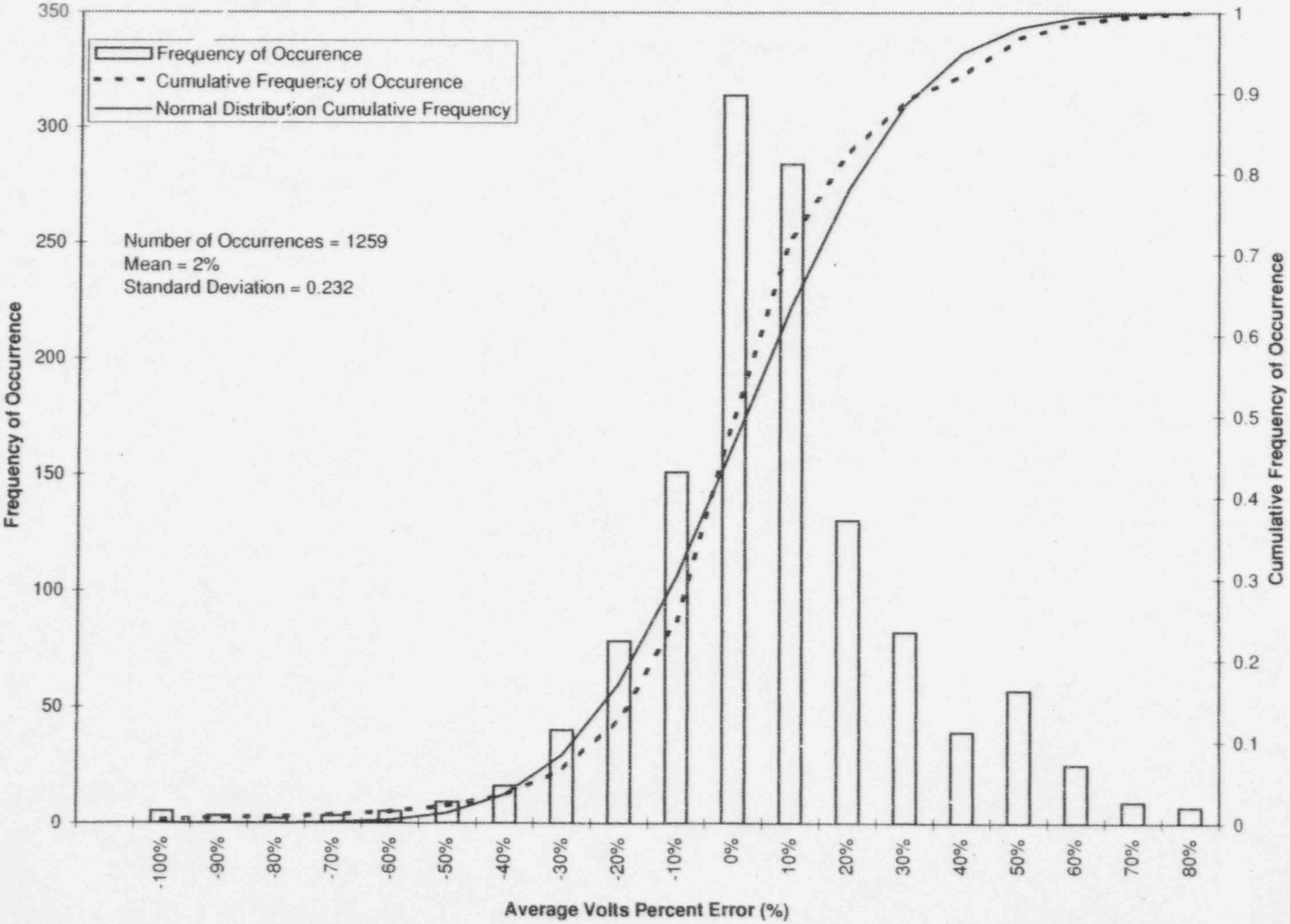


Figure 27b: Distribution of Maximum Volts Percent Error, Calls with > 100% Error Removed

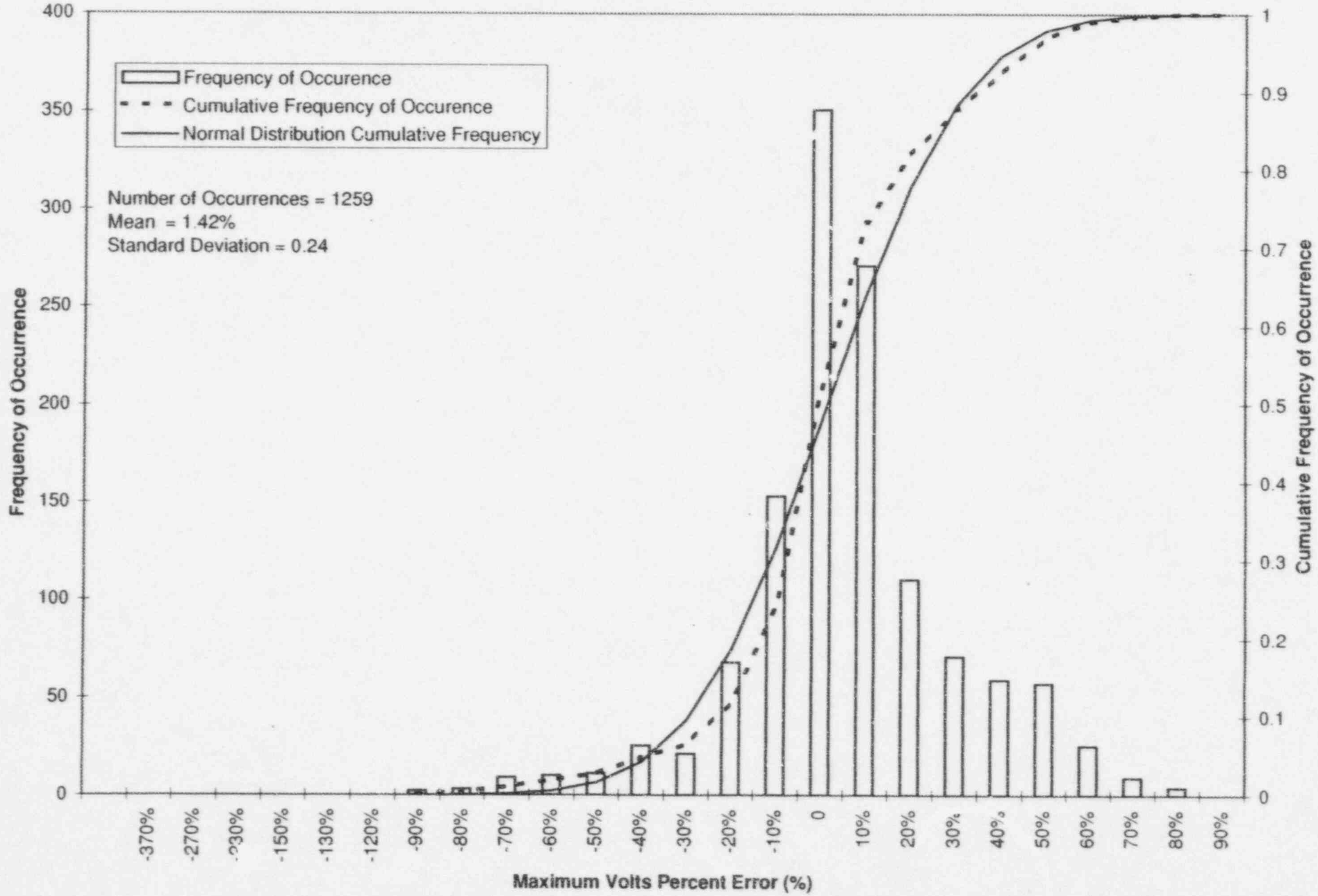
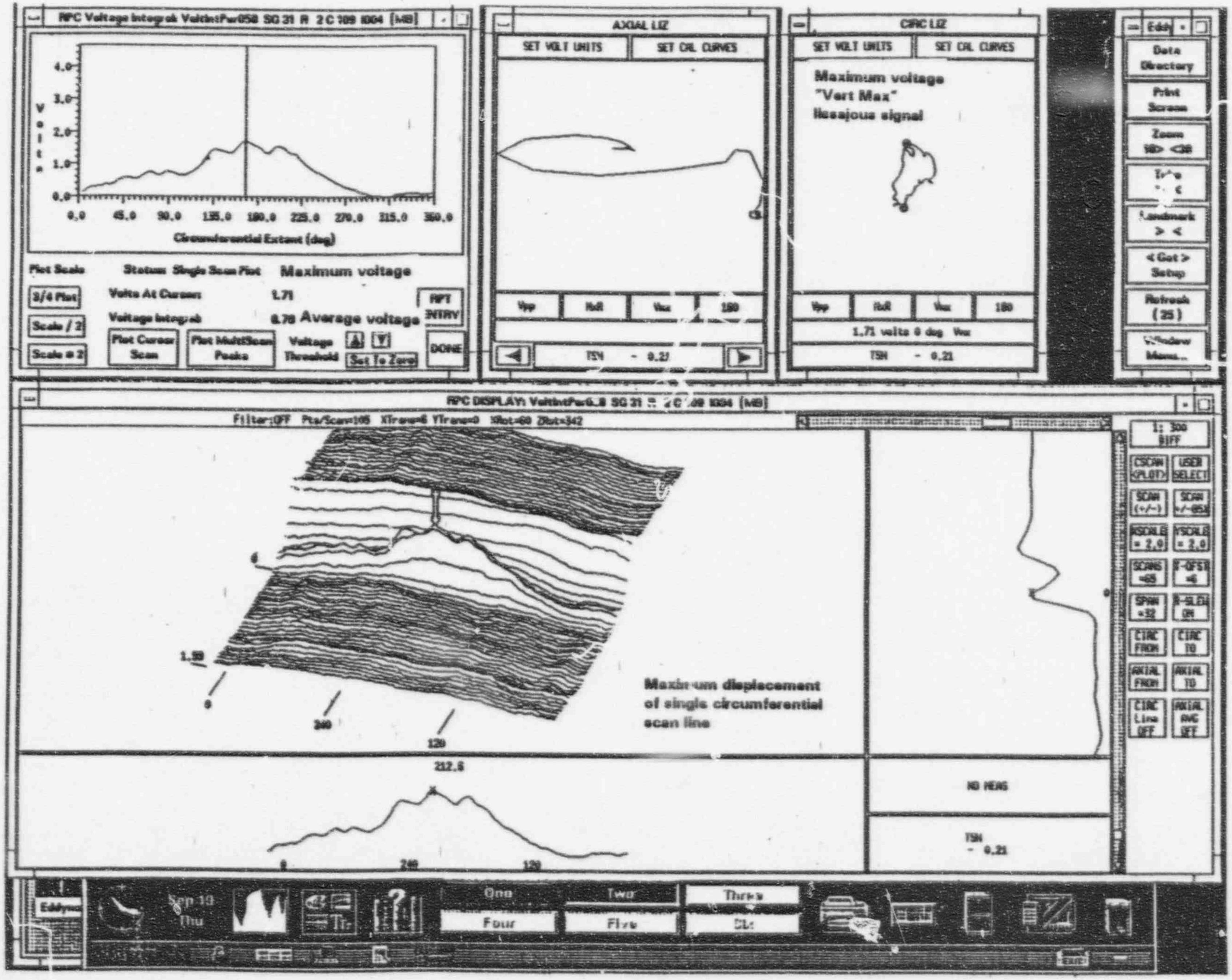
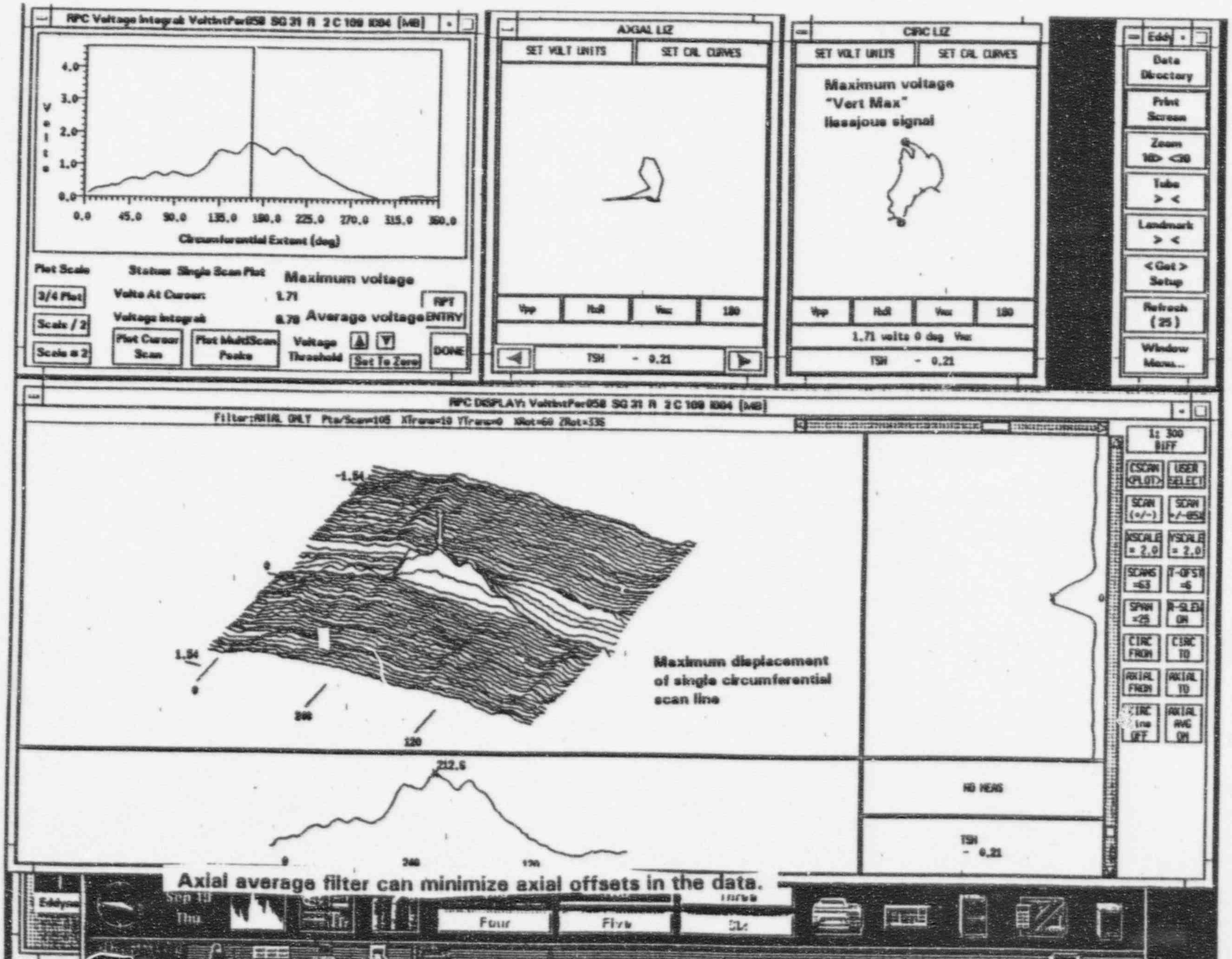


Figure 30A



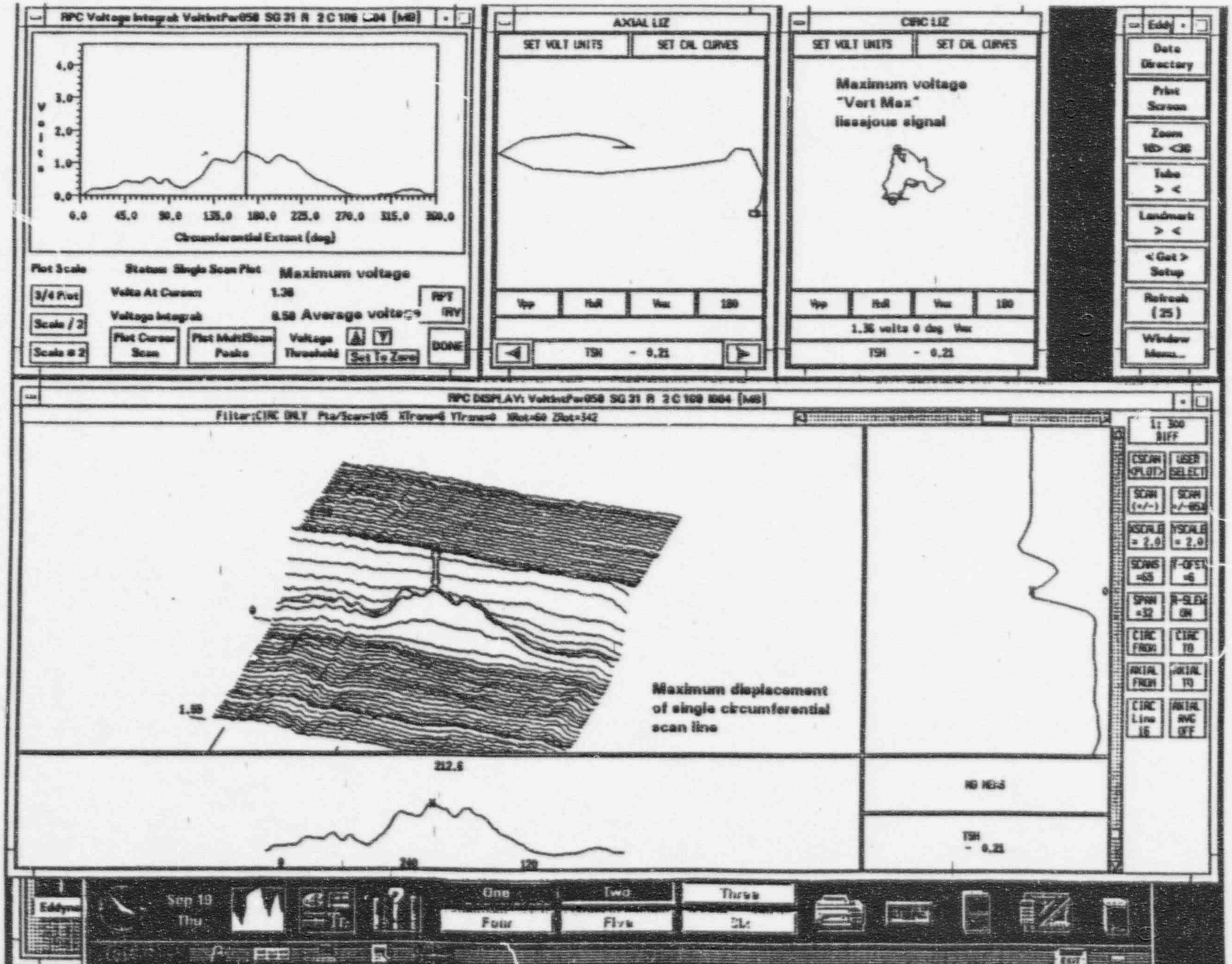
C-Scan plot
without filtering

Figure 30B



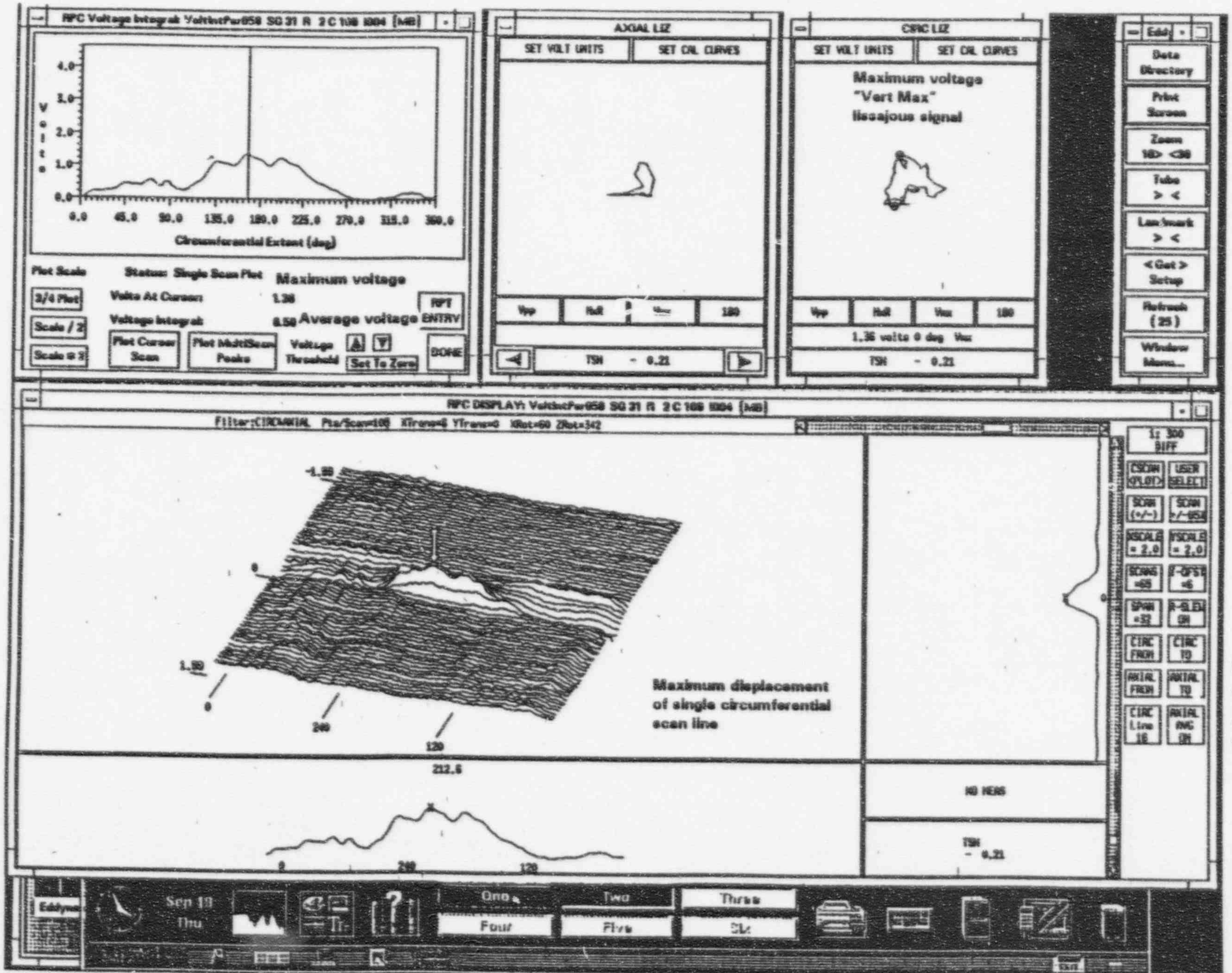
C-Scan plot with AXIAL AVG filter applied

Figure 30C



C-Scan plot with CIRC LINE filter applied

Figure 30D



C-Scan plot
with CIRC &
AXIAL LINE
filters applied

Attachment D

BYRON UNIT 1 RESPONSE TO

REQUEST FOR ADDITIONAL INFORMATION DATED October 3, 1996 (REFERENCE 6)

RELATED TO THE BRAIDWOOD, UNIT 1 CYCLE LENGTH ASSESSMENT

Reference: Braidwood Response (Reference 2g)

1. **The data provided in Table 5 in the submittal dated September 24, 1996, indicate that a number of steam generator (SG) tubes burst axially during testing and several exhibited mixed mode cracking. Explain the basis for including these data in the burst correlation's. Since both axial and circumferential flaws were identified in a number of the pulled tubes, discuss the uncertainty involved in using other data obtained from in-situ tests when the morphology of the cracking could not be definitively determined.**

   Response (10/17/96):

   As identified in Table 5, indications which burst in the axial direction have for the most part been indications with minimal degradation (low voltage) bursting at pressures near virgin tube burst pressures. This clearly demonstrates that tubes with substantial circumferential degradation will not burst under accident conditions.

   Axial cracking present in pulled tubes along with circumferential cracking would result in lower burst pressures and higher leak rates compared to tubes with circumferential cracks alone. If axial cracking in combination with circumferential cracks significantly influenced burst or leakage, tubes would have leaked at higher rates or burst at the axial crack. No tubes with mixed mode cracks, identified in Table 5, burst axially at the area of degradation (failure occurred at locations away from the TTS degradation). Consequently, conservative burst and leak rate correlation's would result from testing tubes with both axial and circumferential cracks. This would be true for both pulled tube tests and insitu tests.

2. **The staff has evaluated the data supplied by the licensee in Table 19b to verify the validity of the licensee's proposed correction factors of 0.58 and 0.76. Based on this evaluation, the staff has concluded that using fixed values to convert voltage data could result in significant errors in the analysis. This conclusion is based on the level of scatter observed in a sample of data provided in this table. The staff also assessed the correction factor used by the licensee to adjust 0.115-inch coil probe voltages to equivalent 0.80-inch coil probe voltages. The results**

of this staff assessment do not support the licensee's proposed correction factor of 0.78. Specifically, the staff's assessment indicates that the use of fixed values of correction factors to adjust voltages for different calibration procedures and probes can lead to significant errors in the adjusted voltages. In addition, the normalization values used by the licensee were non-conservative based on values determined in the staff's independent assessment. Accordingly, due to the high degree of scatter in the data, discuss whether it is more appropriate to bound the normalization factors at an elevated confidence level when adjusting voltages.

Response (10/17/96):

Linear regression analysis of field data acquired using two different normalization techniques with two different coils was presented in response to Question 19. Results of the regression analysis of maximum and average voltages identified that a linear relationship between the two different normalization techniques exists using the 0.080" and 0.115" RPC, and identified the relationships between voltages from the two coils.

For the 0.080" RPC, the slope of the regression line for the 20 Volt normalization as a function of the 10 Volt normalization, was calculated to be 0.51 with an r-squared value of 0.957 and a standard error of 0.046. These results indicate that there is a good linear fit of the normalization data with a small error band around the linear relationship for the 0.080" RPC data.

For the 0.115" RPC, the slope of the regression line for the 20 Volt normalization as a function of the 10 Volt normalization, was calculated to be 0.68 with an r-squared value of 0.857 and a standard error of 0.114. These results indicate that there is a good linear fit of the normalization data with a small error band around the linear relationship for the 0.115" RPC data.

Taking the ratio of the normalization correction factors (slopes of the regression lines) for the two coils (0.51/0.68) provides a correction factor for data acquired with the 0.115" RPC relative to the 0.080" RPC. Applying this factor provides voltages consistent with data acquired with the 0.080" RPC. Applying the coil size correction factor to the 0.115" RPC data and plotting the data (now consistent with 0.080" RPC voltages) with the 0.080" RPC for the two normalization techniques was performed to assess the coil size correction factor. Linear regression analysis of this data resulted in a slope of 0.51 with an r-squared value of 0.91 and a standard error of 0.068.
The data obtained for the field study was analyzed using the voltage integral software. Analyst uncertainty as determined by blind test of Byron Unit 1 indications (presented in response to Question 25) was determined to be 32% and 30% for average and maximum volts, respectively. Scatter in the field data is expected as a result of the analyst uncertainty associated with analyzing the data. Results of the regression analyses show the scatter associated with voltage normalization and coil size is well within the scatter associated with analyst uncertainty. Analyst uncertainty is

accounted for in the end-of-cycle distributions and does not need to be double counted in either the burst or leak correlation's.

Therefore, the probabilistic analyses of the field data supports the use of a constant normalization and coil size correction factor without the application of additional confidence levels. The coil size and normalization correction factors identified in response to RAI Questions 19 and 20 have been determined and applied consistent with the voltage normalization procedures used for application of GL 95-05.

3. **The correction factor for converting voltages from 0.115-inch coils to 0.080-inch coils varies significantly based on independent staff calculations using the data supplied in Table 19b as discussed in Item 4 below. This conclusion introduces uncertainty into the proposed voltage threshold for SG tube leakage. Discuss the effects of this uncertainty on your conclusions.**

   Response (10/17/96):

   This question has been addressed in response to Question 2. An electronic version of the data included in Table 19b has been provided to the staff for independent calculation. Scatter in the field data is expected as a result of the analyst uncertainty associated with analyzing the data. Results of the regression analyses show the scatter associated with the coil size correction factor is well within the scatter associated with analyst uncertainty. Analyst uncertainty is accounted for in the end-of-cycle distributions and does not need to be double counted in either the burst or leak correlation's.

4. **Clarify the normalization of voltage data. For example, in your response to Item 5 of the staff's request for additional information (RAI) dated September 9, 1996, and in submittal dated August 2, 1996, it is stated that no calibration corrections were applied to measurements recorded when the probe voltage was set at 10 volts on the 100-percent through-wall hole. However, the values listed in Table 5 of the response to the previous RAI do not appear to correlate with data provided elsewhere in the submittal. For example, one of the six leakage datum has a reported average voltage of 1.66 volts. Applying a correction factor of 0.75 to adjust for probe coil differences results in a voltage greater than any of the date in Figure 14a. Clarify this apparent discrepancy.**

   Response (10/17/96):

   Clarification of this RAI response was provided in the Braidwood Unit 1 Reference 2g submittal, therefore this question has been addressed and further clarification is not provided for the Byron Unit 1 EOC analysis.

5. **Several values important in assessing the end-of-cycle (EOC) structural and leakage integrity of Braidwood 1 SG tubes been modified since the submittal dated August 2, 1996. For example, the burst and leakage correlation's in response to the prior RAI have been adjusted to account for industry material property data and revised values for analyst error. Accordingly, re-evaluate the Braidwood 1 EOC assessment considering all changes to the proposed methodology. Address the use of bounding voltage correction values as discussed in Item 3 above and the limiting growth rate distribution in light of the responses to Items 2 and 3 of the prior RAI.**

   Response (10/17/96):

   The results in this report main body Sections 5.0 and 6.0 have been updated to include the modified normalization correction factor, coil size correction factor, analyst uncertainty and industry LTL properties as reported in response to the RAI questions.

   The question on growth rates is addressed for the Byron Unit 1 cycle length assessment below.

   An assessment was performed of Byron Unit 1 growth rates to determine the appropriate intervals to be used. Because full cycle operation is being evaluated, growth rates from as near a full cycle as possible were considered to minimize the uncertainty associated with short interval growth rates. Figure 5a and 5b presents the maximum and average growth rates for the three Byron Unit 1 intervals for which inspections sensitive to circumferential indications were performed (1994 to 1995, 1994 to 1996 and 1995 to 1996). The growth rates are for 0.080" RPC data normalized to 1 year of operation. The data was analyzed as a part of the 1996 voltage integral software look-back and includes indications repaired in 1995 and 1996.

   The distribution of growth rates shown in Figures 5a and 5b provide the following observations: the growth rate distributions for longer intervals, approximately one full cycle of operation (1994 to 1995 and 1994 to 1996), are smooth with relatively short tails and is peaked at the middle. The distribution for the short operating interval, approximately one quarter of an operating cycle (1995 to 1996) is not smooth, has long tails in both directions and is flat. The curves on the figures show that there is a significant difference in the short and long cycle growth rates.

   Because there are some large short interval growth rates, an evaluation of the voltage distribution of 1995 and 1996 indications present in 1994 was performed. If the large short interval growth rates were real it would be expected that the distribution of indications present from 1994 to 1996 would be significantly greater than the distribution of indications present from 1994 to 1995. Figures 5c and 5d show the Frequency of indications versus the maximum and average voltage in volts,

Attachment D

BYRON UNIT 1 RESPONSE TO

REQUEST FOR ADDITIONAL INFORMATION DATED October 3, 1996 (REFERENCE 6)

RELATED TO THE BRAIDWOOD, UNIT 1 CYCLE LENGTH ASSESSMENT

Reference: Braidwood Response (Reference 2g)

1. **The data provided in Table 5 in the submittal dated September 24, 1996, indicate that a number of steam generator (SG) tubes burst axially during testing and several exhibited mixed mode cracking. Explain the basis for including these data in the burst correlation's. Since both axial and circumferential flaws were identified in a number of the pulled tubes, discuss the uncertainty involved in using other data obtained from in-situ tests when the morphology of the cracking could not be definitively determined.**

   Response (10/17/96):

   As identified in Table 5, indications which burst in the axial direction have for the most part been indications with minimal degradation (low voltage) bursting at pressures near virgin tube burst pressures. This clearly demonstrates that tubes with substantial circumferential degradation will not burst under accident conditions.

   Axial cracking present in pulled tubes along with circumferential cracking would result in lower burst pressures and higher leak rates compared to tubes with circumferential cracks alone. If axial cracking in combination with circumferential cracks significantly influenced burst or leakage, tubes would have leaked at higher rates or burst at the axial crack. No tubes with mixed mode cracks, identified in Table 5, burst axially at the area of degradation (failure occurred at locations away from the TTS degradation). Consequently, conservative burst and leak rate correlation's would result from testing tubes with both axial and circumferential cracks. This would be true for both pulled tube tests and insitu tests.

2. **The staff has evaluated the data supplied by the licensee in Table 19b to verify the validity of the licensee's proposed correction factors of 0.58 and 0.76. Based on this evaluation, the staff has concluded that using fixed values to convert voltage data could result in significant errors in the analysis. This conclusion is based on the level of scatter observed in a sample of data provided in this table. The staff also assessed the correction factor used by the licensee to adjust 0.115-inch coil probe voltages to equivalent 0.80-inch coil probe voltages. The results**

of this staff assessment do not support the licensee's proposed correction factor of 0.78. Specifically, the staff's assessment indicates that the use of fixed values of correction factors to adjust voltages for different calibration procedures and probes can lead to significant errors in the adjusted voltages. In addition, the normalization values used by the licensee were non-conservative based on values determined in the staff's independent assessment. Accordingly, due to the high degree of scatter in the data, discuss whether it is more appropriate to bound the normalization factors at an elevated confidence level when adjusting voltages.

Response (10/17/96):

Linear regression analysis of field data acquired using two different normalization techniques with two different coils was presented in response to Question 19. Results of the regression analysis of maximum and average voltages identified that a linear relationship between the two different normalization techniques exists using the 0.080" and 0.115" RPC, and identified the relationships between voltages from the two coils.

For the 0.080" RPC, the slope of the regression line for the 20 Volt normalization as a function of the 10 Volt normalization, was calculated to be 0.51 with an r-squared value of 0.957 and a standard error of 0.046. These results indicate that there is a good linear fit of the normalization data with a small error band around the linear relationship for the 0.080" RPC data.

For the 0.115" RPC, the slope of the regression line for the 20 Volt normalization as a function of the 10 Volt normalization, was calculated to be 0.68 with an r-squared value of 0.857 and a standard error of 0.114. These results indicate that there is a good linear fit of the normalization data with a small error band around the linear relationship for the 0.115" RPC data.

Taking the ratio of the normalization correction factors (slopes of the regression lines) for the two coils (0.51/0.68) provides a correction factor for data acquired with the 0.115" RPC relative to the 0.080" RPC. Applying this factor provides voltages consistent with data acquired with the 0.080" RPC. Applying the coil size correction factor to the 0.115" RPC data and plotting the data (now consistent with 0.080" RPC voltages) with the 0.080" RPC for the two normalization techniques was performed to assess the coil size correction factor. Linear regression analysis of this data resulted in a slope of 0.51 with an r-squared value of 0.91 and a standard error of 0.068.
The data obtained for the field study was analyzed using the voltage integral software. Analyst uncertainty as determined by blind test of Byron Unit 1 indications (presented in response to Question 25) was determined to be 32% and 30% for average and maximum volts, respectively. Scatter in the field data is expected as a result of the analyst uncertainty associated with analyzing the data. Results of the regression analyses show the scatter associated with voltage normalization and coil size is well within the scatter associated with analyst uncertainty. Analyst uncertainty is

accounted for in the end-of-cycle distributions and does not need to be double counted in either the burst or leak correlation's.

Therefore, the probabilistic analyses of the field data supports the use of a constant normalization and coil size correction factor without the application of additional confidence levels. The coil size and normalization correction factors identified in response to RAI Questions 19 and 20 have been determined and applied consistent with the voltage normalization procedures used for application of GL 95-05.

3. **The correction factor for converting voltages from 0.115-inch coils to 0.080-inch coils varies significantly based on independent staff calculations using the data supplied in Table 19b as discussed in Item 4 below. This conclusion introduces uncertainty into the proposed voltage threshold for SG tube leakage. Discuss the effects of this uncertainty on your conclusions.**

   Response (10/17/96):

   This question has been addressed in response to Question 2. An electronic version of the data included in Table 19b has been provided to the staff for independent calculation. Scatter in the field data is expected as a result of the analyst uncertainty associated with analyzing the data. Results of the regression analyses show the scatter associated with the coil size correction factor is well within the scatter associated with analyst uncertainty. Analyst uncertainty is accounted for in the end-of-cycle distributions and does not need to be double counted in either the burst or leak correlation's.

4. **Clarify the normalization of voltage data. For example, in your response to Item 5 of the staff's request for additional information (RAI) dated September 9, 1996, and in submittal dated August 2, 1996, it is stated that no calibration corrections were applied to measurements recorded when the probe voltage was set at 10 volts on the 100-percent through-wall hole. However, the values listed in Table 5 of the response to the previous RAI do not appear to correlate with data provided elsewhere in the submittal. For example, one of the six leakage datum has a reported average voltage of 1.66 volts. Applying a correction factor of 0.75 to adjust for probe coil differences results in a voltage greater than any of the date in Figure 14a. Clarify this apparent discrepancy.**

   Response (10/17/96):

   Clarification of this RAI response was provided in the Braidwood Unit 1 Reference 2g submittal, therefore this question has been addressed and further clarification is not provided for the Byron Unit 1 EOC analysis.

5. **Several values important in assessing the end-of-cycle (EOC) structural and leakage integrity of Braidwood 1 SG tubes been modified since the submittal dated August 2, 1996. For example, the burst and leakage correlation's in response to the prior RAI have been adjusted to account for industry material property data and revised values for analyst error. Accordingly, re-evaluate the Braidwood 1 EOC assessment considering all changes to the proposed methodology. Address the use of bounding voltage correction values as discussed in Item 3 above and the limiting growth rate distribution in light of the responses to Items 2 and 3 of the prior RAI.**

Response (10/17/96):

The results in this report main body Sections 5.0 and 6.0 have been updated to include the modified normalization correction factor, coil size correction factor, analyst uncertainty and industry LTL properties as reported in response to the RAI questions.

The question on growth rates is addressed for the Byron Unit 1 cycle length assessment below.

An assessment was performed of Byron Unit 1 growth rates to determine the appropriate intervals to be used. Because full cycle operation is being evaluated, growth rates from as near a full cycle as possible were considered to minimize the uncertainty associated with short interval growth rates. Figure 5a and 5b presents the maximum and average growth rates for the three Byron Unit 1 intervals for which inspections sensitive to circumferential indications were performed (1994 to 1995, 1994 to 1996 and 1995 to 1996). The growth rates are for 0.080" RPC data normalized to 1 year of operation. The data was analyzed as a part of the 1996 voltage integral software look-back and includes indications repaired in 1995 and 1996.

The distribution of growth rates shown in Figures 5a and 5b provide the following observations: the growth rate distributions for longer intervals, approximately one full cycle of operation (1994 to 1995 and 1994 to 1996), are smooth with relatively short tails and is peaked at the middle. The distribution for the short operating interval, approximately one quarter of an operating cycle (1995 to 1996) is not smooth, has long tails in both directions and is flat. The curves on the figures show that there is a significant difference in the short and long cycle growth rates.

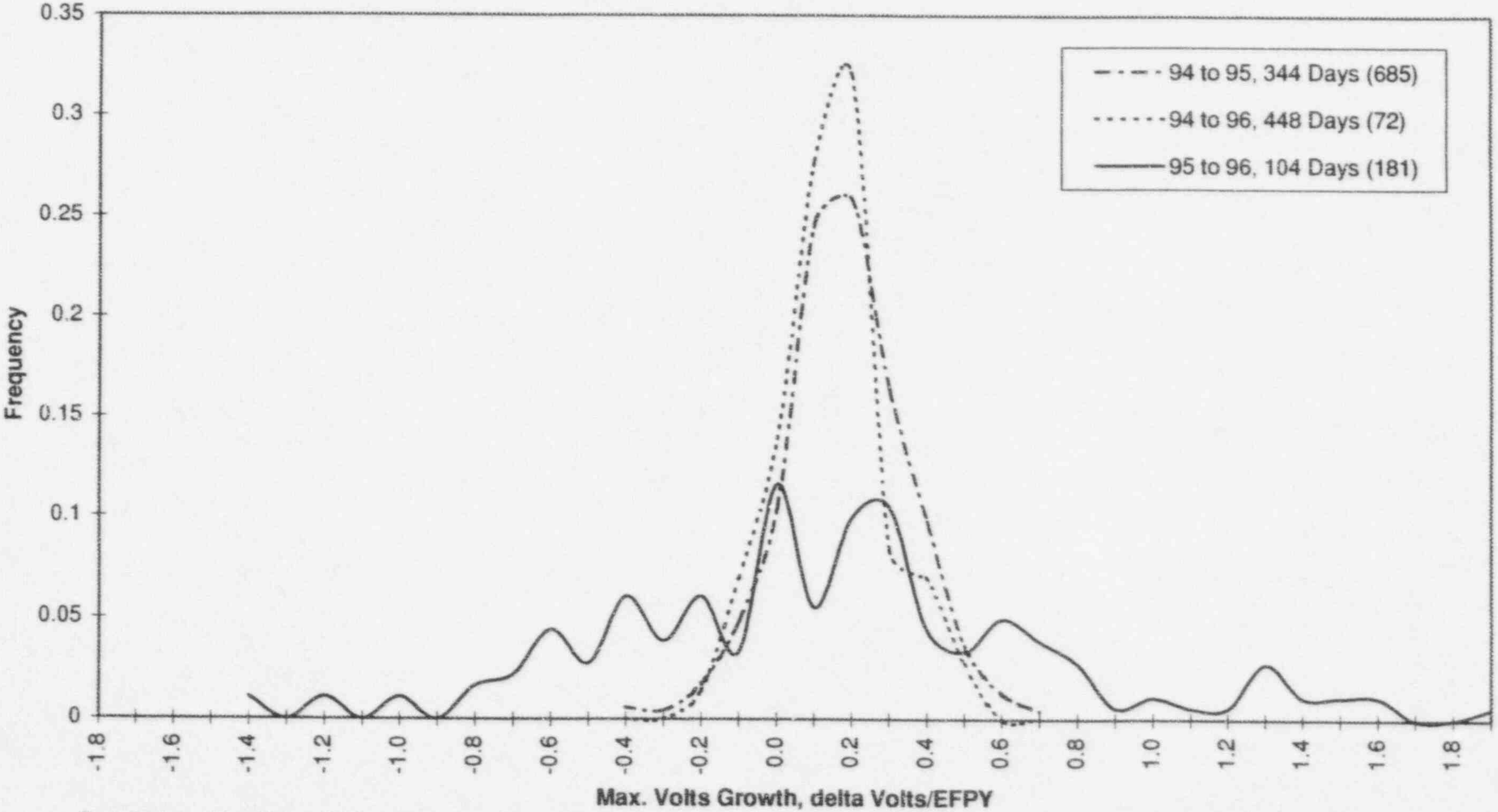
Because there are some large short interval growth rates, an evaluation of the voltage distribution of 1995 and 1996 indications present in 1994 was performed. If the large short interval growth rates were real it would be expected that the distribution of indications present from 1994 to 1996 would be significantly greater than the distribution of indications present from 1994 to 1995. Figures 5c and 5d show the Frequency of indications versus the maximum and average voltage in volts,

respectively. The figures show that there is no significant difference in size of indications present from 1994 to 1995 compared to 1994 to 1996. This indicates that full cycle growth rates are appropriate for a full operating cycle evaluation.

As discussed in response to Questions 2 and 3 the use of the bounding voltage correction values is appropriate. Scatter in the field data is expected as a result of the analyst uncertainty associated with analyzing the data. Results of the regression analyses show the scatter associated with voltage normalization and coil size is well within the scatter associated with analyst uncertainty. Analyst uncertainty is accounted for in the end-of-cycle distributions and does not need to be double counted in either the burst or leak correlation's.

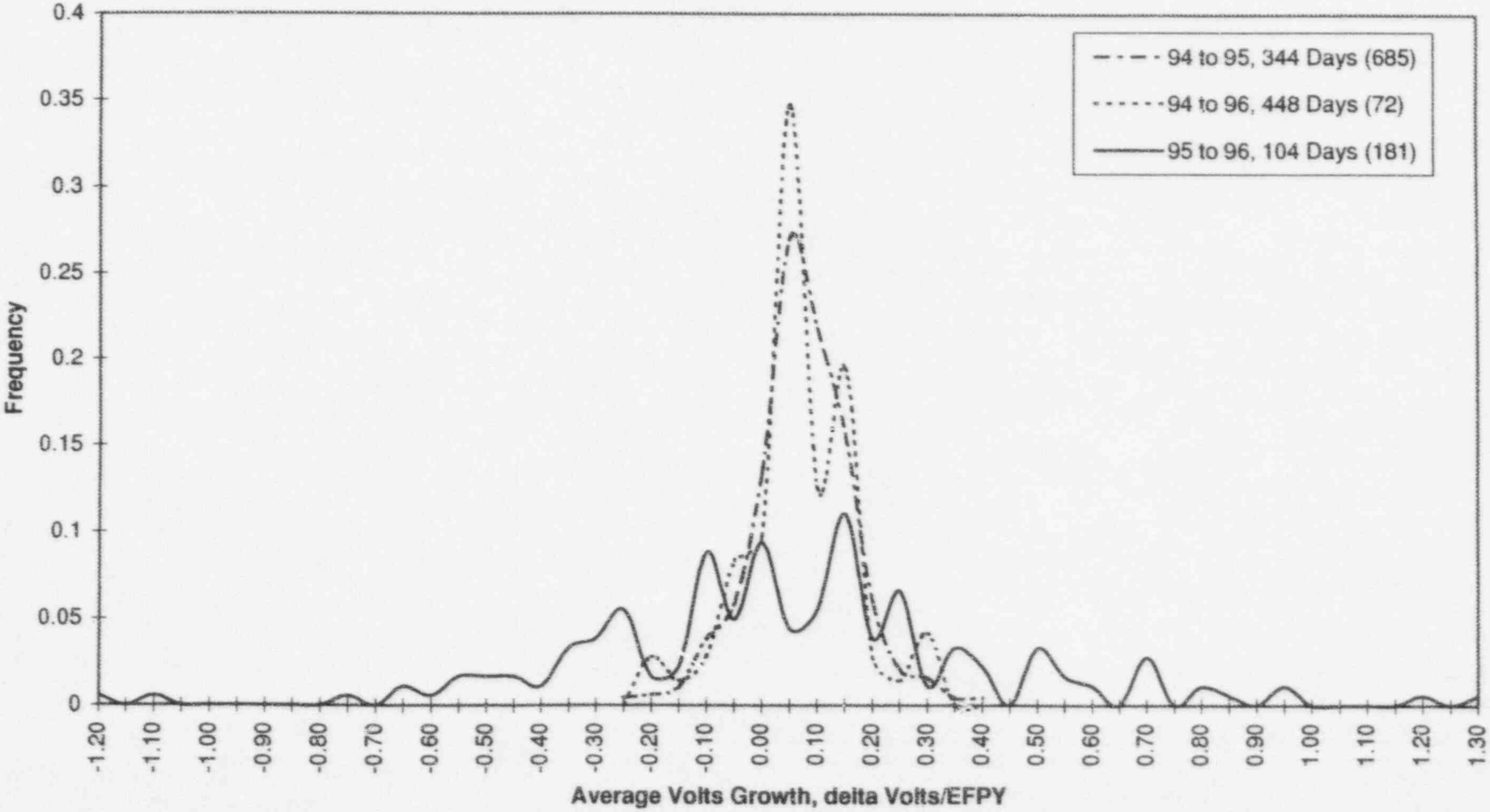
Results of the probabilistic analyses of the field data supports the use of a constant normalization and coil size correction factor without the application of additional confidence levels. The coil size and normalization correction factors identified in response to RAI Questions 19 and 20 have been determined and applied consistent with the voltage normalization procedures used for application of GL 95-05.

Evaluation of Byron Maximum Voltage Growth for Three Operating Intervals
Figure 5a

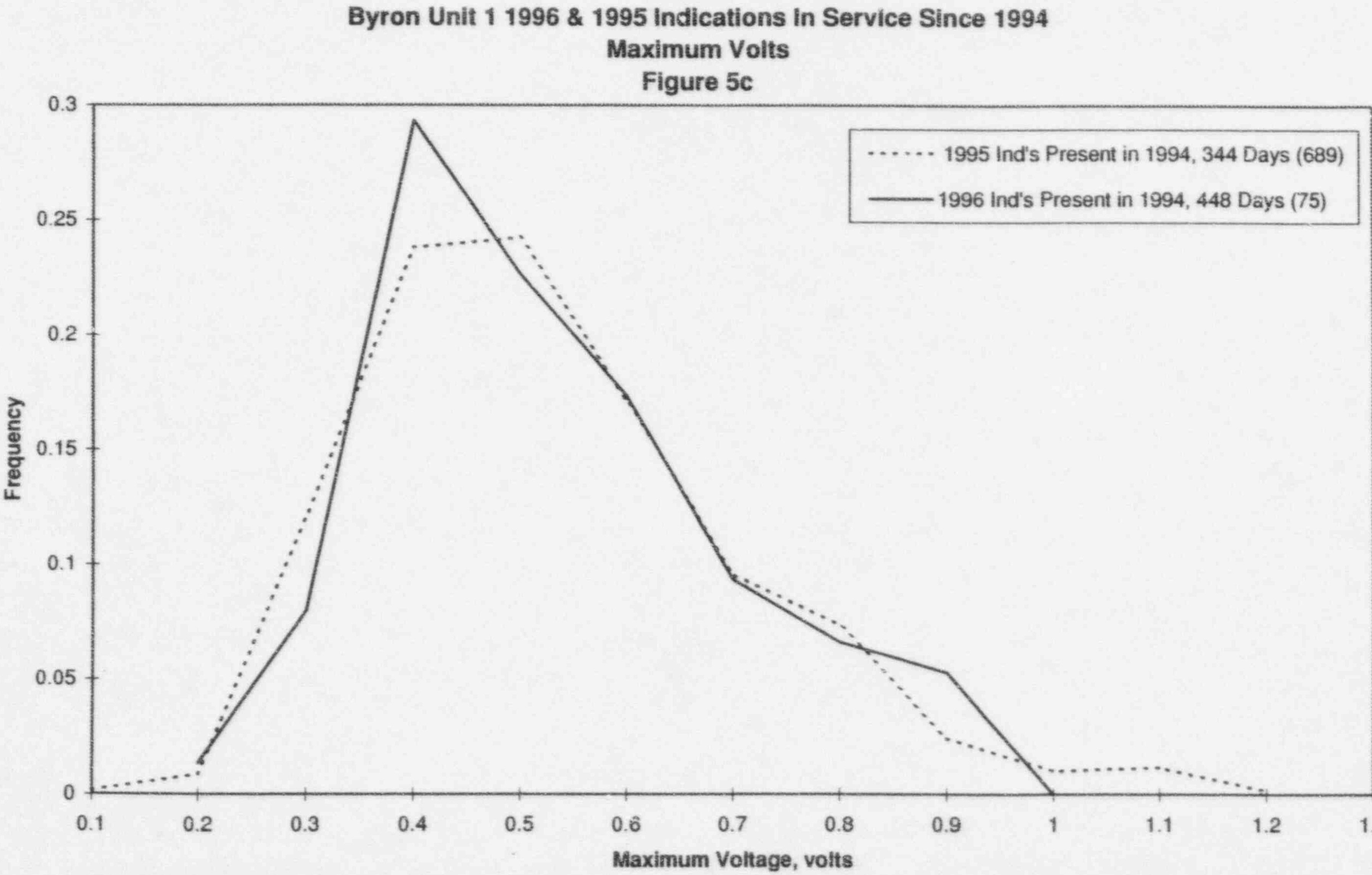


Conclusion: Significant Difference in the Short Cycle Growth Rate Distribution Compared to the Growth Rate Distributions Obtained from Full Cycle Operation

Evaluation of Byron Average Voltage Growth for Three Operating Periods
Figure 5b



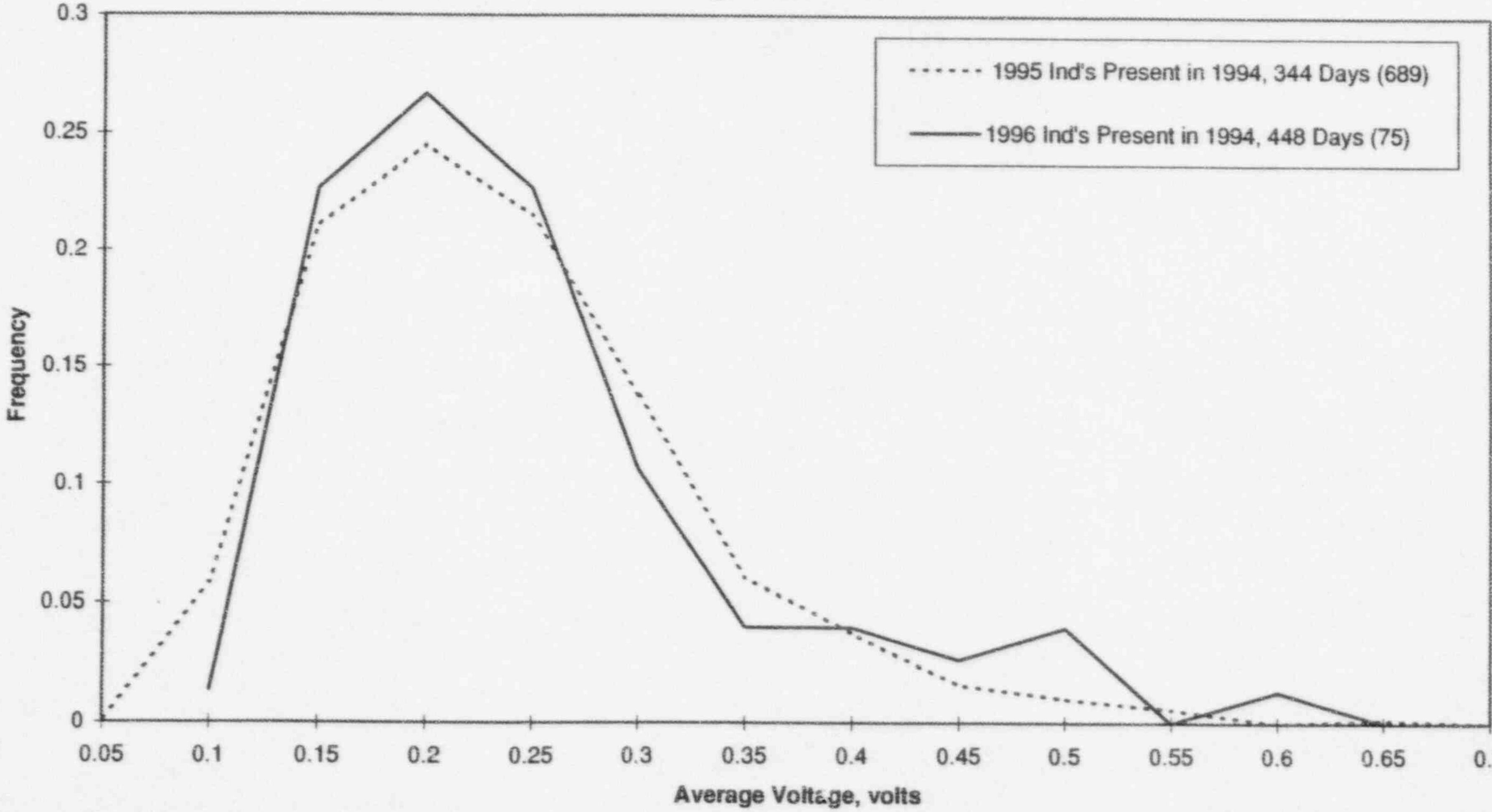
Conclusion: Significant Difference in the Short Cycle Growth Rate Distribution Compared to the Growth Rate Distributions Obtained from Full Cycle Operation



Conclusions: No Significant Difference in Size of Indications Present from 1994 - 1995 Compared to 1994 - 1996. This Indicates that Full Cycle Growth Rates are Appropriate for a Full Operating Cycle

VIRGRWTH.XLS

Byron Unit 1 1996 & 1995 Indications In Service Since 1994
Average Volts
Figure 5d



Conclusions: No Significant Difference in Size of Indications Present from 1994 - 1995 Compared to 1994 - 1996. This Indicates that Full Cycle Growth Rates are Appropriate for a Full Operating Cycle