Braidwood Unit 1

Cycle Length

Assessment Report Addendum

August 1, 1996

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Executive Summary

ComEd has performed further assessment of the Braidwood Unit 1 steam generator tube degradation to determine the appropriate operating cycle length. The objective is to document a technical basis for Braidwood 1 full cycle operation for a nominal 461 days above 500°F. This represents 165 days beyond ComEd's current commitment to the NRC of an October 15, 1996 mid-cycle steam generator inspection outage. ComEd has determined the requirements to demonstrate steam generator tube integrity, following the methodology of the upcoming steam generator rule, after full cycle operation to be:

1. The structural requirements of draft Regulatory Guide 1.121 must be satisfied,
2. Reactor coolant leakage must limit site boundary dose to a small fraction of 10CFR100 limits should a main steam line break (MSLB) event occur.

The assessment documented in this report uses new information resulting from work being performed for the ComEd/EPRI Circumferential Indication Repair Criteria Program. The new information includes;

1. Re-analysis using recently developed voltage integral software which determines an average indication voltage,
2. End of cycle (EOC) voltage distribution predictions following the methodology of NRC Generic Letter, GL 95-05 (Voltage Based Repair Criteria for Westinghouse Steam Generator Tubes Affected by Outside Diameter Stress Corrosion Cracking),
3. Review of industry tube pull/insitu pressure test indication voltages for development of an upper voltage bound structural limit for average and maximum, and
4. Development of a Braidwood site specific probability of detection (POD) to address Byron Unit 1 inspection improvements.

Based on this new information ComEd believes a technical basis is provided for Braidwood Unit 1 to operate full cycle (nominal 461 days above 500°F). The conclusions of the report are provided below.

The structural margin assessment demonstrates adequate margin will be maintained for the degradation distribution for 461 days of operation above 500°F at Braidwood Unit 1.

The leak rate analysis submitted in the previous Braidwood Unit 1 Cycle Length Assessment remains bounding, and demonstrates margin to site allowable leakage limits for the combined degradation mechanisms of top of the tube sheet circumferential cracks, F* (no leakage) and tube support plate ODSCC.

The additional 165 days of operation greater than 500°F does not reduce margin to structural or leakage integrity requirements.

Operation of Braidwood Unit 1 for a full cycle of 461 days of operation above 500°F does not challenge steam generator tube structural or leakage requirements.

Resolution of four items required for extension of the Braidwood Unit 1 mid-cycle steam generator tube inspection to October 15, 1996 are addressed throughout this report. These items are summarized below:

1. Insitu pressure/leak testing during a midcycle inspection. ComEd has analyzed Byron and Industry tube pull and insitu pressure test data to establish a relationship to NDE parameters in order to assess the integrity of Braidwood Unit 1 tubes after operation of 461 days above 500°F. This report demonstrates that operation of an additional 165 days above 500°F does not significantly reduce steam generator tube integrity.
2. Pull tubes concurrent with 3.0 volt IPC during upcoming refuel outage. ComEd will pull tubes with circumferential indications during the upcoming refuel outage in order to assess circumferential indication morphology. Results presented in this report regarding the relationship between eddy current parameters indicates that the circumferential indication morphologies at Byron Unit 1 and Braidwood Unit 1 are similar.
3. Plug circumferential indications upon detection. ComEd will continue to plug all circumferential indications detected.
4. Upcoming Braidwood Unit 1 steam generator tube inspection will be performed using inspection and analysis techniques equivalent to those used at Byron Unit 1 in 1996. An assessment of procedures and guidelines to assure an equivalent inspection is in process.

1.0 Introduction

The objective of this report is to document a technical basis for Braidwood 1 full cycle operation for 461 days above 500°F. This represents 165 days of operation beyond the currently approved October 15, 1996 mid-cycle inspection outage. The requirements which must be satisfied to demonstrate that steam generator tube integrity is maintained after full cycle operation are:

1. The structural requirements of draft Regulatory Guide 1.121 must be satisfied.
2. Reactor Coolant leakage must limit site boundary dose to a small fraction of 10CFR100 limits should a MSLB event occur.

The Braidwood Unit 1 full cycle operation assessment uses a combination of probabilistic and deterministic approaches. Sufficient data is available to predict a probabilistic end of cycle distribution; deterministic lower bounds are used to predict burst pressure and leakage. Additional supporting information for the deterministic approach is the information summarized in Section 2.0 that Byron Unit 1 level of degradation bounds Braidwood Unit 1.

This report provides new information which is the result of work being performed for the ComEd/EPRI Circumferential Indication Repair Criteria Program. The new information to be presented in this report includes:

1. Re-analysis using recently developed voltage integral software which determines an average indication voltage,
2. End of cycle (EOC) voltage distribution predictions following the methodology of GL 95-05 (Voltage Based Repair Criteria for Westinghouse Steam Generator Tubes Affected by Outside Diameter Stress Corrosion Cracking),
3. Review of industry tube pull/insitu pressure test indication voltages for development of an upper voltage bound structural limit for average and maximum voltage, and
4. Development of a Braidwood site specific POD to address Byron Unit 1 inspection improvements.

The Byron Unit 1 look-back information previously presented in the Braidwood Unit 1 Cycle Length Assessment (Reference 1) and an addendum to this report (Reference 2) is used to predict a realistic EOC voltage distribution of circumferential indications. The predicted EOC distribution is used to assess the steam generator tubes compliance to Regulatory Guide 1.121 and to site allowable leakage limits.

The structural margin assessment demonstrates adequate margin will be maintained for the degradation distribution for 461 days of operation above 500°F at Braidwood Unit 1.

The leak rate analysis submitted in the previous Braidwood Unit 1 Cycle Length Assessment remains bounding, and demonstrates margin to site allowable leakage limits for the combined degradation mechanisms of top of the tube sheet circumferential cracks, F* (no leakage) and tube support plate ODSCC.

The additional 165 days of operation greater than 500°F does not reduce margin to structural or leakage integrity requirements.

Operation of Braidwood Unit 1 for a full cycle of 461 days of operation above 500°F does not challenge steam generator tube structural and leakage requirements.

2.0 Review of Byron Bounds Braidwood

Information presented in References 1 and 2 develops the basis that Byron bounds Braidwood. Byron has demonstrated that there is substantial margin to safety limits after operation for a full cycle of 448.5 days above 500°F. The technical basis for this period of operation has been accepted by NRC. A summary of these two reports is provided below.

- Based upon look-back of 1996 0.080" Rotating Pancake Coil (RPC) data, there was slow growth of Byron Unit 1 1996 circumferential indications; after one full cycle of operation the maximum voltage of the distribution grew from 0.55 volts in 1994 to 1.11 volts in 1996. Based upon the number and size of indications, Byron degradation rates bound Braidwood.

- Byron Unit 1 tube pulls and insitu pressure testing demonstrated that structural integrity of the Byron steam generator (SG) tubes is not threatened. The size of the Byron Unit 1 indications bounds those detected at Braidwood Unit 1 and therefore structural integrity at Braidwood is not threatened.

- The increase in the number of indications at Byron Unit 1 in 1995 and 1996 are due to an inspection transient resulting from changes in inspection and analysis techniques and not from accelerated growth of indications. The number of indications at Braidwood Unit 1 has been adjusted by a POD to account for similar inspection transients.

- The number of Braidwood Unit 1 indications identified during the last Braidwood Unit 1 refueling outage, A1R05, (23) are far fewer than identified at Byron Unit 1 in their 1994 refueling outage (132), Byron Unit 1 mid-cycle (2578) inspection and the Byron Unit 1 1996 refueling outage (3478). Therefore Braidwood degradation is bounded by Byron.

- Inspections at Braidwood have detected and repaired circumferential indications well before they become structurally significant; the size of the largest indication detected decreased from 2.53 maximum volts to 1.36 maximum volts from the Spring to Fall 1995 outages.

- 1995 Byron tube pull indications had margin to the structural limit after minimally 342 days of operation above 500°F. In addition, the 1994 tube pull results support full cycle operation above 500°F, subsequently ComEd has demonstrated that structural integrity is maintained with significant margin after 448.5 days or longer with temperatures greater than 500°F.

- There was increased industry and ComEd awareness of circumferential indications during the Braidwood A1R05 inspection as a result of the Byron 1994 inspection where circumferential indications were first detected.

- The maximum estimated leak rate for Braidwood is 15.8 gpm during a MSLB (including leakage from TSP ODSCC and F*), using conservative assumptions, which is less than the

26.8 gpm site allowable limit (from Reference 1), based upon the new information, this analysis remains bounding.

- The chemical environment within the Braidwood Unit 1 SG's has not influenced the top of tube sheet initiation or the propagation of these indications (from Reference 1).
- Byron and Braidwood have had no measurable primary-to-secondary leakage attributed to circumferential cracks.
- Compared to industry circumferential indication experience, the number of Braidwood 1 circumferential indications is similar with other plants (from Reference 1).

3.0 Braidwood Inspection Evaluation

In order to form a technical basis for Braidwood Unit 1 full cycle operation, it must be demonstrated that the inspection performed during the fifth refueling outage (A1R05) was of a high quality to ensure the structural and leakage integrity of the steam generator tubes is maintained. The A1RO5 steam generator inspection was the last inspection prior to the current cycle of operation. The A1RO5 inspection used the three coil RPC probe (circumferential sensitive, axial sensitive and 0.080" RPC) with the ANSER analysis software. This was the second inspection using these techniques and was preceded by the 1994 Byron tube pull confirming the presence of circumferential cracks. The tube pull data resulted in a higher level of circumferential crack awareness at Braidwood.

An assessment of a predicted beginning of cycle (BOC) POD for the Braidwood Unit 1 A1RO5 outage, for use in determination of an EOC Braidwood Unit 1 voltage distribution, is presented in Appendix A.

3.1 Size of Indications Detected

Data obtained from the Byron Unit 1 1996 look-back analysis for SG C was used to assess the sensitivity of the 0.080" RPC to detect degradation levels before they challenge structural integrity (Defined in Section 5.4). This is determined by comparing the number of tubes where degradation was identified by both the +point and 0.080" RPC with the number of tubes where degradation was identified by the +point coil alone. The results from this comparison are shown in Figure 3.1 where the number of tubes identified by both +point and the 0.080" RPC, and the number of tubes identified by +point alone are shown as a function of the +point vert max voltage for each tube. The data represents tubes with indications detected and repaired in 1996. The broken line in Figure 3.1 represents indications which would have been detected if the 0.080" RPC was used alone. The solid line represents those indications which would not have been detected if the 0.080" RPC was used alone.

Figure 3.1 demonstrates that: (1) degradation was detected by both the +point and 0.080" RPC for the largest degradation levels where the +point voltages are greater than approximately 0.98 volts, (2) most flaws (>80% +point detected flaws) detected by +point also were detected by the 0.080" RPC for +point voltages from 0.8 to 1 volt, and (3) approximately half the degraded tubes that

were detected by +point were detected by the 0.080" RPC for voltage in the range from 0.6 to 0.8 volts. The +point coil identified substantially more tubes as being degraded than did the 0.080" RPC for voltages less than 0.5 volts.

Industry experience over the past 6 years also supports that indications which may challenge structural integrity are found and removed from service the first time steam generator tubes are inspected with a coil sensitive to circumferential indications. Because growth rates are low (from Byron look-back results), large indications do not occur in one cycle of operation. This experience is supported by the inspection results at Byron and Braidwood Units 1.

Table 3.1 presents information on the largest average and largest maximum voltages detected at Byron and Braidwood Units 1 for the inspections completed to date. This data demonstrates that indications which could challenge the structural/leakage integrity of the tubes have been detected and repaired and the size of indications being detected is smaller in each successive inspection.

3.1.1 Conclusions

1. Growth rates for OD initiated circumferential cracks at the roll transition are low.
2. Circumferential indications in tubes have been detected and repaired using 0.080" RPC well before they challenge structural/leakage integrity.
3. Based upon Byron Unit 1 look-back results, all +point vertical maximum voltages greater than 1 volt can be detected with 0.080" RPC.
34 Braidwood Unit 1 look-back results demonstrates for the largest 10/95 voltage circumferential indication a signal is present in the 2/95 inspection data.

3.2 Inspection Comparison to Byron

In addition to the probe improvements discussed above, the inspections performed at Braidwood Unit 1 used ANSER analysis software. Analysts using ANSER analysis software have been used throughout the industry and have been successful in detecting circumferential indications before they challenge the structural limit, following full cycle operation. An evaluation of the detectability of indications using ANSER compared to EddyNet95 was performed. The comparison to EddyNet95 is being made because it may have contributed to an inspection transient at Byron Unit 1 1996. Figures 3.2, 3.3 and 3.4 show the eddy current testing (ECT) analysis graphics for small, medium and large indications as detected by ANSER and EddyNet95. The graphics show that the indications are detectable using ANSER but not as pronounced as with the filter capabilities of EddyNet95. The maximum voltages of the indications are consistent between ANSER and EddyNet95.

As stated above, it was concluded in Reference 2 that the large number of indications detected at Byron in 1996 were the result of an inspection transient. The inspection transient was partly due to the use of the +point probe, filter capabilities of EddyNet95 which was used in 1996 (ANSER was used in 1995) and partly due to improved analyst sensitivity to circumferential indications, gained through experience from Byron Unit 1 1995 tube pulls. Appendix A provides further evaluation of the differences in inspection techniques between Braidwood Unit 1 and Byron Unit 1 and the resulting site specific Braidwood Unit 1 POD.

3.2.1 Conclusion

Improvements in analysis tools and analyst sensitivity have improved detection of circumferential indications. Small indications are detectable with the use of ANSER analysis software. Analysts using ANSER analysis software have been used throughout the industry and have been successful in detecting circumferential indications before they challenge the structural limit, following full cycle operation. Appropriately trained analysts using 0.080" RPC and the specific ECT procedures applied in the look-back have and will succeed in detecting all circumferential indications before they challenge structural integrity.

4.0 Average Voltage

4.1 Basis for Average Voltage

Eddy current maximum voltage is one of the primary non-destructive examination NDE parameters used to assess the condition of steam generator tubes. This parameter has proven to be an effective indicator of degradation in steam generator tubes for a wide range of degradation mechanisms and morphologies. For circumferential cracking, maximum voltage can be an effective indicator for structural and leakage integrity assessments, 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. This morphology is prevalent in most OD circumferentially cracked tubes. However, service experience indicates there can be a small percentage of the tubes where the circumferential crack front is essentially symmetric. In these instances, maximum voltage may underestimate the level of degradation, by measuring the eddy current response over a portion of the tube circumference, and does not characterize the degradation over the entire tube circumference at one time. Average voltage provides a measure of the average degradation over the entire tube circumference, and can be used as a compliment to maximum voltage to ensure symmetrical crack fronts are properly assessed.

ComEd evaluated an average voltage relationship and its possibilities for establishing a comparison criteria for voltage versus burst and pressure tests (Section 6.0). An objective of this evaluation included correlating data with test results from consecutive eddy current inspections as well as industry tube pulls and insitu pressure test tubes.

4.1.1 Conclusions

Average voltage can be used with maximum voltage in predicting EOC distributions for use in assessing steam generator tube integrity to ensure that all crack morphologies are assessed.

4.2 Average Voltage Look-Back and Re-analysis

4.2.1 Introduction

ComEd performed a look-back and re-analysis evaluation of the Byron and Braidwood Unit 1 circumferential tube sheet indications detected during previous eddy current inspections. An eddy

current evaluation was also performed on industry insitu pressure test and tube pulls data from different utilities. All of the eddy current evaluations were performed using a Voltage integral (voltage averaging) software developed by Zetec, Inc. The maximum voltage from the integral voltage software were also calculated as part of the evaluation. The objectives of the look back are to:

1) determine the maximum and average voltage for the indications at Braidwood and Byron Unit 1,
2) assess the average and maximum voltage growth, and
3) compare the average voltage results to structural data.

4.2.2 Scope

The look-back analysis consisted of analyzing the 0.080" RPC and +Point data for indications detected during the 1995 (SG B) and 1996 (SG C) eddy current inspections. One hundred three (103) indications identified during the 1994 eddy current inspection were re-analyzed with the 0.080" RPC probe. Re-analysis of thirty-nine (39) Braidwood Spring and Fall 1995 0.080" RPC indications was performed for all SG's. Fifty-Six (56) industry tubes that were either pulled, pressure or burst tested were re-evaluated. Further discussion of the industry tubes is presented in Section 6.0

4.2.3 Voltage Integral Discussion

A voltage integral value is the area between the plot line and the voltage threshold line (see Figure 4.1a) and is calculated with respect to one complete circumferential scan line that produces an average voltage. These measurements are made in conjunction with the Eddynet95 RPC program and are discussed in more detail below.

4.2.4 Voltage Integral Features

a. Plotting a single circumferential plot line in the voltage integral window requires an initial active data plot in the RPC C-scan window of Eddynet95 Figure 4.1a. This plot line has been nulled or "zeroed" with respect to the lowest data point in the line by the software. This plot line is selected for the largest vertical component of the indication.

b. A Volts-at-cursor plot is calculated as the difference between the vertical voltage threshold line and the data value where the cursor intersects the circumferential plot line.

c. When a voltage integral plot is performed by selecting a Plot Cursor Scan, the program calculates and displays the voltage integral value. The voltage integral value is the area between the plot line and the voltage threshold line. This value is calculated with respect to one complete circumferential scan. Examples: A straight line elevated to a constant voltage value of 1.0 volts over the entire circumference of the tube would yield a voltage integral value of 1.0 volts. A straight line elevated to a constant voltage value of 1.0 volts over one-half of the entire circumference of the tube, then dropping to 0.0 volts for the remaining half of the tube would yield a voltage integral value of 0.5

volts. This would effectively have half of the area between the plot line and the threshold line as would the first example plot.

4.2.5 Voltage Integral Measurements

Voltage integral measurements are derived from a plot defined as a single circumferential scan plot.

For each adjacent data point pair in the scan, the arithmetic mean (average) of the vertical components for the two points is computed. This value is divided by the total number of data points between the start and end locations of the scan. All of these values are summed. This is the data point average sum. The voltage integral value is the data point average sum multiplied by the voltage scale. This value is the same as the area underneath the circumferential scan line.

4.2.6 Voltage Integral Data Analysis Guidelines

The look-back and re-analysis evaluation for the Byron Unit 1 circumferential indications reported during the 1995 and 1996 eddy current inspections were performed by Rockridge Technologies Inc., at Benecia California from June 17 - June 25, 1996. The Braidwood Unit 1 and Industry tube evaluations were performed by ComEd's Level III ECT analysts. Data analysis guidelines were developed and administered prior to the look-back evaluation. The course included eight hours of classroom instruction, with an additional eight hours of hands-on training with the voltage integral software.

The purpose of the guidelines is to provide general instructions and to define specific requirements for the look-back analysis. The look-back analysis guidelines were developed to provide a structure to ensure the data is analyzed (a) in accordance with the appropriate techniques and practices that reflect current industry experience, (b) in a consistent and repeatable manner, and (c) in compliance with ComEd requirements.

To provide voltage consistency, the voltage was normalized on the 100% axial notch to 20 volts peak-to-peak for the 0.080" pancake coil in the main Eddynet95 Lissajous window as shown in Figure 4.1b. After setting the 0.080" pancake coil to 20 volts, the set volt units in the circumferential lissajous RPC window was set to the Circumferential to Main Eddy in the Circumferential Voltage Scale Menu popup.

After the normalization was performed, the data was analyzed in the RPC display. A C-Scan display was plotted for the expansion region of interest as shown in Figure 4.1c. Using the Axial and Circumferential Strip Chart Cursors, isolate the C-Scan line associated with the maximum vertical channel displacement as shown in Figure 4.1c. Clicking the Plot Cursor Scan button in the RPC Voltage Integral display window replicates the circumferential line scan generated in the main RPC DISPLAY. The cursor is then positioned to the maximum vertical displacement as shown in Figure 4.1d. The Volts-at-Cursor will change as the cursor is moved along the trace while the Voltage Integral value remains constant. The circumferential line-scan baseline trace determines the zero reference point for voltage measurements.

For consistency, the data analysts were instructed to suppress a circumferential scan line above the tube sheet which was free of any possible indications. The chosen 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 that occur consistently in each scan line.

Reporting the voltage values was accomplished by using the Report Entry display. Pressing the RPT ENTRY button activates the Report Entry Display with the Voltage Integral value automatically entered in the ARC field. Also included in the report was the Volts-At-Cursor "maximum voltage" using a vertical maximum measurement from the circumferential lissajous window. The analyst would type the three letter code "MAX" in the percent field of the report entry display.

4.3 Average Voltage Look-Back Results

Figures 4.2a and 4.2b show the average and maximum voltage distributions for the Braidwood Spring 1995 mid-cycle and Fall 1995 refueling outage. These distributions are increased by a POD of 0.2 to address inspection and analysis improvements made since the inspection was performed. This POD is discussed in more detail in Appendix A. The Braidwood Unit 1 distribution is discussed in more detail in Section 5.0.

Figures 4.3 and 4.4 show the average and maximum voltage growth for the Byron Unit 1 indications. Braidwood Unit 1 growth rates were not calculated due to difficulty converting the 2/95 data for the 10/95 indications, efforts will continue to convert and analyze the data to assess growth rates for the 10/95 circumferential indications. The Byron Unit 1 growth rates were used in the Braidwood Unit 1 cycle length assessment discussed in more detail in Section 5.0. It is important to note that the 1996 Byron Unit 1 population of SG C 0.080" RPC circumferential indications is much smaller than 1995 (see Figure 3 of Reference 2).

A comparison of the average voltage to the maximum voltage is presented in Figure 4.5 for Byron Unit 1 1996 SG C 0.080" RPC indications and Figure 4.6 for all Braidwood Unit 1 2/95 and 10/95 0.080" RPC indications. The figures show a good relationship between the average voltage and the maximum voltage determined during the average voltage look-back. This relationship is expected because of the crack morphology of the Byron tube pulls which show many short non-coplanar cracks in a band typically around the circumference of the tube and not a single deep crack. A tube with deep cracks, corresponding to a large maximum voltage, would, in this case, also have a large average voltage. As discussed above, the average voltage look-back software selected the null point for calculation of the maximum voltage. This feature provides a more consistent analysis and reduces the analyst variability. The fact that the slopes of the average voltage versus maximum voltage for Byron Unit 1 and Braidwood Unit 1 are similar leads to a conclusion that the degradation morphology is similar.

As discussed in Reference 2, the tube with the most limiting circumferential indication detected at Byron or Braidwood was identified as being row 23 column 44 from steam generator at Byron. This was based upon maximum voltage and tube pull metallographic crack sizing results. This tube was pulled in 1994. During re-evaluation of industry tube pull data using the average voltage software and normalized to the same procedure, this tube has a maximum voltage of 4.14 volts compared to the 5.5 volts using previous techniques. This does not change the conclusions that this is the limiting tube indication detected at Byron or Braidwood and the other indication voltages detected are significantly smaller than this indication. The next largest 0.080" RPC indication

maximum voltage is 2.53 volts at Braidwood and 2.23 volts at Byron, both detected the first time a 100% top of tube sheet (TTS) RPC inspection was performed.

5.0 Structural Integrity Evaluation For Braidwood

The following summarizes the evaluation procedure used to demonstrate that Braidwood can operate for one full cycle (461 days above 500°F).

- Demonstrate that the 0.080" RPC used during the previous inspection for Braidwood Unit 1 has a POD that ensures structurally significant defects were detected and removed from service in a manner equivalent to the inspection technology used at Byron.
- Determine a POD that reflects the inspection technology used at Braidwood relative to that used at Byron.
- Determine a BOC distribution for Braidwood that is equivalent to that which would have been found if the Braidwood SG's were inspected using technology similar to that used at Byron.
- Predict the degradation distribution at Braidwood at the end of one complete cycle of operation (461 days of operation above 500°F) using: (1) the Braidwood BOC and POD, which have been adjusted to simulate an inspection technology equivalent to the Byron inspection, (2) the degradation growth rates from look-back to 1994, 1995, and 1996 SG B and SG C inspection results from Byron Unit 1, (3) analyst uncertainty obtained from the blind test of Byron tubes, and (4) probe wear from a study performed of the Byron 1996 Unit 1 ECT data.
- Demonstrate that Industry and Byron experience bounds the predicted EOC degradation distribution at Braidwood and there is an adequate level of safety for the EOC degradation distribution after one complete cycle of operation.

5.1 Detection Capability and POD

The results from the 1996 and 1995 inspections at Byron were used to assess the inspection capability of the inspection techniques used at Braidwood and to define a POD for the 0.080" RPC relative to the +point coil.

An overall POD was defined for the inspection technology used at Braidwood in October of 1995 relative to the inspection technology used at Byron during the 1996 inspection. The POD was defined from consideration of the differences in the coils (+point vs. 0.080" RPC) and differences in the analyst sensitivity and software used to evaluate the data (EddyNet95 vs. ANSER). The calculation of an overall Braidwood Unit 1 POD, based upon Byron Unit 1 inspection data, is presented in Appendix A. The result is that a conservative POD of 0.20 is applicable to the Braidwood Unit 1 Fall 1995 inspection.

5.1.1 Conclusion

A conservative POD of 0.20 is applicable to the Braidwood Unit 1 Fall 1995 SG tube ECT inspection and addresses the Byron Unit 1 inspection improvements not utilized at Braidwood Unit 1 during the last inspection.

5.2 Braidwood Unit 1 Degradation Distribution and Comparison With Byron Inspection Results

Table 5.1 summarizes the February and October 1995 inspection results for Braidwood Unit 1. As indicated by the table, very few tubes with circumferential indications were identified during the inspections (16 tubes in February 1995 and 23 tubes in October 1995). The voltage data in Table 5.1 was obtained by re-analysis of the circumferential indications using the new Zetec average voltage software. A 100% hot leg TTS RPC inspection of each steam generator at Braidwood Unit 1 was performed to detect the indications.

Figures 5.1 and 5.2 present a comparison of the frequency distribution for the Braidwood Unit 1 inspection results adjusted for the POD and the inspection results obtained at Byron Unit 1 for steam generator B in October of 1995 for vertical maximum and average voltage, respectively. The information in Figures 5.1 and 5.2 demonstrate that the initial inspection at Braidwood Unit 1 in February of 1995 with the 0.080" RPC detected the largest and most structurally significant flaws. These flaws were removed from service. The figures also show that the degradation levels at Braidwood Unit 1, adjusted for POD, are within the degradation levels at Byron Unit 1.

Because the degradation at Braidwood Unit 1 is bounded by the degradation at Byron Unit 1 in size and number of indications the Byron Unit 1 growth rates can be used for application in predicting a Braidwood Unit 1 EOC voltage distribution.

5.2.1 Conclusion

The Braidwood Unit 1 February 1995 inspection techniques detected the largest and most structurally significant flaws and removed them from service. Braidwood Unit 1 indication distribution is bounded by Byron Unit 1.

5.3 End of Cycle Distribution For Braidwood Unit 1

The procedure used to predict the EOC voltage distribution for Braidwood after one full cycle of operation (461 days above 500°F) followed the methodology in NRC GL 95-05 and implemented in Byron and Braidwood IPC submittals (WCAP-14277), or

$$N_i = N_{di} / POD - N_{ri} , \qquad (1)$$

where

N_i = the number of flaws at the beginning of the up coming cycle for the ith degradation level,
N_{di} = the number of flaws detected by NDE at the ith degradation level, and
N_{ri} = the number of flaws repaired at the ith degradation level.

Implementing repair on detection, i.e., $N_{di} = N_{ri}$, Eq. 1 becomes

$$N_i = N_{di} (1/ POD - 1). \quad (2)$$

A POD = 0.20, as described in Appendix A, and the N_{di} vertical maximum and average voltage distributions presented in Table 5.1 for the Braidwood October 1995 inspection were used in Eq. 2 to obtain the BOC distributions.

The BOC voltage distribution represented by Eq. 2 was adjusted for probe wear, analyst uncertainty, and degradation growth rate to determine the EOC distribution following the methodology in GL 95-05. The probe wear and analyst uncertainty were developed as normal distributions, the standard deviations for probe wear and analyst uncertainty were 0.06 and 0.20, respectively. No cut off of the distribution tails were used for either of the distributions. The bases for the probe wear and analyst uncertainty are presented in Appendix A.

The degradation growth rates were obtained from look-back to 1994, 1995 and 1996 Byron inspection results using the methodology in GL 95-05. The combined growth rates from the inspections are presented in Figures 4.3 and 4.4 for average voltage and, vertical maximum voltage respectively. Consistent with GL 95-05, the negative growth rates seen in the figures were set equal to zero for development of the EOC distribution.

The EOC voltage distributions for vertical maximum and average voltage were obtained using a Monte Carlo sampling procedure. The results from the computations are presented in Figures 5.3 and 5.4 for average voltage and, vertical maximum voltage respectively, where the EOC distribution is presented along with the adjusted number of flaws detected by the 0.080" RPC as described in Section 5.2.

5.3.1 Conclusion

Conservative EOC voltage distributions are predicted using the methodology of GL 95-05 for use in structural (Section 5.4) and leakage assessments (Section 7.0).

5.4 Structural Margins

An assessment was made to determine if there was adequate structural margin for the predicted EOC voltage distribution. To accomplish this evaluation, relationships between burst pressure and vertical maximum and average voltages were determined from available Byron (including two EDM simulations) and industry burst tests for pulled tubes and insitu tested tubes. These relationships are presented in Figures 5.5 and 5.6 for average and vertical maximum voltages, respectively. These relationships were developed using lowest tolerance level (LTL) material strength properties (Braidwood Unit 1, 95/95 lower bound properties at 650°F divided by industry room temperature sample mean (Reference 3)), to adjust burst/insitu pressures, and a curve that bounds all of the LTL burst points. Further discussion on this assessment is presented in Section 6.0.

The structural limit for Braidwood was based on the margins specified in Regulatory Guide 1.121, i.e., the higher of 1.43 times postulated faulted load and 3 times normal operating pressure differential. For Braidwood, the limiting condition is 3 times the normal operating pressure differential which is 4,035 psi.

Tubes with voltages less than or equal to the structural limit at EOC have adequate margin of safety against burst. Tubes with voltages greater than the structural limit at EOC must be evaluated to determine if there is adequate margin against burst.

The basis for this evaluation is that the conditional probability of burst is acceptably low for the sum of all tubes with voltages beyond the structural limit at EOC. Because a statistically based burst correlation cannot be developed with the available data, the sum of the voltage frequencies beyond the structural limit is used to assess the margin. The acceptance criterion is that the sum of all frequencies for voltages beyond the structural limit is less than $2x10^{-2}$ per steam generator.

The value of $2x10^{-2}$ has been defined to limit the number of tubes with voltages beyond the structural limit, and to be consistent with the criterion that the conditional probability of burst for the sum of the tubes with voltages beyond the structural limit is less than approximately 10^{-4}. The sum of the frequencies equal to $2x10^{-2}$ was selected to maintain frequencies no greater than 10^{-2} to 10^{-3} near the structural limit where the burst probability would be less than 10^{-2}, and frequencies no greater than 10^{-3} to 10^{-4} for higher voltages where the burst probability would be greater than 10^{-2}. In addition, this criterion limits the number of tubes with voltages greater than the structural limit to 2% or less of the total number of tubes in the EOC distribution. It also ensures that the large majority of tubes have voltages significantly less than the structural limit, and consequently, have low burst probabilities.

Ninety Nine (99) percent of the Braidwood Unit 1 EOC indications have voltages less than the structural limit. The sum of the frequencies for voltages beyond the structural limit for all four steam generators at EOC for Braidwood is $6.6x10^{-3}$ and $1.1x10^{-4}$ for average and maximum voltages, respectively. Consequently, it is concluded that the EOC distribution for Braidwood has acceptable structural integrity.

5.4.1 Conclusions

The voltage structural limit for the limiting pressure of 4,035 psi is shown on Figures 5.5 and 5.6. The results from the margin assessment are summarized in Table 5.2.

Table 5.2. Results of Structural Margin Assessment

Parameter	Vertical Maximum Voltage	Average Voltage
Structural Limit Voltage	3.64 volts	0.91 volts
Limit for Sum of Voltage Frequencies > Structural Limit (per Steam Generator)	2.0×10^{-2}	2.0×10^{-2}
Sum of Voltage Frequencies > Structural Limit (461 Days)	1.1×10^{-4}	6.6×10^{-3}
Sum of Voltage Frequencies > Structural Limit (296 Days)	1.09×10^{-4}	3.7×10^{-3}

The results from the structural margin assessment presented in Table 5.2 demonstrate that the structural criteria were met for both the vertical maximum and average voltages, and adequate margin will be maintained for the degradation distribution through the end of 461 days of operation above 500°F at Braidwood.

Based upon distribution of indications detected at Braidwood and Byron Unit 1, presented in Reference 2, this distribution represents significant conservatism in the tail of the EOC distribution.

The change in the EOC voltage distribution from the currently approved October 15, 1996 mid-cycle to the refueling outage scheduled 165 days later is presented in Figures 5.7 and 5.8 for maximum and average voltage, respectively. The results in the Figures and Table 5.2 indicate that there is no significant reduction in margin from an October 15, 1996 mid-cycle inspection to a March 29, 1997 refueling outage.

6.0 Industry Tube Pull/Insitu Pressure Test Voltage Analysis

6.1 Scope of Review

Voltage analysis of industry outside diameter top of the tube sheet circumferential indications, which were pulled or insitu pressure tested, was performed. The analysis was performed to determine an EOC voltage limit for tubes with circumferential indications, to demonstrate compliance to Regulatory Guide 1.121 structural limit of three times NOP differential, or 4035 psi. A breakdown of available industry tube pulls and insitu pressure testing ECT data is provided in Table 6.1. EddyNet95 was used for the analysis.

6.2 Correction Factors

In order for the analysis to provide consistent results between plants three correction factors were anticipated. The first correction factor addresses the voltage normalization. The second correction factor was for tube wall thickness. Tubes with wall thickness of 0.043 and 0.048 inch are included in the industry data-base. The third correction factor addresses the difference between data acquired with the 0.080" RPC Vs. the 0.115" RPC.

6.2.1 Voltage Normalization Correction Factor

Voltage normalization was addressed by setting the voltage to 10 volts on the 100% through wall ASME drilled hole which was available on all calibration standards with the exception of Byron Unit 1 tube pull R23C44. Because the Braidwood Unit 1 and Byron Unit 1 look-back and re-analysis were normalized by setting the voltage to 20 volts on a 100% EDM axial notch, a correction was required. The correction factor was determined by the following procedure:

1. Set volts to 20 volts on a 100% axial EDM notch
2. Read voltage of the 100% through wall hole = X volts
3. X volts /10 volts = voltage normalization correction factor

Check data:

4. Set volts to 10 volts on a 100% through wall hole
5. Read voltage of the 100% axial EDM notch = Y
6. 20 volts/Y = voltage normalization correction factor

The voltage normalization correction factor was calculated using calibration standards used for analysis of Byron, Braidwood, ANO and Calvert Cliffs data. The voltage normalization correction factor used to compare the industry tube pull analysis data to Braidwood and Byron Unit 1 look-back data is 0.58. Byron tube R23C44 was analyzed with a normalization of 20 volts on the 100% through wall EDM axial notch with no correction required.

6.2.2 Tube Wall Thickness Correction Factor

In order to assess the voltage affects of tube wall thickness, the voltage of the 100% axial EDM notch and 100% drilled through wall hole were measured for tubes of different wall thickness, after consistent voltage normalization. The voltages from the different tube wall thicknesses were similar (Byron (0.043"), Braidwood (0.043"), ANO (0.048"), and Calvert Cliffs (0.048"). Therefore no voltage correction for tube wall thickness was required. All tubes analyzed were 3/4 inch and therefore no correction for tube diameter is required.

6.2.3 Rotating Pancake Coil Correction Factor

Based upon Byron Unit 1 1996 look-back results, on average, the 0.115" RPC voltage is 24% greater than the 0.080" RPC voltage. Therefore, the 0.115" RPC voltages are corrected by a factor of 0.76.

6.3 Conclusions

The average and maximum voltage is plotted in Figures 5.5 and 5.6 against pressure for tubes which have been burst or insitu pressure tested. The voltages have been adjusted for normalization to 20 volts on the 100% through wall EDM axial notch (same normalization of Byron and Braidwood look-back re-analysis) and for differences in coil (0.115" vs. 0.080" RPC). No corrections were required for wall thickness or tube diameter (all tubes 0.75 inch). Test pressures have been adjusted using LTL material strength properties (Braidwood Unit 1 95/95 lower bound properties at 650°F divided by industry room temperature sample mean (Reference 4)). From this data, curves are drawn to establish an upper bound voltage limit for the Regulatory Guide 1.121 structural limit of three times normal operating differential pressure (4035 psi) and for the main steam line break limit (2560 psi). These limits are identified in Table 5.2. The data points for insitu pressure testing represent the lower limit for the test since the tubes were not taken to burst. The actual burst pressure of the tubes is bounded by this point.

As discussed in Section 4.3 a relationship between average and maximum voltage (Figure 6.1), similar to Byron Unit 1 and Braidwood Unit 1, exists. This implies a similar degradation morphology between industry circumferential cracks.

7.0 Leak Rate Analysis

Figure 7.1 shows the leak rate measured from industry tube pull leak testing and insitu pressure testing versus the indications maximum voltage. The leak rates have been normalized to operating temperature and the MSLB pressure of 2560 psi. The voltages were obtained as discussed in Section 6.0. Maximum voltage provides a good 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 maximum voltages for which leakage has been detected through tube pull leak testing and insitu pressure testing (Figure 7.1) is greater than 1.1 volts with a maximum leakage of all tests of 0.162 gpm. The number of tubes from the Braidwood Unit 1 EOC distribution above this threshold is 25. The leak rate assessment provided in Reference 1 remains conservative and demonstrates that the maximum estimated leak rate for TSP ODSCC, TTS degradation, and F* mechanisms of 15.8 gpm during a MSLB, using conservative assumptions, is less than the 26.8 gpm site allowable limit (takes credit for Technical Specification reduced primary coolant iodine levels).

7.1 Conclusions

The leak rate analysis submitted in Reference 1 remains bounding and demonstrates the margin to site allowable leakage limits for the combined degradation mechanisms of top of the tube sheet circumferential cracks, TSP ODSCC, and F*.

8.0 Braidwood Inspection Improvements

The next TTS inspection to be performed at Braidwood Unit 1 will be comparable to the inspection performed at Byron Unit 1 in 1996 with regards to probe, analysis software and analyst training. This will include using the plus point probe with the plus point, 0.080" and 0.115" RPC. The analysis software to be used is still being evaluated. The Braidwood Unit 1 inspection will be performed to the same guidelines as Byron's 1996 inspection. Training of analysts will be performed to these same guidelines and Byron Unit 1 1996 and Braidwood Unit 1 1995 data will be used for the analyst site specific performance demonstration test.

9.0 Conclusions

The results from the structural margin assessment presented in Table 5.2 demonstrate that the structural criteria were met for both the vertical maximum and average voltages, and adequate margin will be maintained for the degradation distribution through the end of 461 days of operation above 500°F at Braidwood.

The change in the EOC distribution from the currently approved October 15, 1996 mid-cycle to the refueling outage scheduled 165 days later does not significantly reduce the margin to the structural requirements.

The leak rate analysis submitted in Reference 2 remains bounding and demonstrates the margin to site allowable leakage limits (a small percentage of 10CFR100 limits) for the combined degradation mechanisms of top of the tube sheet circumferential cracks, TSP ODSCC, and F*.

Operation of Braidwood Unit 1 for a full cycle of 461 days does not challenge steam generator tube structural requirements.

Steam Generator tubes with TTS degradation will be repaired.

10.0 References

1. Braidwood Unit 1 Cycle Length Assessment Report, Transmitted to U.S. NRC February 23, 1996
2. Braidwood Unit 1 Cycle Length Assessment Report Addendum, Transmitted to U.S. NRC May 17, 1996
3. EPRI Draft Report NP-6864-L Revision 2, Dated August 1993, PWR Steam Generator Tube Repair Limits: Technical Support Document for Expansion Zone PWSCC in Roll Transitions

Appendix A

End Of Cycle Distribution Calculation Inputs

A.1 Braidwood Unit 1 Site Specific POD Calculation

The results from the 1996 and 1995 inspections at Byron Unit 1 were used to assess the inspection capability of the inspection techniques used at Braidwood and to define a POD for the 0.080" RPC relative to the +point coil.

An overall POD was defined for the inspection technology used at Braidwood in October 1995 relative to the inspection technology used at Byron Unit 1 during its 1996 inspection. The POD was defined from consideration of the differences in the coils (+point vs. 0.080" RPC) and differences in the analyst sensitivity and software used to evaluate the data (EddyNet95 vs. ANSER). The calculation of an overall Braidwood Unit 1 POD based upon Byron Unit 1 inspection data is presented here. The result is that a conservative POD of 0.20 is applicable to the Braidwood Unit 1 Fall 1995 inspection.

Two Methods were Used to Determine a Braidwood Unit 1 POD:

<u>Method 1:</u>

1. As reported in Reference 2, 78 percent of 1996 plus point indications were present in the SG C look-back to 1995 using the EddyNet95 software. The original 1995 analysis was performed with ANSER and without the knowledge of the 1995 Byron Unit 1 tube pulls. Applying the 78% factor to the 860 repaired SG B 1996 indications results in 670 additional indications which could have been detected in 1995 if the conditions of the 1996 inspection were present in 1995. Because the plus point probe was used in both 1995 and 1996, this represents improvements due to the software and analyst sensitivity, which were the major changes between inspections.

2. During the look-back of SG B 1995 indications, it was determined that 745 of the 978 SG B 1995 +point indications were present in 1995 with 0.080 RPC data. This represents improvements due to use of the +point probe in 1995, the first inspection with +point.

3. Combining the data provides a 0.080" RPC POD for the 1995 inspection at Byron. This value also represents the improvements between the Byron 1 1996 inspection and the Braidwood 1 Fall 1995 inspection which was performed with the RPC probe (no plus point coil), without experience gained from Byron 1 1995 tube pulls and with ANSER software. The POD calculation for SG B is shown below:

$$\frac{\text{Number of 1995 SG B Repaired 0.080" RPC Ind's}}{\text{Total Number of 1995 SG B Repaired Ind's + Number of 1996 Ind's Present in 1995}}$$

$$\frac{745}{978 + 670} = 0.45$$

This results in a POD of 0.45 to address differences from the inspection at Byron Unit 1 and Braidwood Unit 1 in 10/95. This POD multiplied by a POD of 0.6 to address other unknown issues for use at Braidwood Unit 1 provides an overall POD of 0.27.

Method 2:

1. 1996 Indication look-back showed that 34% of 1996 indications are detectable with the 0.080 RPC. Therefore a POD of 0.34 could be used.

2. Using a POD of 0.33 is conservative. The 1996 Byron Unit 1 inspection is the second inspection using the plus point probe. The size of the indications detected and repaired in 1996 is smaller than those detected and repaired in 1995, so it is expected that a smaller percentage of the plus point indications to be detected with the 0.080" RPC in 1996 than 1995 based on Figure 3.1. Sixty seven percent of plus point indications had an 0.080" RPC indication in 1995.

Use of 0.34 combined with a POD of 0.6 to address other unknown issues for use at Braidwood Unit 1 results in an overall POD of 0.20 for all voltage ranges.

The value of this overall POD is dominated by the smaller levels of degradation and is realistic for small flaws. The results in Figure 3.1 indicate that a POD of close to 1 is more representative for larger flaws, and that using POD = 0.20 will be very conservative for tubes with relatively large degradation levels.

A.2 NDE Uncertainty

Two factors were considered for NDE uncertainty input into the cycle length assessment. The two factors being probe wear and analyst variability.

A.2.1 Probe Wear

An assessment to quantify the effects of probe wear on indication voltages was performed. The probe wear was determined from the trends of calibration group voltages from the first tube to the last tube in the calibration group. During SG tube inspection analysis, voltages are normalized for each calibration group and therefore this trend represents the greatest indication probe wear uncertainty which could occur. The results of the assessment are presented in Table A.1 and A.2.

Data from the 0.080"RPC on the plus point probe for the Byron Unit 1 1996 Inspection was used in the assessment. Table A.1 identifies the voltage of the 100% EDM notch for the first tube and the last tube for different calibration groups. Table A.2 identifies the voltage of the 100% through wall drilled hole for the first tube and the last tube for different calibration groups. The percent deviation is then calculated for each calibration group from this data. Finally, the standard deviation of the percent probe wear of the different calibration groups is calculated. The results of this assessment are 5.62% & 5.9% probe wear for the 100% TW EDM notch and the 100% TW drilled hole, respectively. The input in the cycle length assessment used for the probe wear measurement uncertainty is six percent. Because tubes were not removed from service based on a specific level of probe wear, no cutoff in the distribution was used in the Braidwood evaluation.

This procedure is similar to what is used for the Byron and Braidwood ODSCC interim plugging criteria. The last tube voltage is generally higher than the first tube voltage which provides conservatism to the calibration group voltages.

A.2.2 Analyst Variability

In Reference 1, ComEd provided information regarding two blind tests performed at Byron Station. The blind tests were conducted with four different analysts. The scope , development, protocol and results are discussed in detail in Section 3.0 of Reference 2. The blind tests included a 100 tube and 200 tube test. Data from three years (1994, 1995 and 1996) were included in the test. As a part of the blind tests, the voltage of the indications detected were recorded by the four analysts. The deviation between the four analysts recorded voltages from the blind tests were used to determine a percent analyst variability for contribution to the NDE uncertainty.

The mean of the voltages reported by the analysts for each tube was calculated and considered to be the reference for that tube. A distribution of the mean voltages is presented for the 100 tube and 200 tubes test in Figure A.1 and A.2, respectively. The deviation from the mean for each analysts reported voltage for each tube was calculated. The analyst variability was calculated by dividing the deviation by the mean. A distribution of analyst variability from the mean is presented for the 100 tube and 200 tube tests in Figure A.3 and A.4, respectively. The standard deviation of the analyst variability for the tests population is then calculated. This procedure is similar to what is used for the Byron and Braidwood ODSCC interim plugging criteria.

The total number of observations was 396 for the 100 tube test and 1127 for the 200 tube test. Of the observations, thirteen were re-evaluated through a resolution process for the 100 tube and 200 tube tests. The criteria used to select observations to be re-evaluated was any voltage which exceeded the mean plus two times the standard deviation of the mean voltages. These tubes were then re-evaluated by a Level III ECT analyst and the resolved value substituted into the data. This process is similar to the resolution process utilized for ECT primary and secondary analysis where discrepancies in the analysis between analysts are submitted to a resolution analyst for disposition. Two additional criteria were used to screen the data. First, any indication which had only one call by the four analysts was not included in the sample. Secondly, observation voltages from different coils for the same indications were excluded.

The results of this assessment are a standard deviation of analyst variability of 0.19 for the 200 tube test and 0.22 for the 100 tube test. A value of 0.20 analyst variability standard deviation was used in the NDE uncertainty input for the cycle length assessment calculation.

Table 3.1
Byron and Braidwood Unit 1
Largest Indication Voltages
For Average and Maximum Voltage

	Byron 0.080 Voltages			Braidwood 0.080 Voltages		
Circ Sensitive Inspection	Outage	Maximum	Integral	Outage	Maximum	Integral
First	B1RO6 (1994)	4.14	1.02	A1M05 (2/95)	2.53	1.21
Second	B1PO2 (1995)	1.24	0.49	A1R05 (10/95)	1.36	0.52
Third	B1RO7 (1996)	1.02	0.57	-	-	-

Inspection Results for Braidwood Unit 1
February and October 1995 - 0.080" Coil
All Steam Generators
Table 5.1

All Data Normalized to 20 volts - 100% EDM Notch

YEAR	PROBE	ROW	COLUMN	MVIR	VIR
Feb-95	610	4	48	0.37	0.21
Feb-95	610	16	111	1.3	0.6
Feb-95	610	4	107	0.77	0.28
Feb-95	610	12	73	0.97	0.27
Feb-95	610	22	44	1.9	0.69
Feb-95	610	21	44	0.71	0.32
Feb-95	610	21	45	2.53	1.21
Feb-95	610	20	46	0.75	0.26
Feb-95	610	19	50	2.5	0.71
Feb-95	610	20	51	1.3	0.4
Feb-95	610	38	48	0.78	0.2
Feb-95	610	26	65	0.64	0.16
Feb-95	610	45	24	1.99	0.41
Feb-95	610	21	39	0.54	0.31
Feb-95	610	23	40	1.8	0.64
Feb-95	610	19	45	0.73	0.21
Oct-95	610	27	38	0.59	0.21
Oct-95	610	22	41	0.56	0.28
Oct-95	610	21	41	0.65	0.23
Oct-95	610	20	42	0.73	0.23
Oct-95	610	25	49	1.15	0.42
Oct-95	610	46	45	0.38	0.2
Oct-95	610	29	61	0.67	0.26
Oct-95	610	23	70	0.26	0.09
Oct-95	610	25	70	0.53	0.21
Oct-95	610	2	109	1.17	0.47
Oct-95	610	3	111	0.33	0.18
Oct-95	610	4	111	0.39	0.16
Oct-95	610	4	109	0.84	0.32
Oct-95	610	9	110	0.61	0.23
Oct-95	610	21	54	1.36	0.52
Oct-95	610	13	102	1.06	0.46
Oct-95	610	15	99	0.69	0.29
Oct-95	610	9	68	0.45	0.1
Oct-95	610	11	49	0.82	0.32
Oct-95	610	16	69	0.88	0.4
Oct-95	610	24	53	0.44	0.15
Oct-95	610	30	53	0.61	0.25
Oct-95	610	8	66	0.6	0.27

Industry Tube Pull and Insitu Pressure Testing
Table 6.1

	Total Number	Available ECT Data
Pulled Tubes	33	24
Number Burst Tested	15	11 (Note 2)
Number Crack MET Size	33	24
Insitu Pressure Tests	33	32
Total Number of Tubes	66	56

Note 1: The largest tube pull indication with no ECT data has a MET average crack depth of 35%, these tubes will not contribute new data to this evaluation

Note 2: Includes 2 Byron tube pull simulations

Table A.1
Plus Point Probe Wear Assessment
Affect on 0.080 Coil Voltage
1996 Data
100% Throughwall EDM Axial Notch

Cal Group	Number of Tubes	100% EDM Notch Voltage		Percent Deviation [(x-y)/x]
		First Tube volts (x)	Last Tube volts (y)	
10	90	20	22.44	12.20%
14	100	20	21.35	6.75%
18	46	20	20.95	4.76%
22	112	20	21.54	7.68%
26	109	20	20.58	2.92%
30	96	20	18.32	-8.39%
34	25	20	19.87	-0.65%
4	49	20	21.97	9.85%
8	31	20	20.61	3.06%
12	77	20	21.82	9.12%
16	90	20	20.63	3.14%
20	44	20	21.38	6.92%
24	98	20	22.44	12.21%

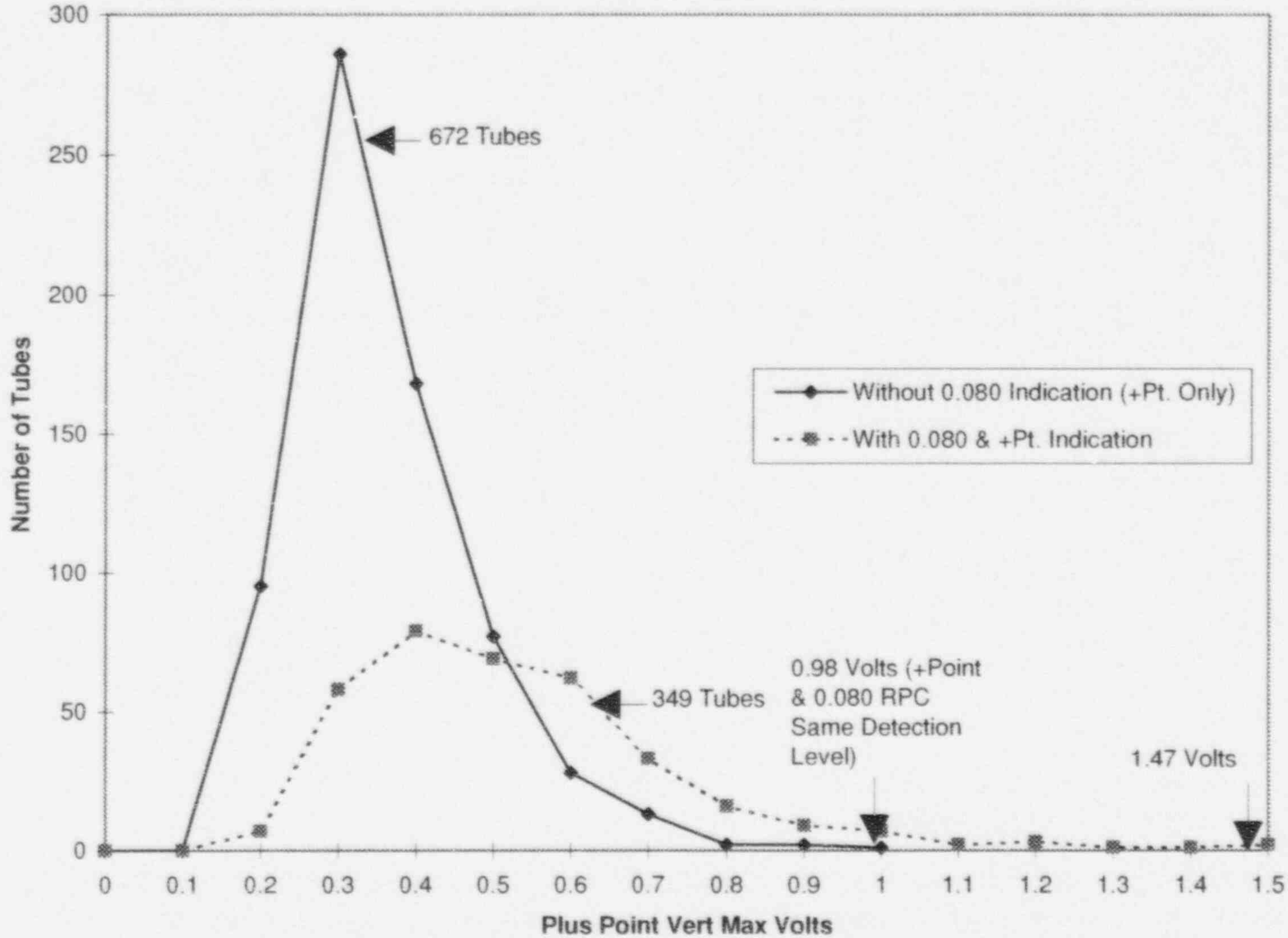
Total Tubes= 735 **Standard Deviation =** 5.62%

Table A.2
Plus Point Probe Wear Assessment
Affect on 0.080 Coil Voltage
1996 Data
100% Throughwall Hole

Cal Group	Number of Tubes	100% Hole Voltage First Tube volts (x)	100% Hole Voltage Last Tube volts (y)	Percent Deviation [(x-y)/x]
14	100	10	10.62	6.20%
18	46	10	10.07	0.70%
22	112	10	11.33	13.33%
30	96	10	10.43	4.31%
34	25	10	10.15	1.52%
96	29	10	11.32	13.20%
100	6	10	9.47	-5.25%
102	45	10	10.58	5.84%
104	29	10	10.75	7.45%
106	41	10	11.13	11.29%

Total Tubes= 459 Standard Deviation = 5.90%

Byron 1996 SG C Circumferential Indications Detected by +Point only and +Point and 0.080" RPC
Figure 3.1



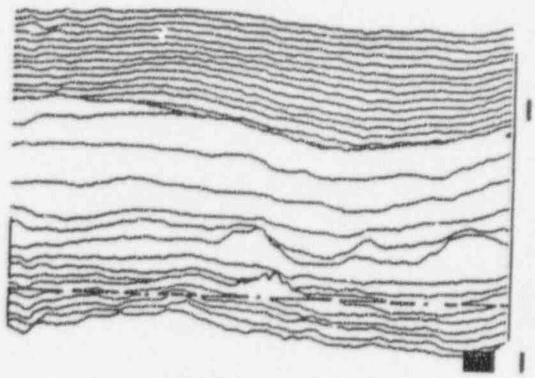


Figure 3.2a

R3 C111 Small Indications

ANSER 0.29 VOLTS

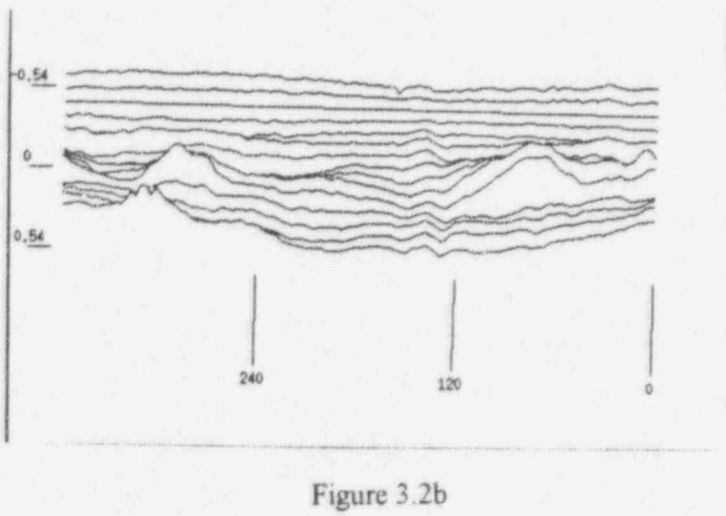


Figure 3.2b

R3 C111 Small Indications

Eddy Net 95 0.30 VOLTS

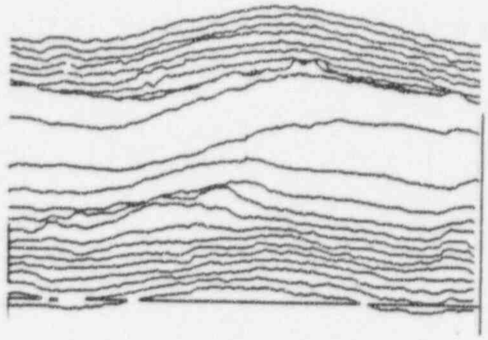


Figure 3.3a

R15 C99 Medium Indications

ANSER 0.45 VOLTS

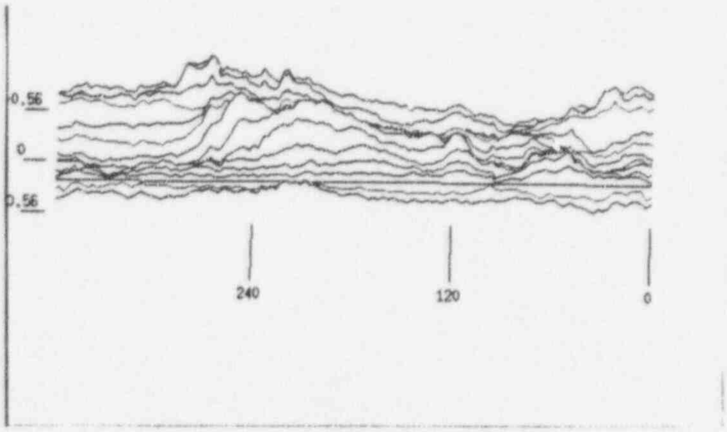


Figure 3.3b

R15 C99 Medium Indications

Eddy Net 95 0.45 VOLTS

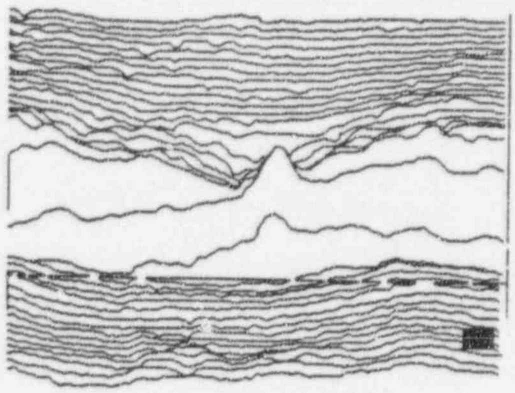


Figure 3.4a

R21 C54 Large Indications

ANSER 0.66 VOLTS

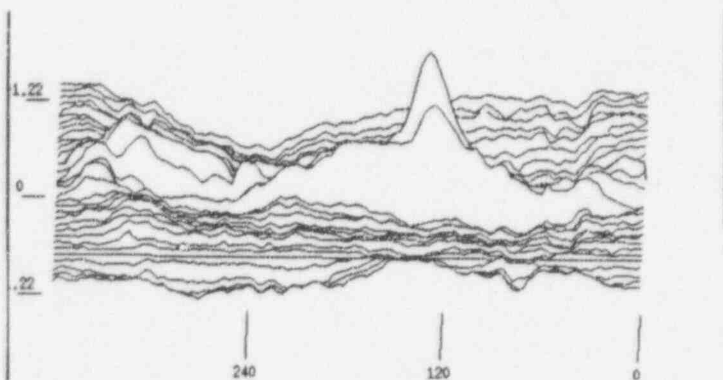


Figure 3.4b

R21 C54 Large Indications

Eddy Net 95 0.67 VOLTS

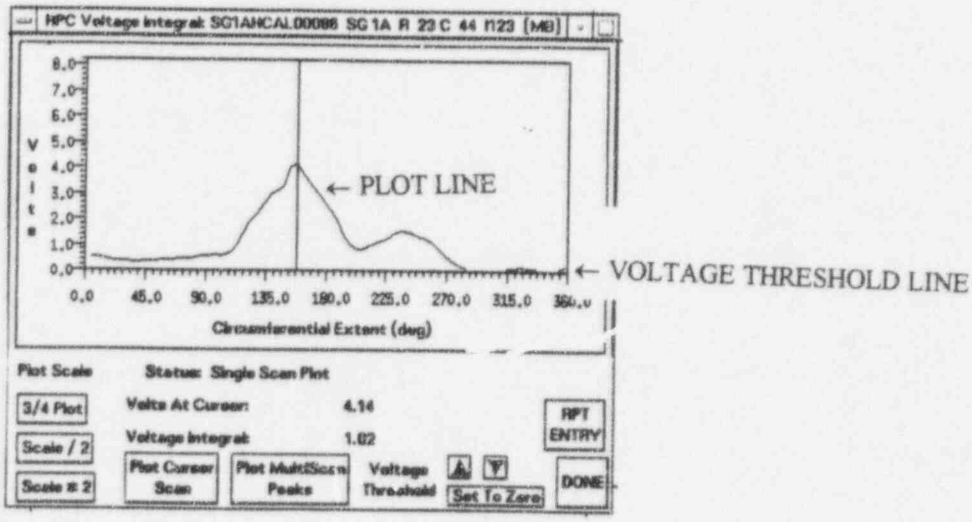


Figure 4.1a: Cursor Scan Line

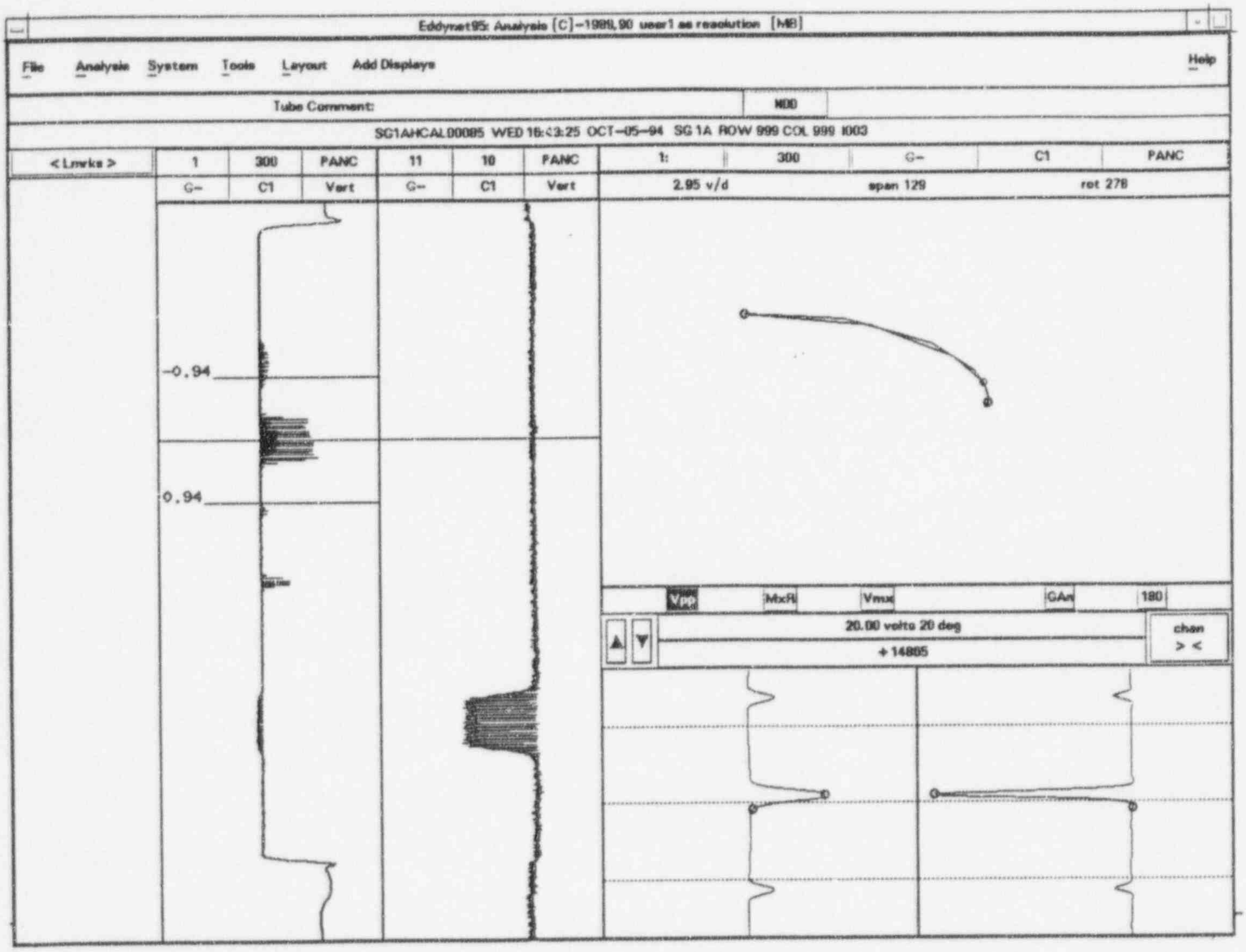


Figure 4.1b: Normalization for the 0.080" RPC to 20Volts

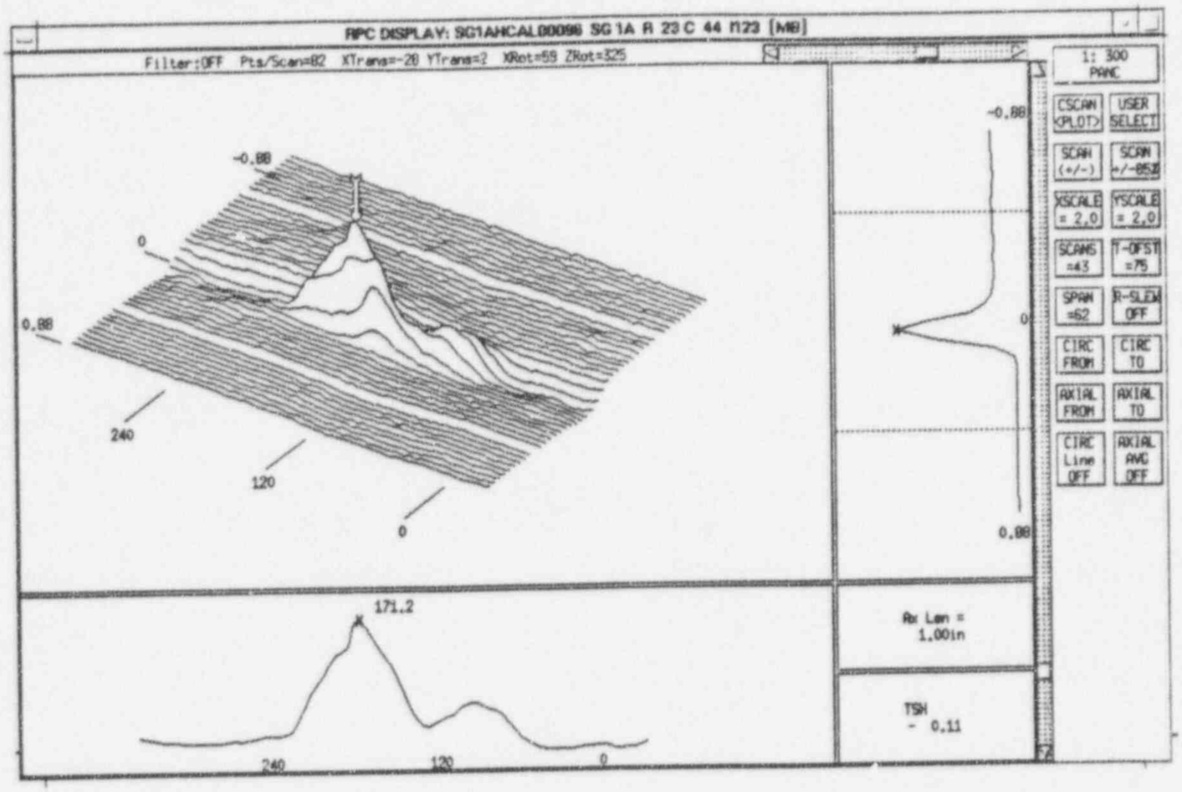


Figure 4.1c: RPC display C-scan Showing Strip Chart Cursors Located at Maximum Vertical Channel Displacement and Expansion Zone Circumferential Indications

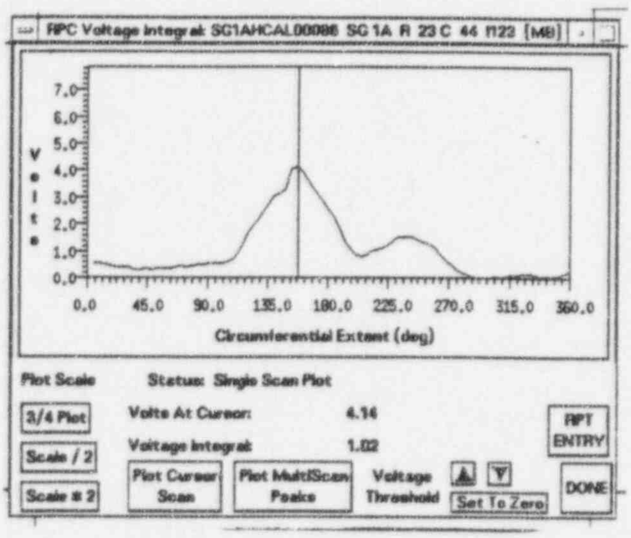
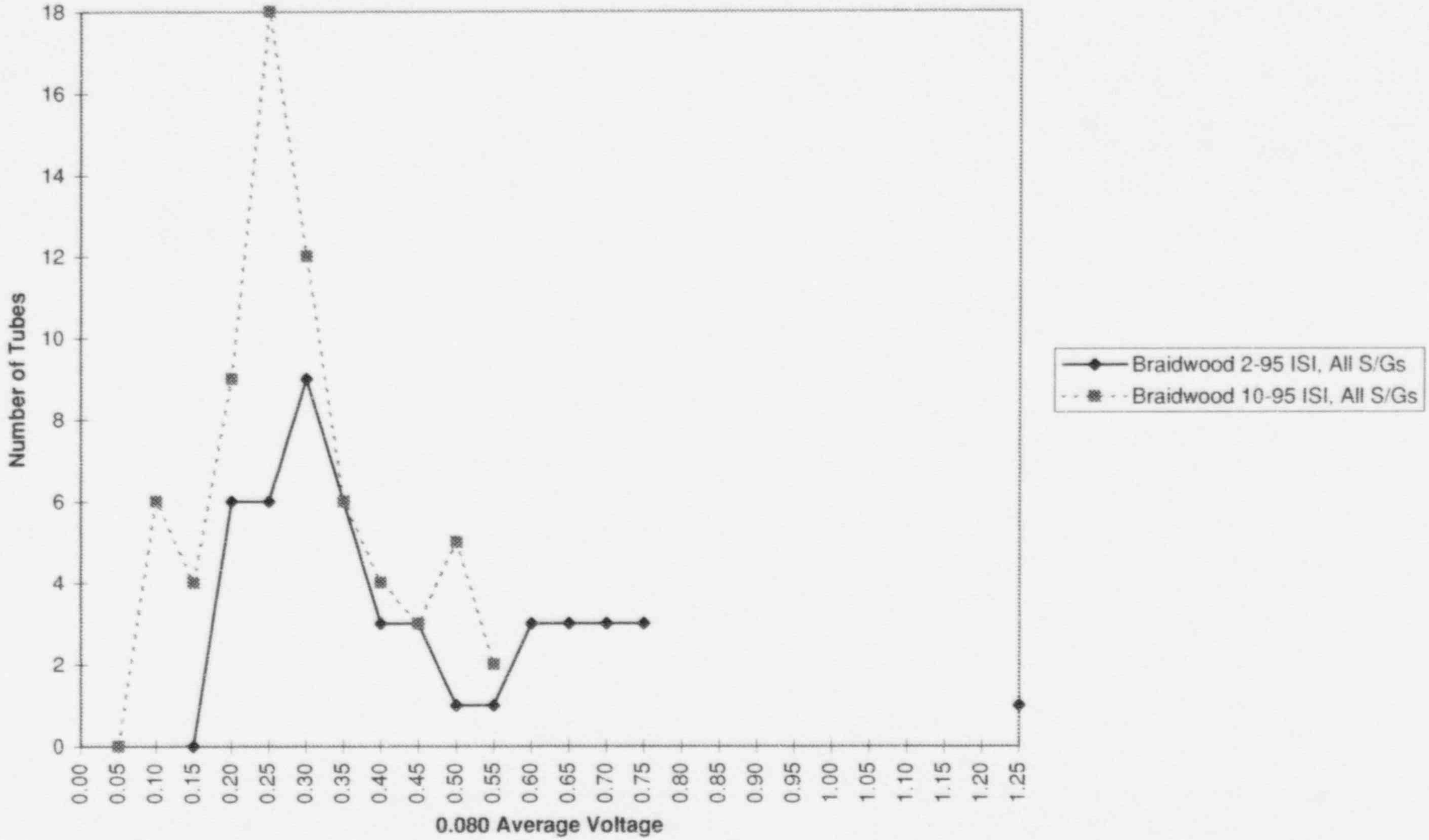


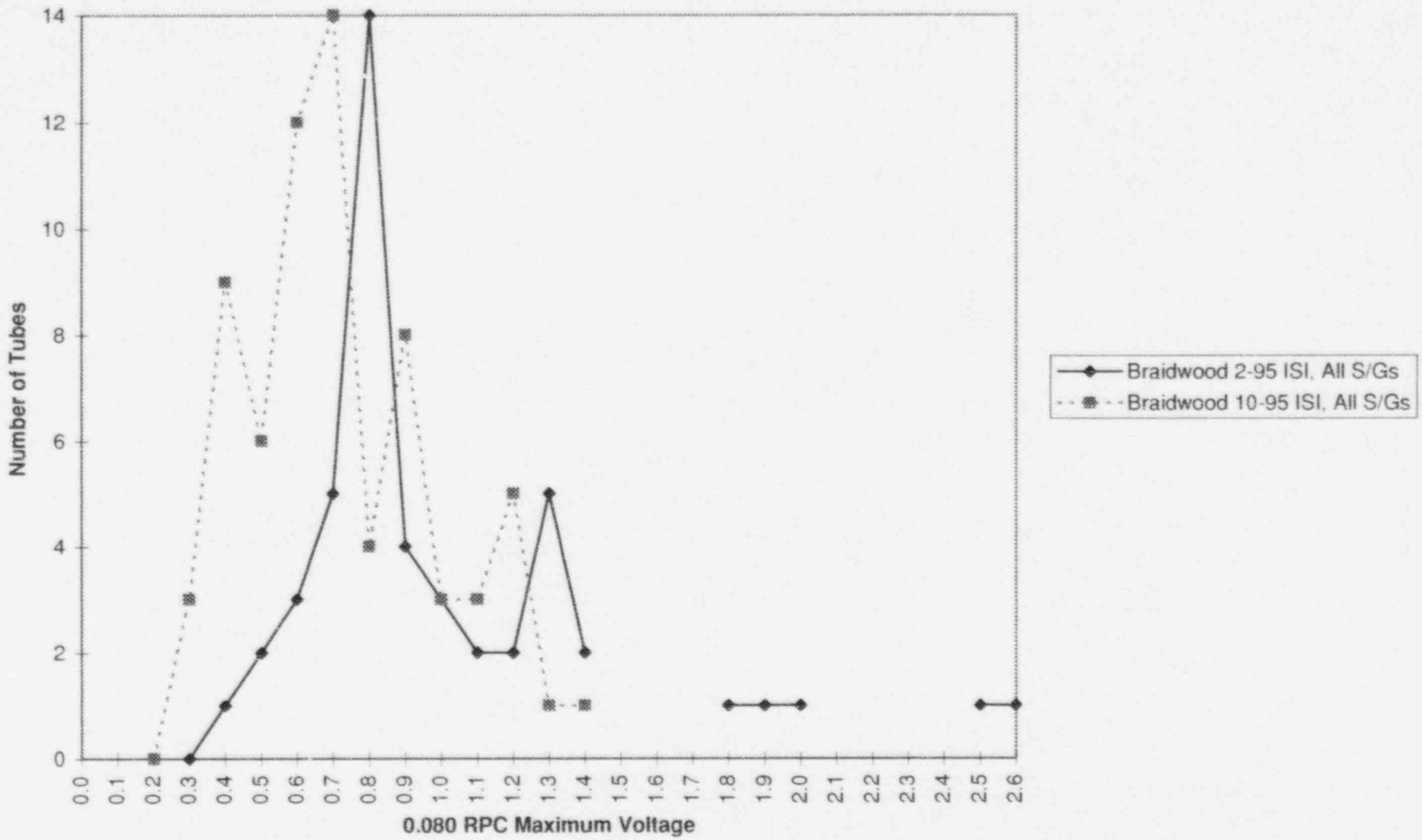
Figure 4.1d: Circumferential Line Scan as Displayed in the RPC Voltage Integral Window Showing Maximum Displacement

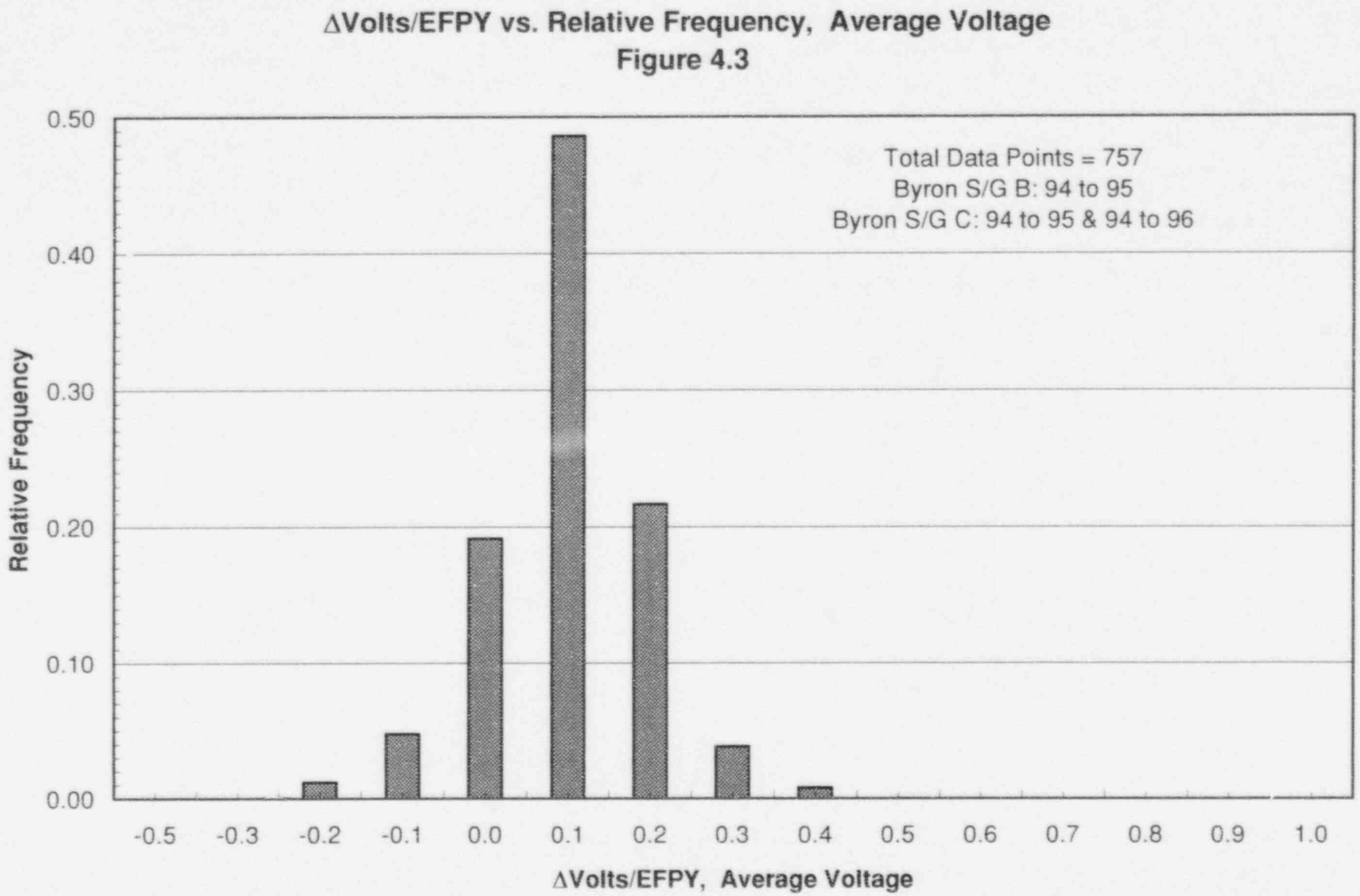
Braidwood Unit 1 2/95 and 10/95 Voltage Re-analysis, 0.080 RPC Average Voltage

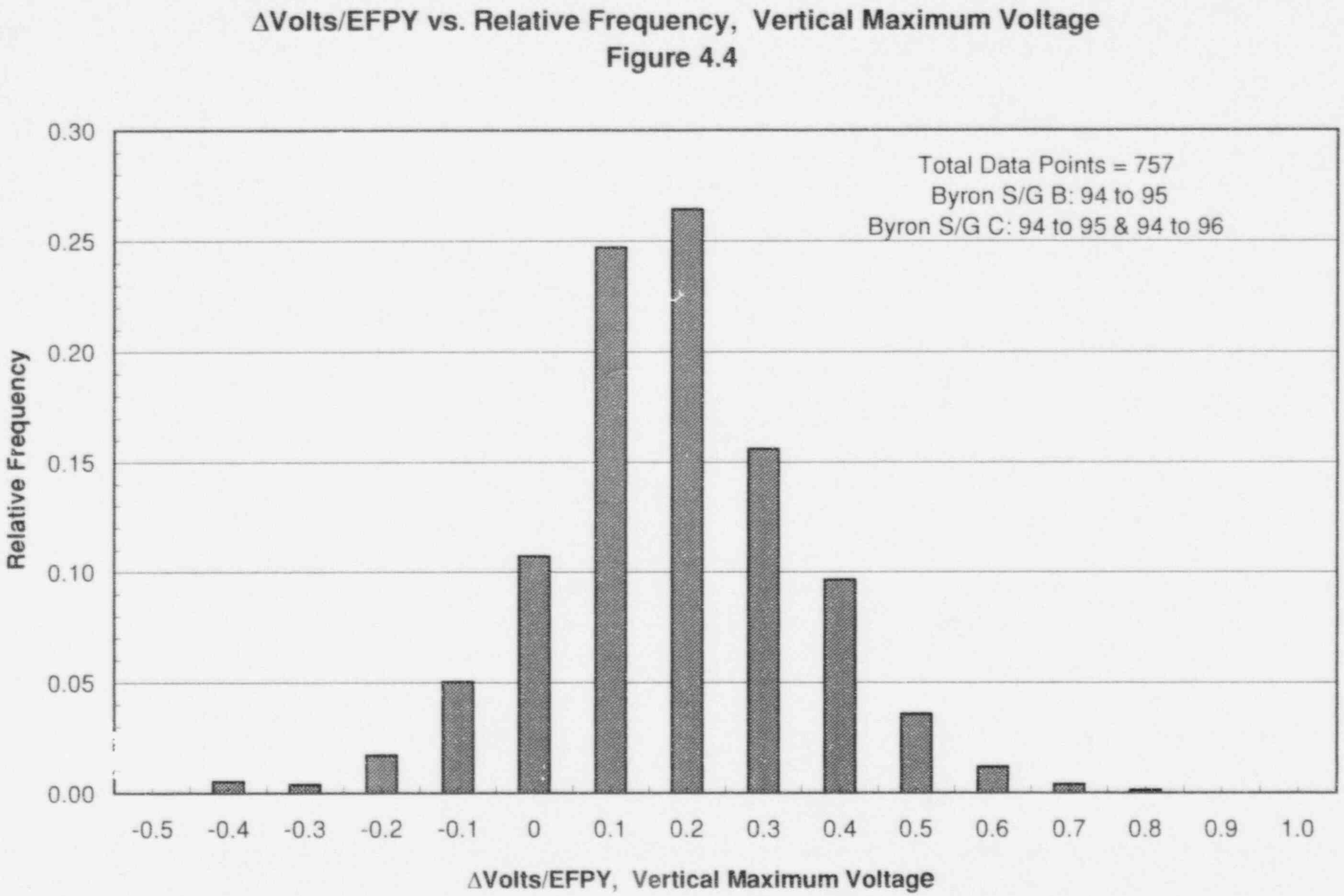
Figure 4.2a



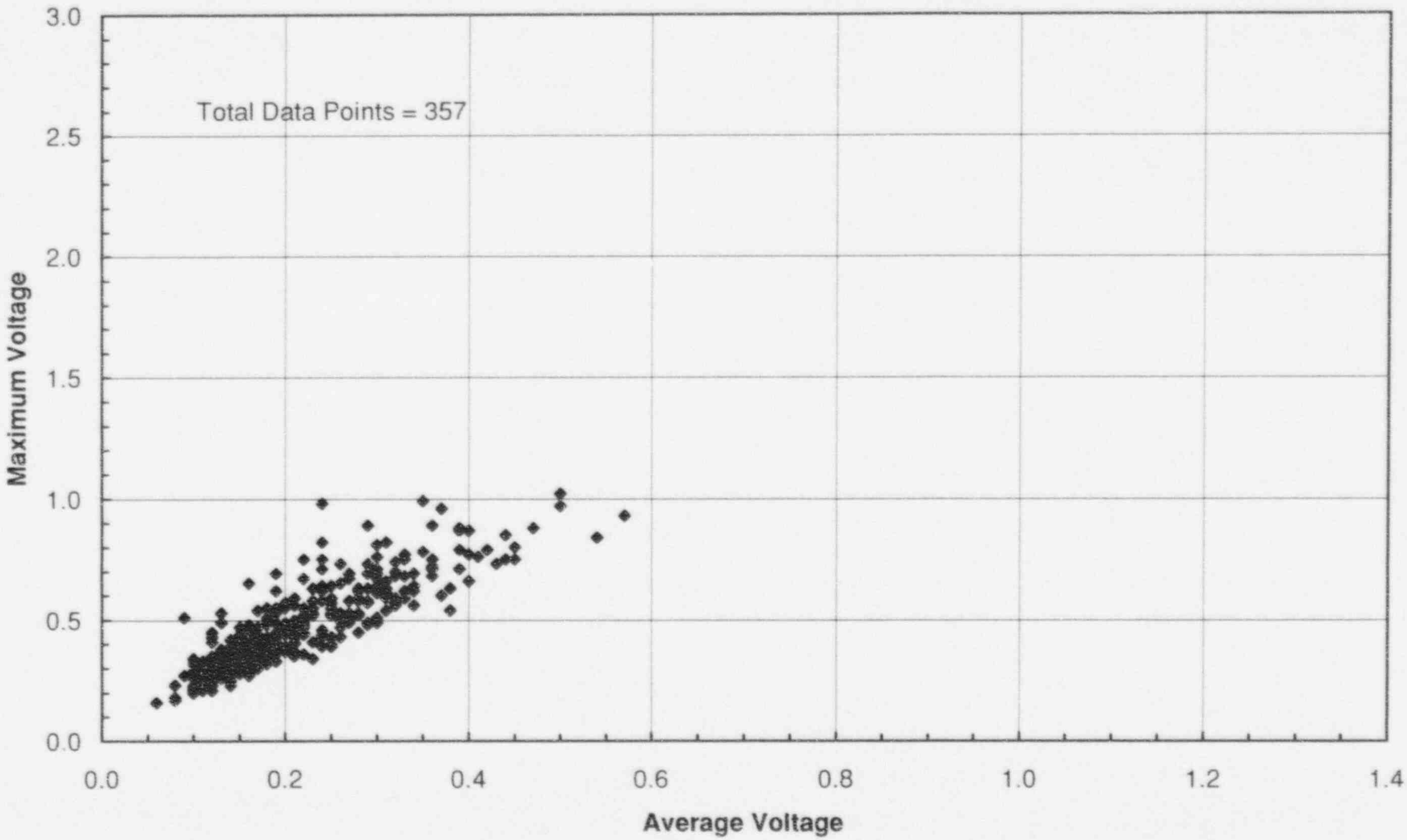
Braidwood Unit 1 10/95 & 2/95 Voltage Integral Re-Analysis 0.080 Maximum Voltage
Figure 4.2b



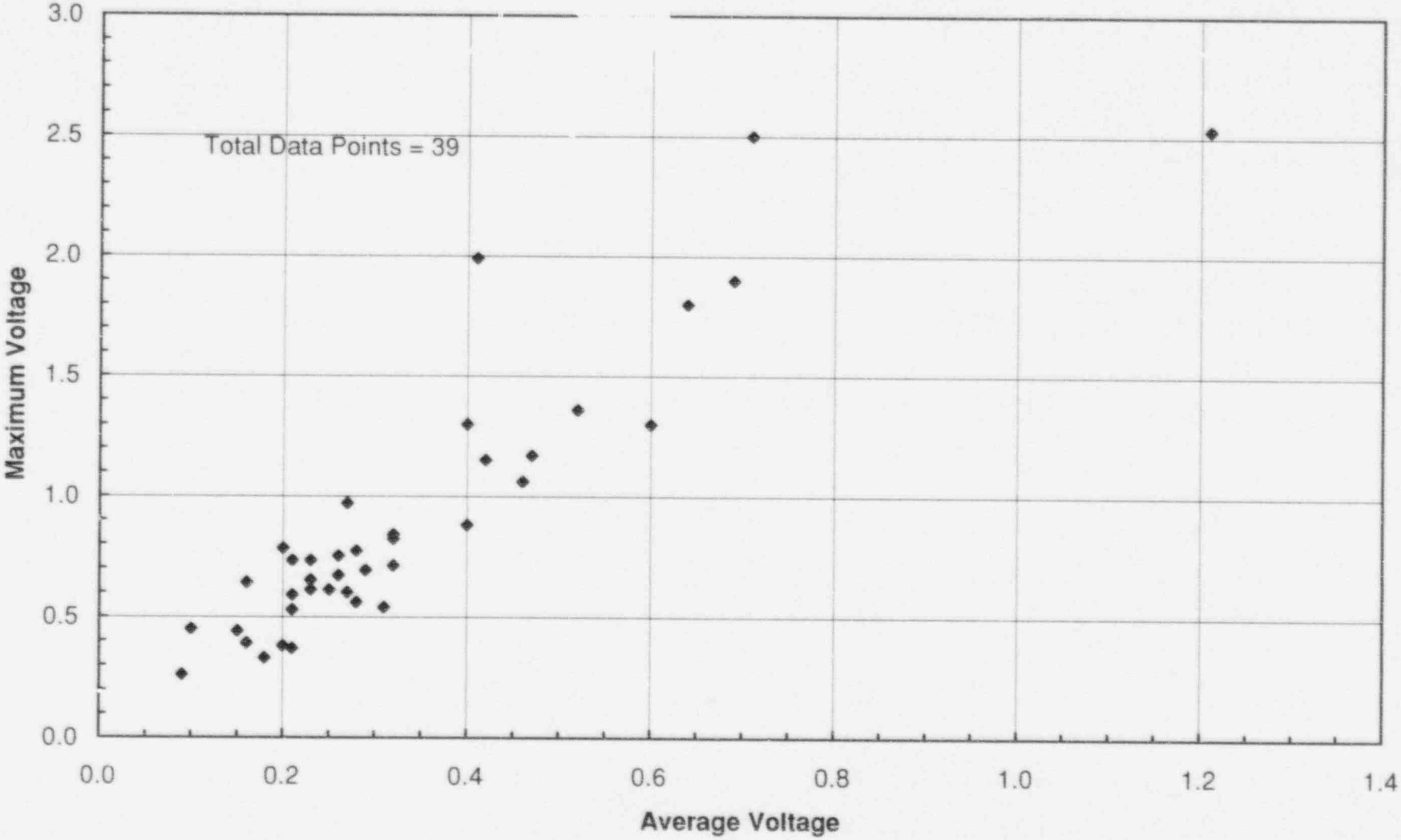

ΔVolts/EFPY vs. Relative Frequency, Average Voltage
Figure 4.3
Total Data Points = 757
Byron S/G B: 94 to 95
Byron S/G C: 94 to 95 & 94 to 96
Relative Frequency
0.50
0.40
0.30
0.20
0.10
0.00
-0.5
-0.3
-0.2
-0.1
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
ΔVolts/EFPY, Average Voltage


ΔVolts/EFPY vs. Relative Frequency, Vertical Maximum Voltage
Figure 4.4
Total Data Points = 757
Byron S/G B: 94 to 95
Byron S/G C: 94 to 95 & 94 to 96
Relative Frequency
0.30
0.25
0.20
0.15
0.10
0.05
0.00
-0.5
-0.4
-0.3
-0.2
-0.1
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
ΔVolts/EFPY, Vertical Maximum Voltage

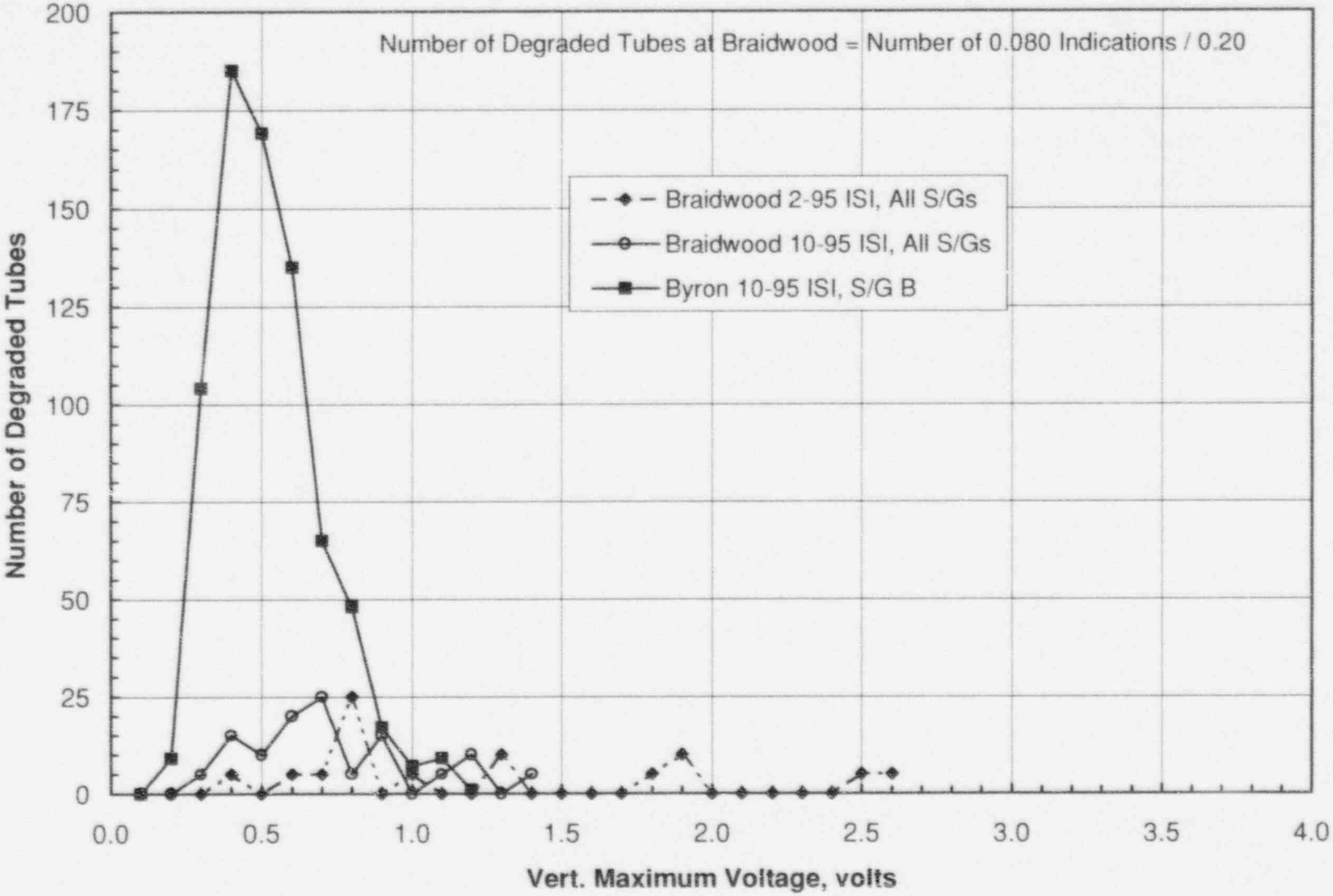
Byron Unit 1 1996 S/G C Indications: Average vs. Maximum Voltage
Figure 4.5



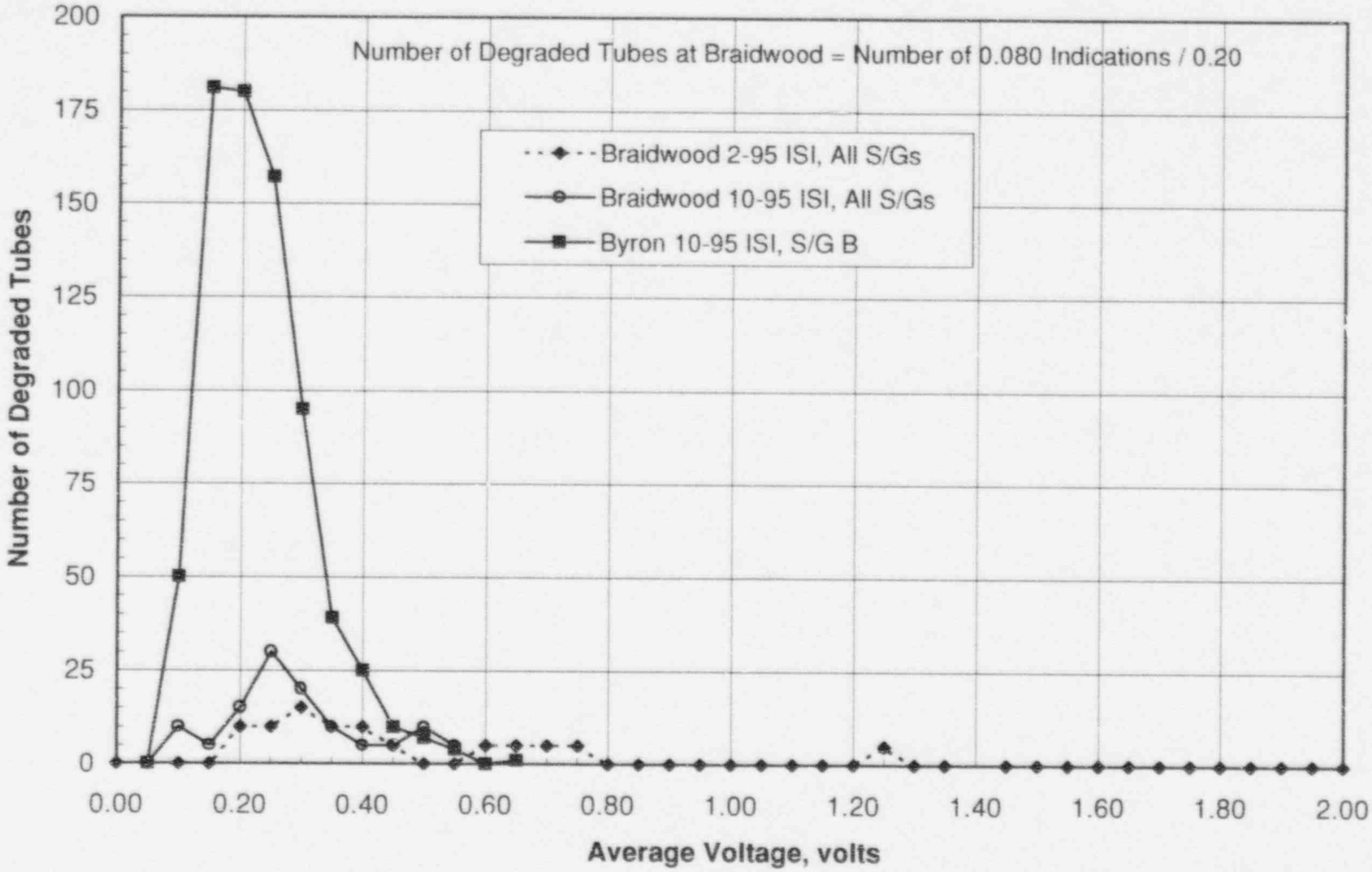
Braidwood: Average vs. Maximum Voltage
Figure 4.6



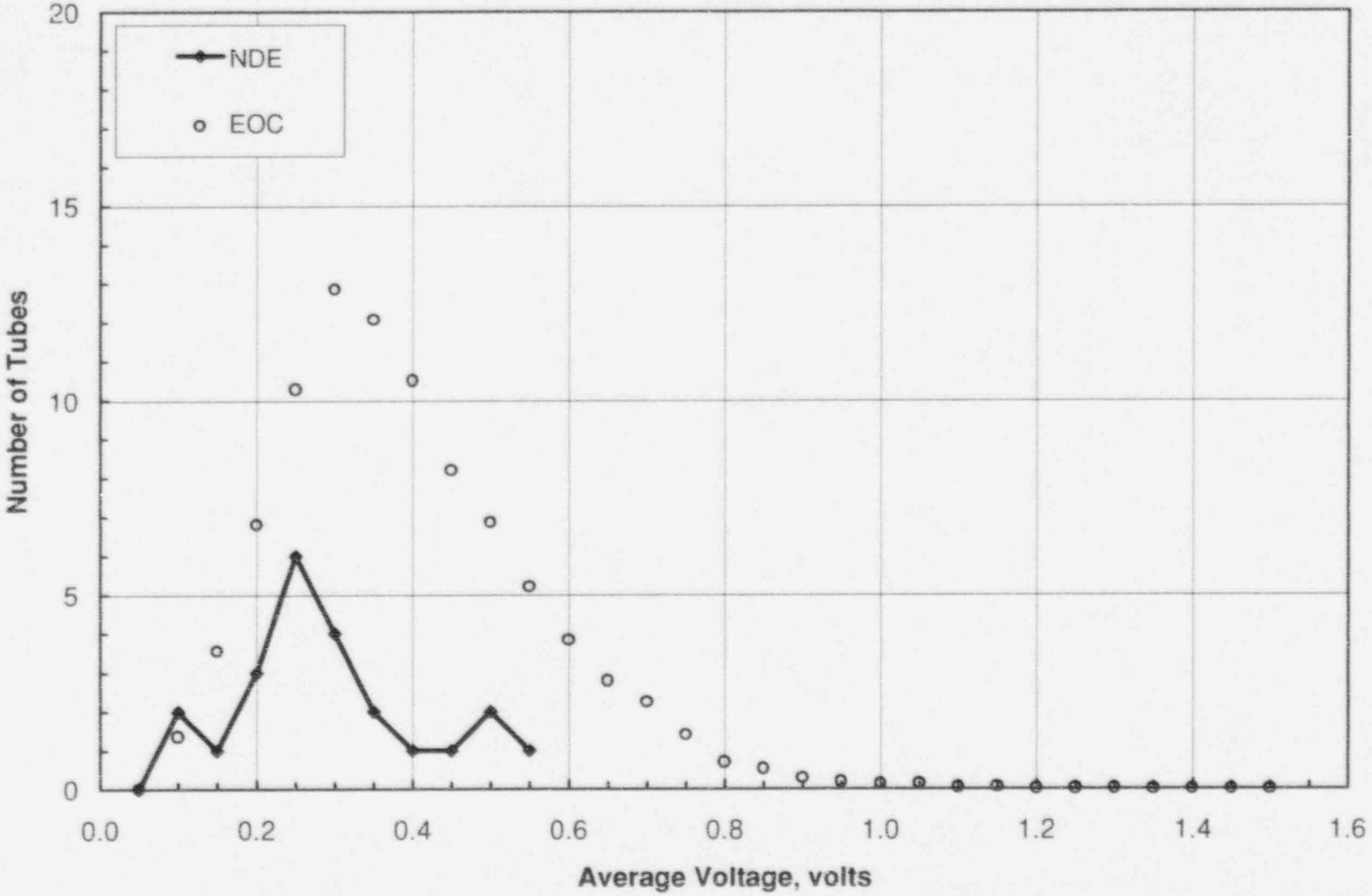
Number of Degraded Tubes vs. Vert. Maximum Voltage
Figure 5.1



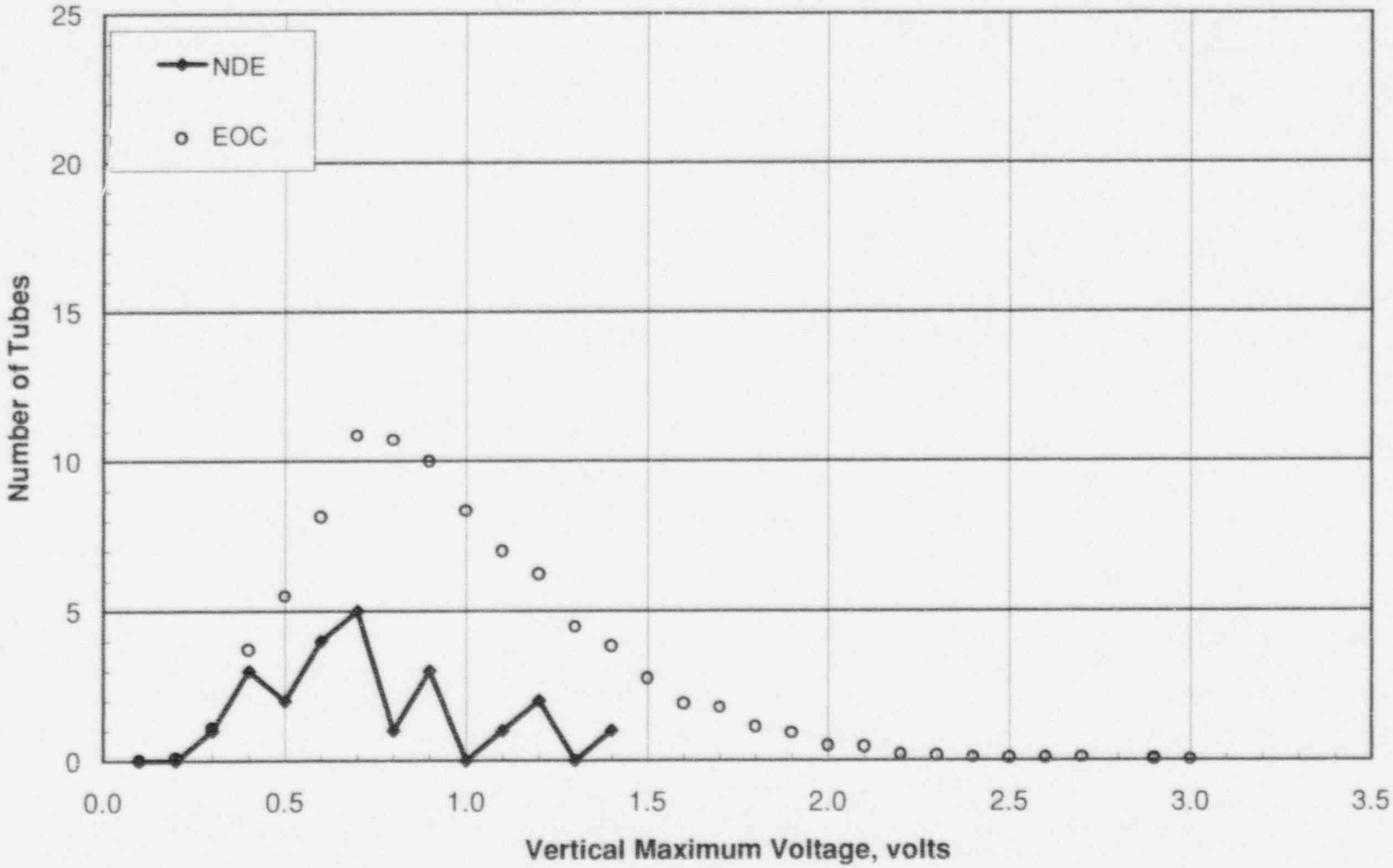
Number of Degraded Tubes vs. Average Voltage
Figure 5.2



Braidwood: Number of Tubes vs. Average Voltage Distribution
461 Days, POD = 0.2, Analyst Uncertainty = 0.2, Probe Wear = 0.06
Figure 5.3

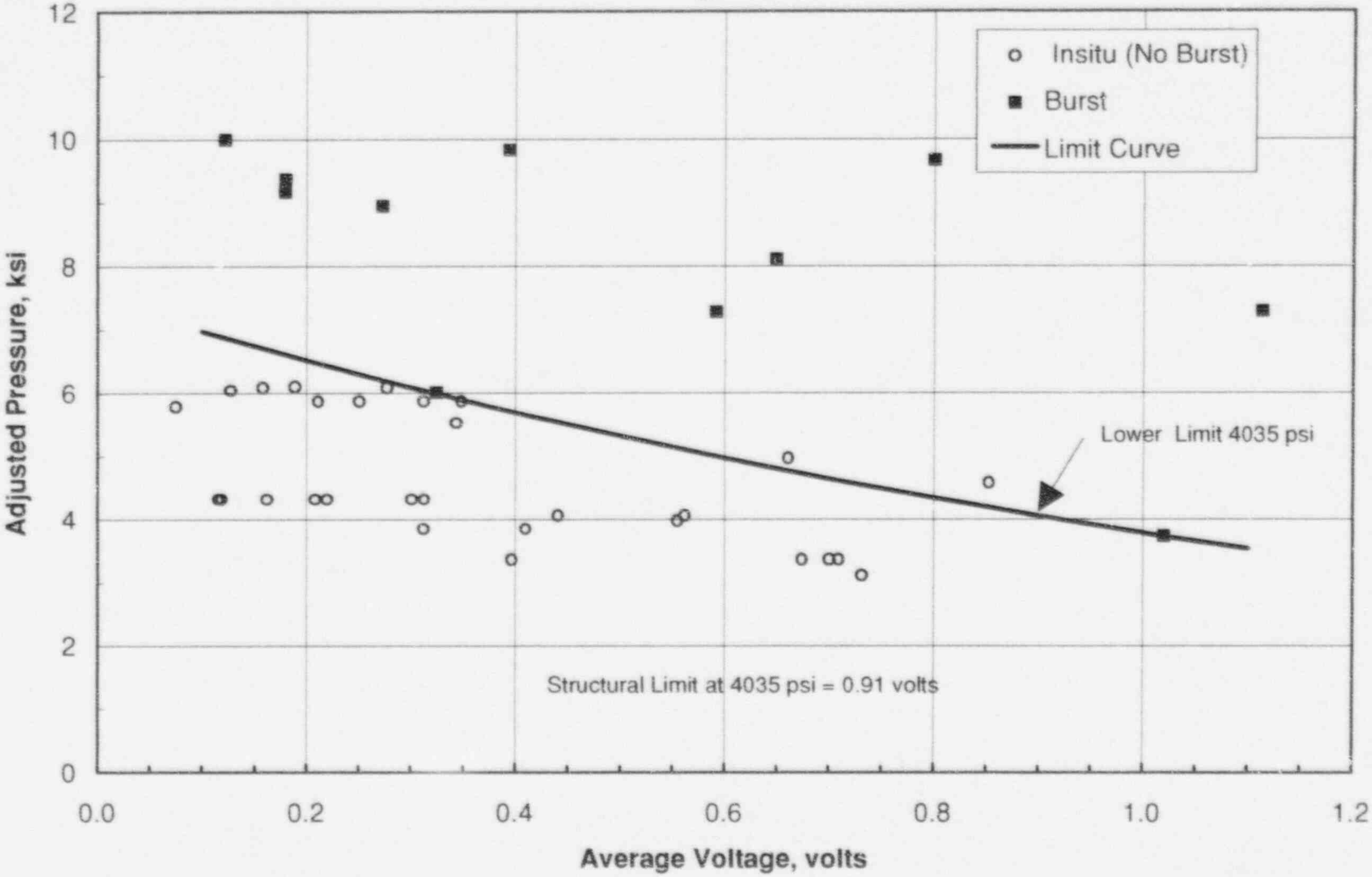


Braidwood: Number of Tubes vs. Vertical Maximum Voltage Distribution
461 Days, POD = 0.20, Analyst Uncertainty, = 0.2, Probe Wear = 0.06
Figure 5.4



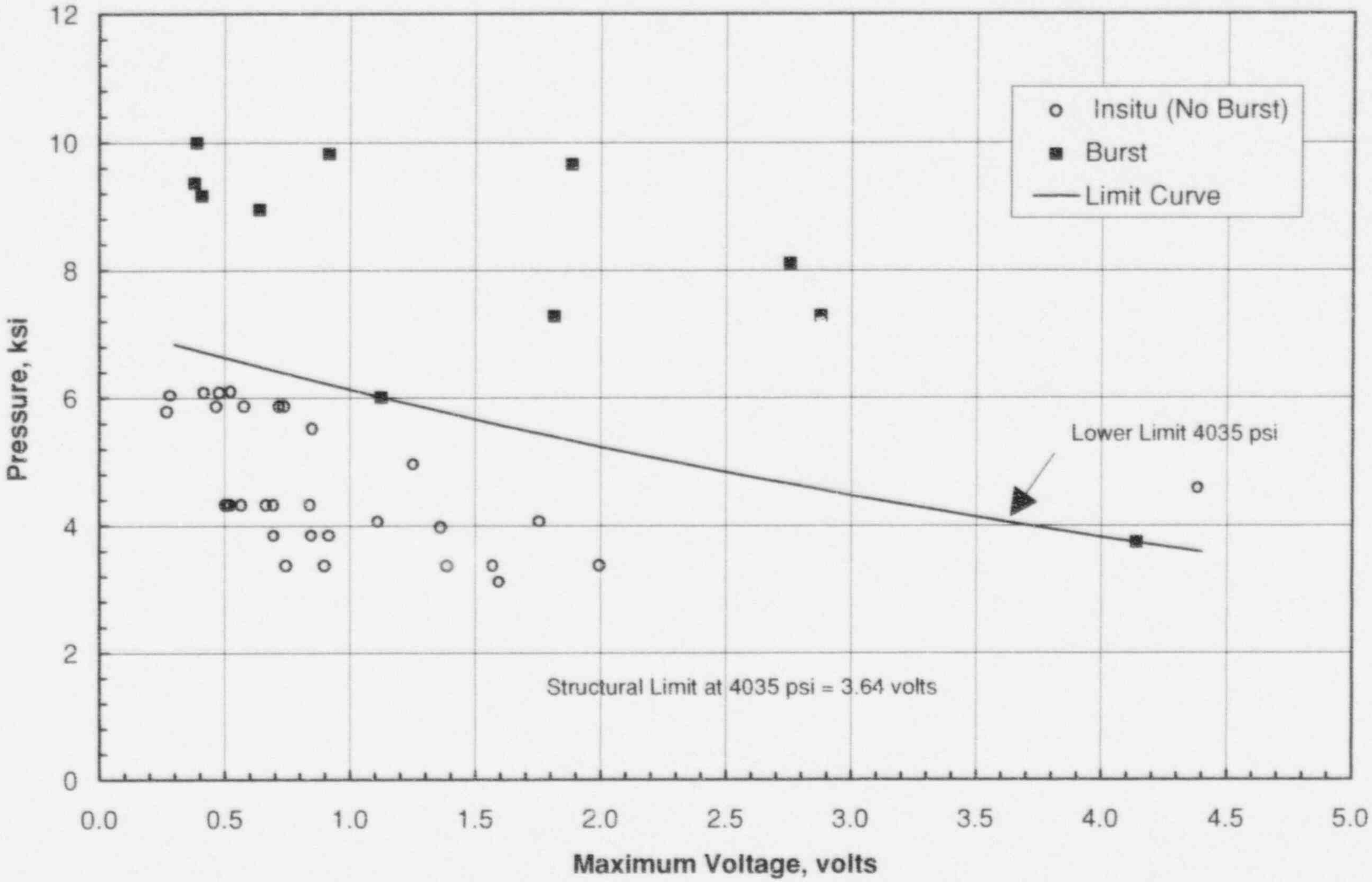
Average Voltage Structural Limit vs. Adjusted Insitu or Burst Pressure Corrected to Braidwood LTL Properties

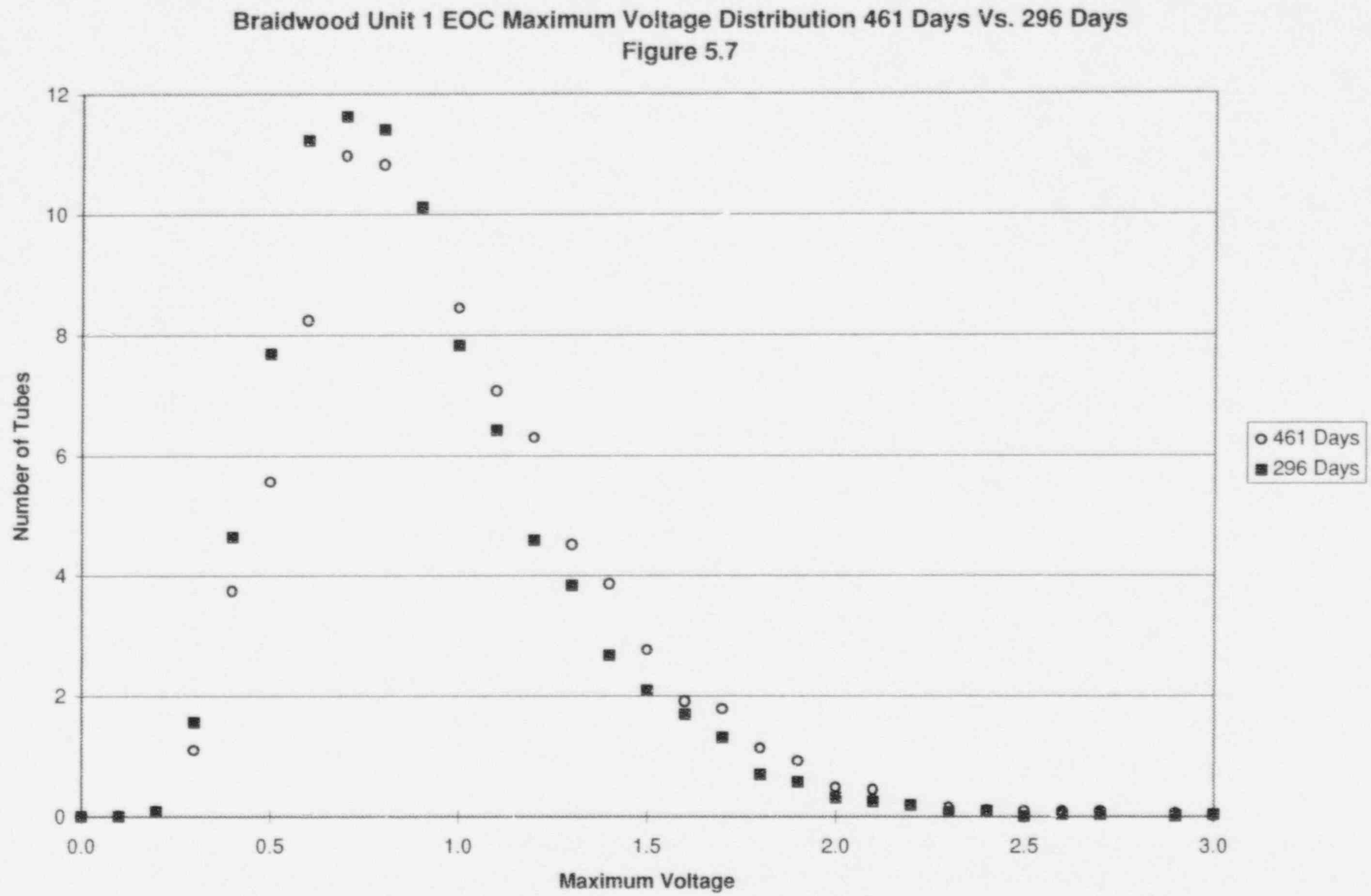
Figure 5.5



Maximum Voltage Structural Limit vs. Adjusted Insitu or Burst Pressure Corrected for Braidwood LTL Properties

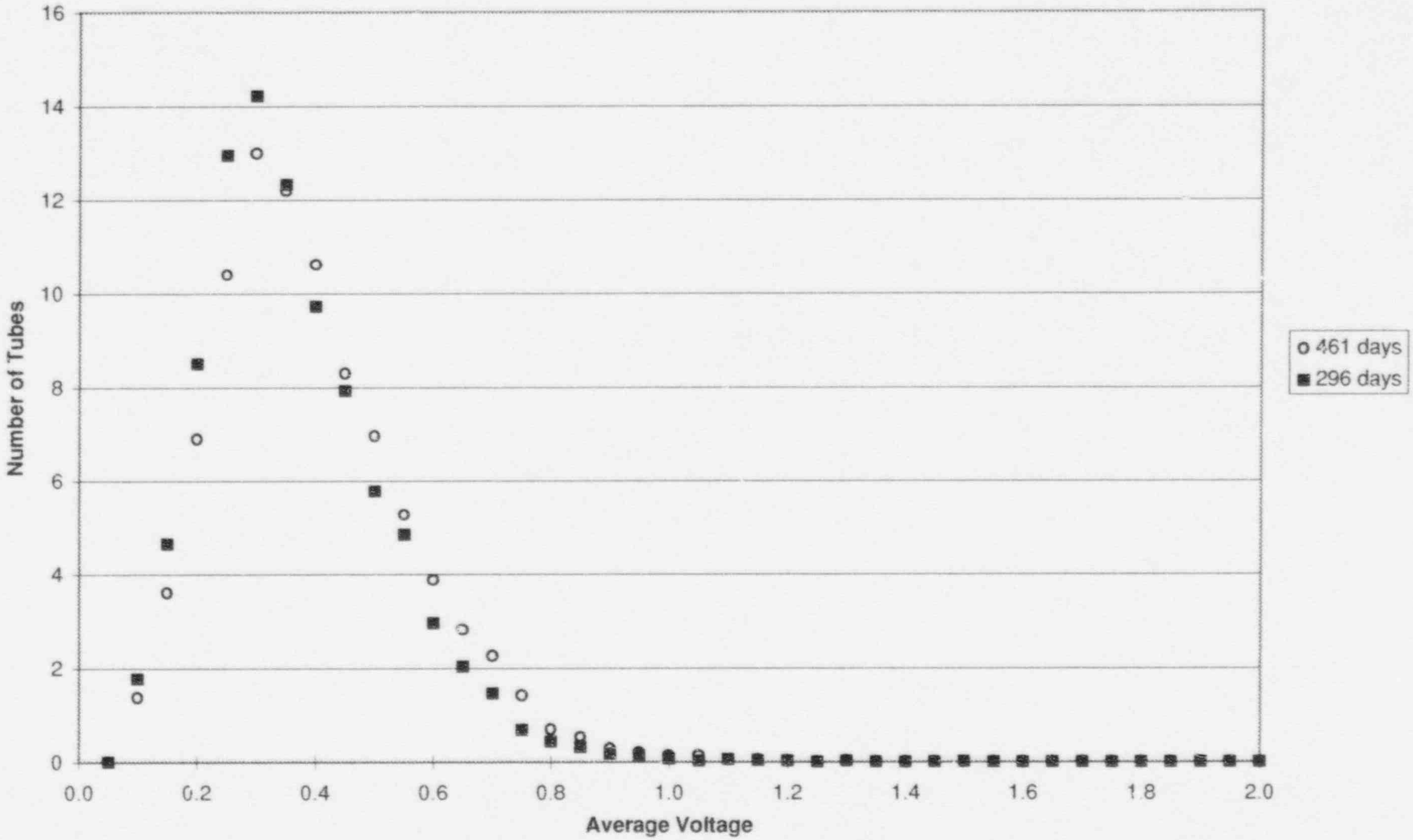
Figure 5.6



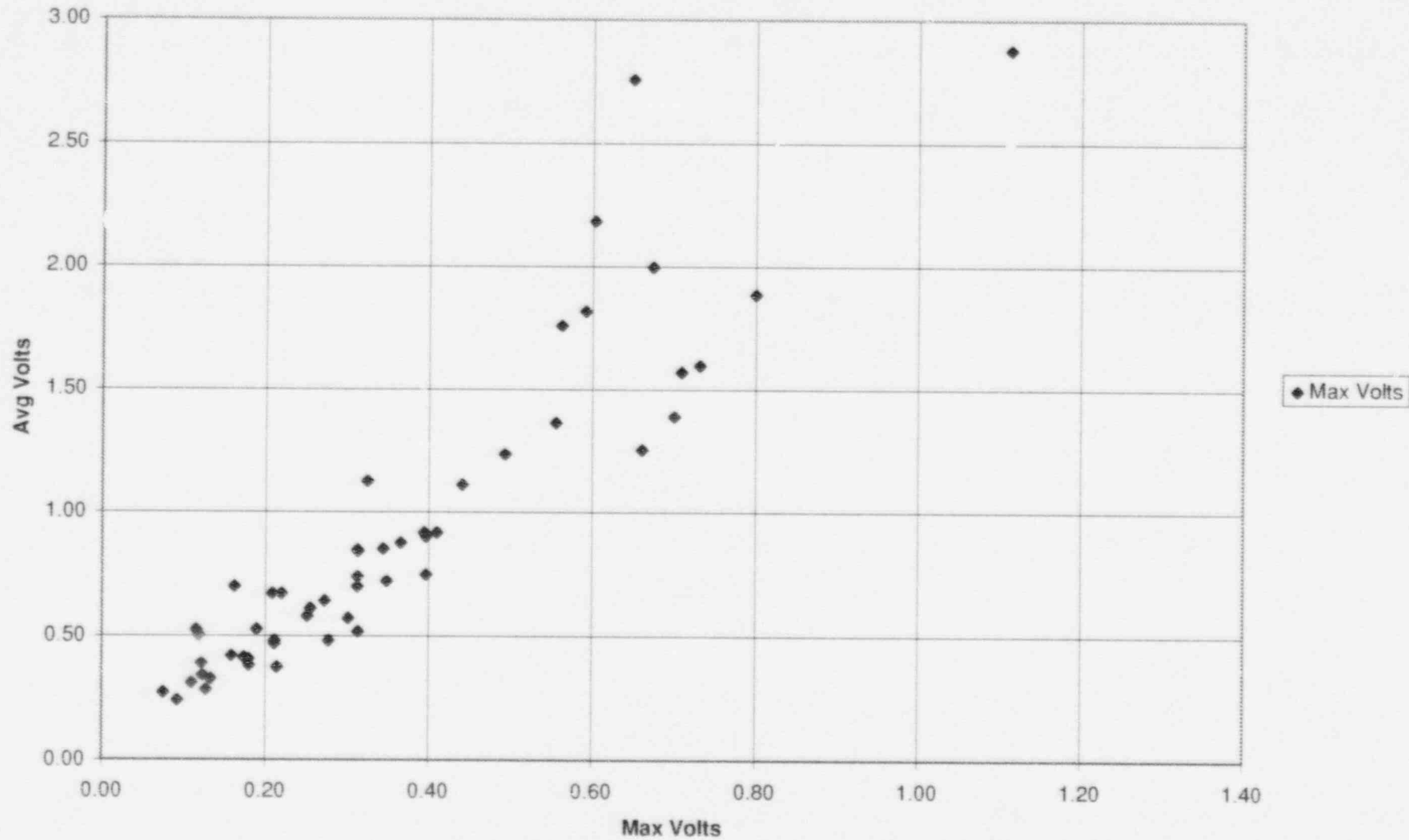


Braidwood Unit 1 EOC Maximum Voltage Distribution 461 Days Vs. 296 Days
Figure 5.7
Number of Tubes
Maximum Voltage
461 Days
296 Days
0
2
4
6
8
10
12
0.0
0.5
1.0
1.5
2.0
2.5
3.0

Braidwood Unit 1 EOC Average Voltage Distribution 461 Days Vs. 296 Days
Figure 5.8

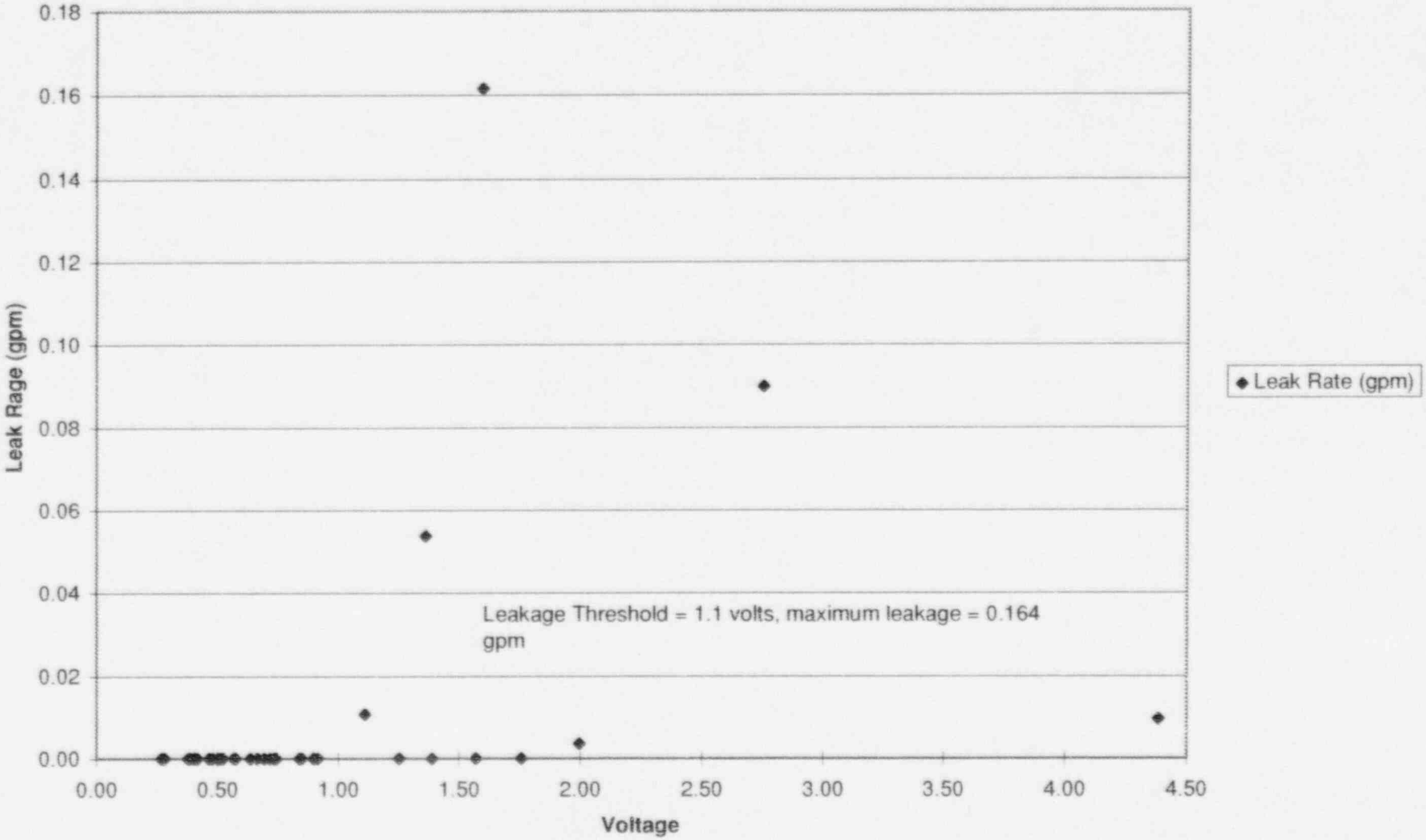


Industry Tube Pull Insitu Pressure Test Average Volts Vs Max Volts
Figure 6.1

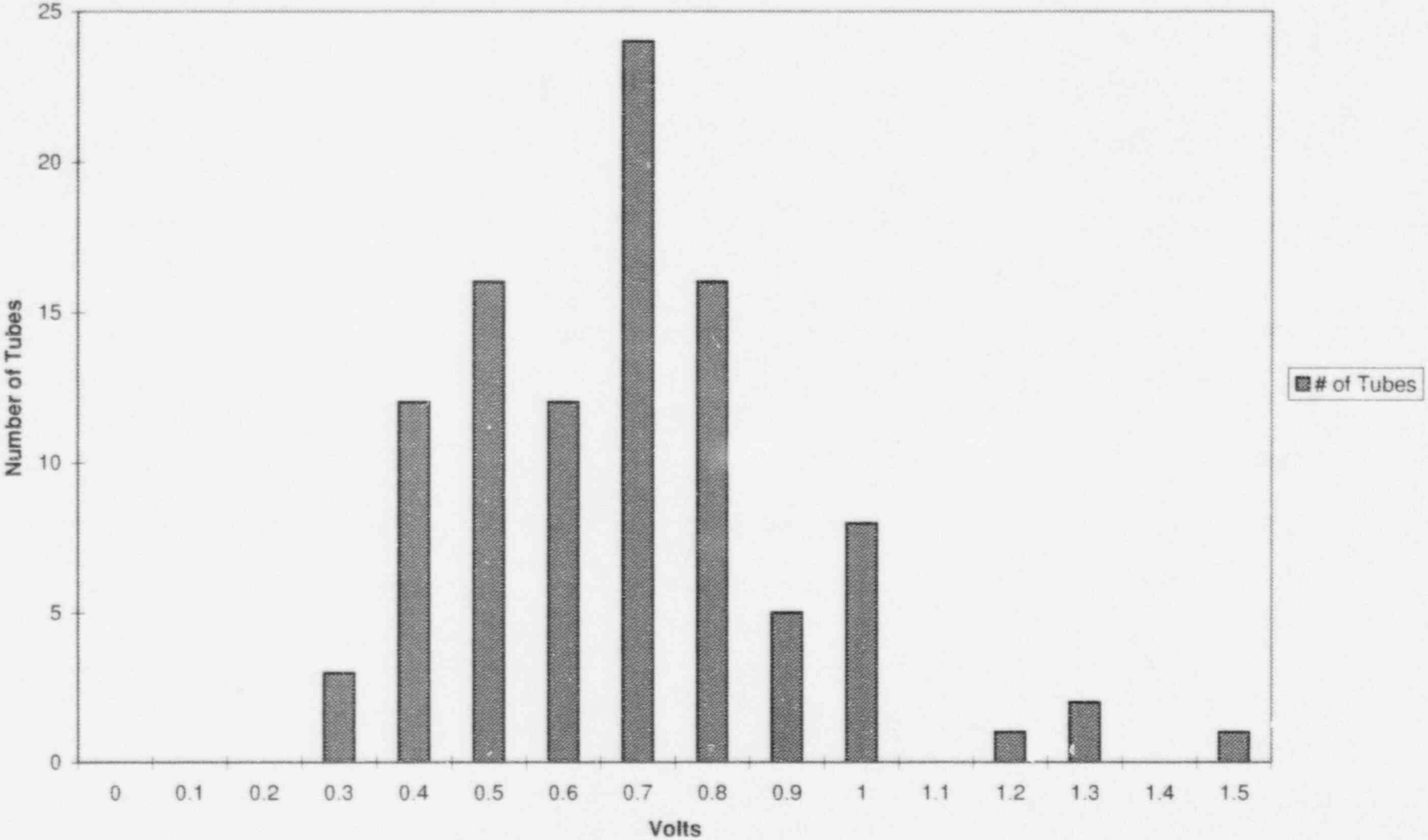


Industry Tube Pull and Insitu Pressure Test Leak Rate (Corrected for Temperature and Pressure) Vs. Maximum Voltage

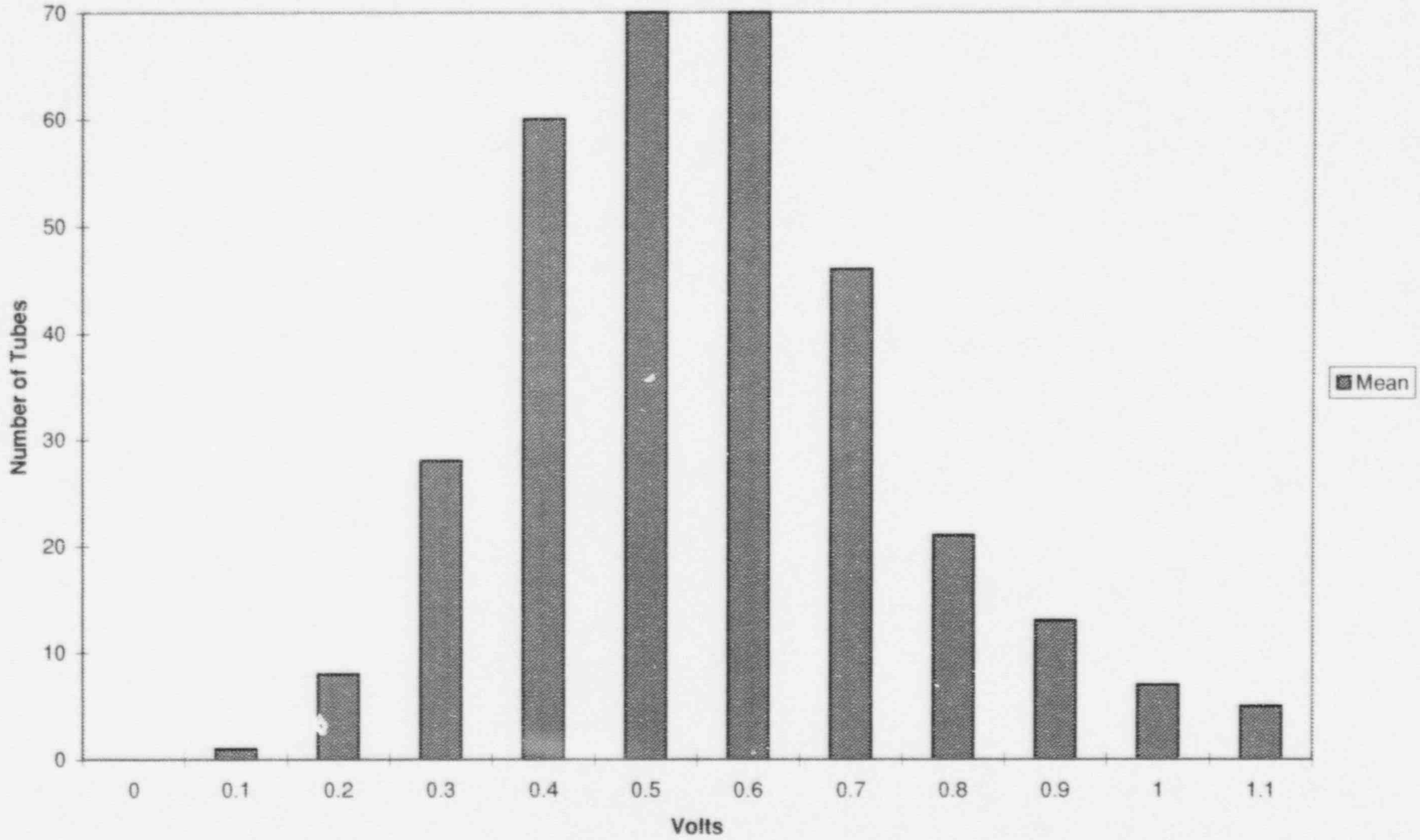
Figure 7.1



Distribution of 100 Tube Blind Test Mean Voltage
Figure A.1

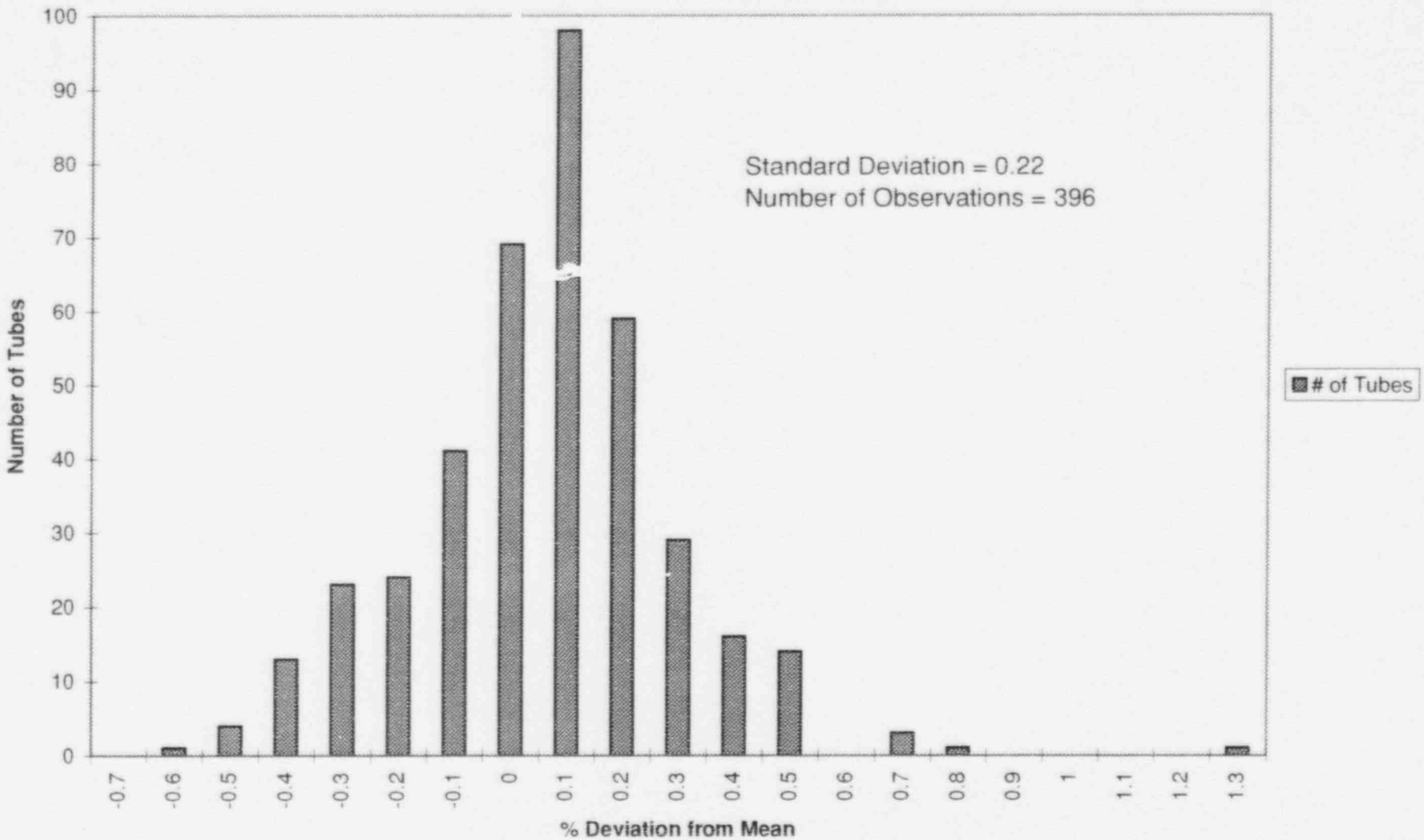


200 Tube Blind Test Distribution of Tube Mean
Figure A.2



100 Tube Blind Test Distribution of Analyst % Deviation from Mean

Figure A.3



200 Tube Blind Test Distribution of Analyst Deviation from Mean
Figure A.4