Meeting Hand-out Materials

for February 21, 2002

Meeting on ODSCC Database

Attachment 2

ODSCC Data Base

NRC Meeting

Feb 21, 2002

NEI

ATTACHMENT 2

Agenda

- Introduction
- ODSCC ARC Leak Rate Correlation & Simulation
- Combining 3/4 and 7 /8 Inch Data Bases
- Response to NRC RAIs
- Future Actions

Introduction

- Issues with the 7/8 inch correlation
  - Small data set
  - Atypical data points
  - Latest tube pull data point resulted in a "*p*" value greater than 5%

Introduction

- BV-1 90 day report submitted Jan 2, 2002
- Industry is pursuing resolution to 7/8 inch correlation issues per the ODSCC data base protocol
  - Analysis refinement
    - Sampling the regression line slope
  - Data base utilization
    - Combining data for 3/4 and 7/8 inch tubes with a 15 volt cutoff
- Awaiting resolution of Addendum 4 request to use exclusion criteria 2c to exclude French data

NEI

Introduction

- Industry action plan – meets 90 day requirement in Protocol #5
  - Discussing potential database changes with NRC today
  - By April 2nd
    - Issue a revision to the database including BV-1 data and issue resolution by letter report
    - Revise WCAP 14277 to delineate the application of the "*p*" value based on sampling the slope of the regression line

NEI

Introduction

- Analysis refinement
  - We will effectively sample the "*p*" value to more accurately reflect the data
  - Industry believes that our analysis changes fall within the guidance of GL 95-05
    - GL does not limit the application of "*p*"
    - Refined analysis will yield results that are more conservative when a correlation is applied
    - NRC approval is not required

Introduction

- Data base utilization
  - We will limit the data base to the 15 volt range needed for ARC applications and merge 3/4 inch leak rate data with 7/8 inch
  - Industry believes that these changes fall within the guidance of GL 95-05 and meets good statistical practice
    - Resolves NUREG 1750 issue
    - We do not view this as a new exclusion criteria
      - Therefore NRC approval is not required

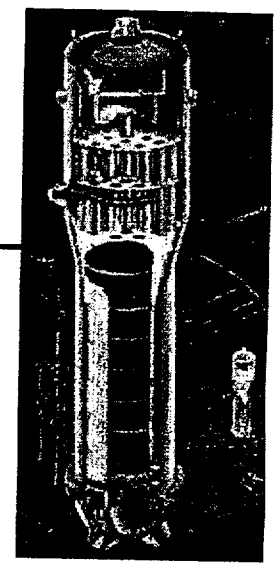
Introduction

- Exclusion Criteria 2c
  - Excluding French data was the initial recommendation of the industry after reviewing the data
    - Causes inaccuracies in the POL curve relative to domestic experience
    - Inaccuracies do not represent a real safety issue but are an artifact of statistical modeling
  - Justification provided in Addendum 4
    - NRC approval is required

NEI

Future Actions

- Industry will issue a letter report by April 2nd
  - New correlations based on a combined data set
  - Guidance on sampling "*p*" value
- Following the April 2nd letter report, licensees will evaluate the impact of the revised data base on their postulated leakage for their current cycle
  - If a problem is identified, it is expected that this evaluation will be documented in each plant's corrective action program
- Licensees with RFOs after April 2nd will use the information supplied by the April 2nd letter report



ODSCC ARC Leak Rate Correlation & Simulation by Monte Carlo Methods

Bob Keating

Nuclear Services Division

Westinghouse Electric Company

ATTACHMENT 3

Purpose of the Meeting

- ODSCC ARC are based on the use of associations of performance variable magnitudes with the bobbin amplitudes of the indications.
- The addition of Plant P1 pulled tube data significantly affects the use of the leak rate correlation at SLB of 2560 psi.
  - The net result is considered unacceptable by the industry and results in evaluation differences between plants with the same tube size.
- Two approaches are being presented today to deal with the issue.
- Topic of this presentation is an approach to bring about an analytical resolution of the issue.

Topics of Discussion

- Describe ARC — ODSCC at TSP intersections.
- Requirements — Generic Letter 95-05
- Correlations — Regression Relations
- Simulation Methods — WCAP-14277
- Recommended Approach —
  - Base the simulation on sampling of the slope.
    - ▸ Simulate the database regression for slopes > 0.
    - ▸ Simulate as uncorrelated for slopes ≤0.
  - This has been loosely referred to as sampling of the *p* values.

Alternate Repair Criteria — ARC

- ODSCC ARC in use for indications at TSP locations since 1992.
- The bases for leaving indications in service in affected SGs are the results of simulating known and expected indications in the SG.
  - Probability of detection and plugging defines the population in service.
  - Growth is used to define the EOC population.
  - The probability of burst during SLB is calculated.
    - Probability of burst is not a topic of discussion today.
  - The total potential leak rate during a SLB is found by considering both the probability of leak and the leak rate from indications expected to leak.

Requirements Documents

- GL 95-05 was issued in 1995 delineating the NRC staff position and guidance on and requirements for the evaluation of the indications.
  - Consideration of uncertainties in the parameters of correlating relations.
  - Rules for using the correlating relations.
- An industry generic methods report was first issued in 1995 which formalized the simulation methods for future evaluations.
  - NRC concurrence with the elements of the methods described was obtained in 1995, and,
  - In 1997 for a 1996 revision to the report.

Elements of the Simulation Process

- Identification of a correlating relationship to the bobbin amplitude as the independent variable.
  - Estimation of the parameters of the relationship.
  - Loglogistic relation for the probability of leak.

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

  - Log-Log linear relation for the leak rate.

$$\log(Leak) = b_3 + b_4 \log(Volts)$$

Steps in the Simulation Process

- Determine distribution parameters for population relations.
  - Population parameters are found from sample parameters.
  - Standard deviation as the square root of the variance, which is distributed as Chi-Square.
  - Intercept and slope as bivariate normal using population variance-covariance matrix and normal distribution.
  - Mean using population variance and normal distribution.
- Simulate all of the indications in a SG using the population parameters.
  - Save the leak rate, etc. and repeat tens of thousands of times.
  - Obtain the 95th percentile from the saved values.

Simulation Requirement of Interest

- The requirement for the simulation of the leak rate is as follows:

> Use of the linear regression fit of the logarithm of the conditional leak rate to the logarithm of the bobbin voltage is subject to demonstrating that the linear regression fit is valid at the 5-percent level with a "*p*-value" test. If this condition is not satisfied, the linear regression fit should be assumed to have a zero slope (i.e., the linear regression fit should be assumed to be constant with voltage).

- The *p* value is the probability of observing the slope value when there really is no correlation.
- Examination of the *p* value is a statistical significance test and not a measure of scientific significance.

Application — Methodology of WCAP-14277

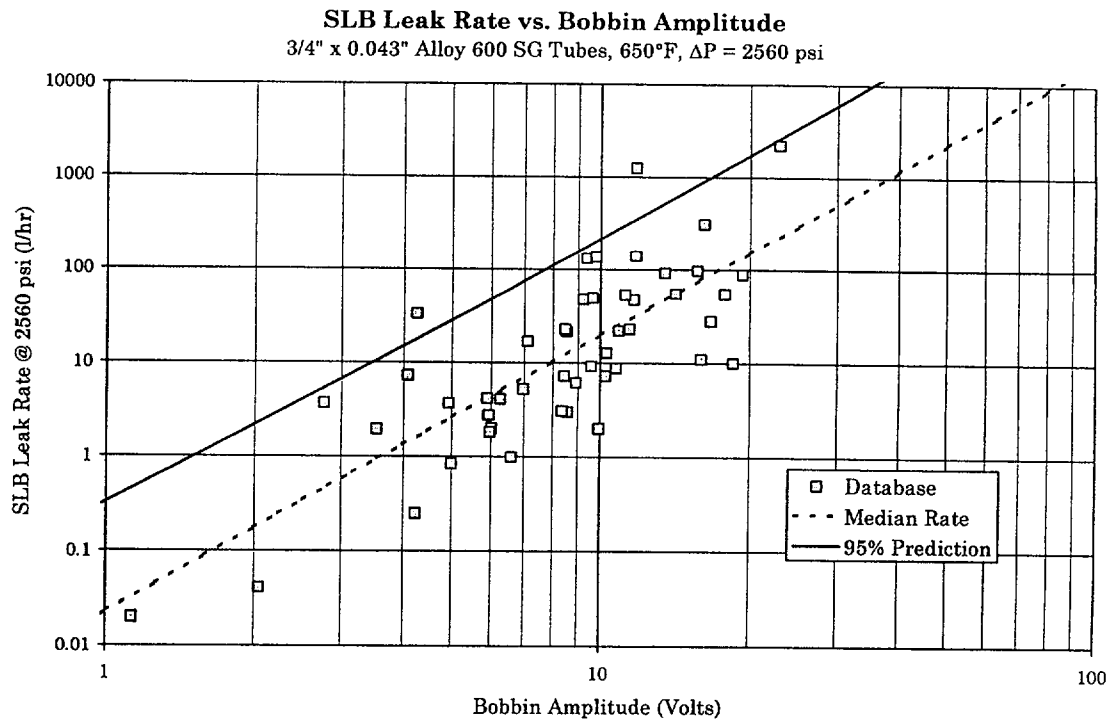
- For $p \geq 5\%$, leak rates are simulated without the regression line.
  - The simulated standard deviation and mean of the population are used for all trials.
  - ***The leak rate of indications that leak is assumed to be independent of the bobbin amplitude.***
- For $p < 5\%$ the leak rates are simulated with the regression line.
  - The slope and intercept are used for all trials.
  - ***Some simulations are performed with a negative slope.***

So, the regression line is only used when there is <u>about</u> a less than 1 in 20 chance that a correlation does not exist.

Data for 3/4" Tubes

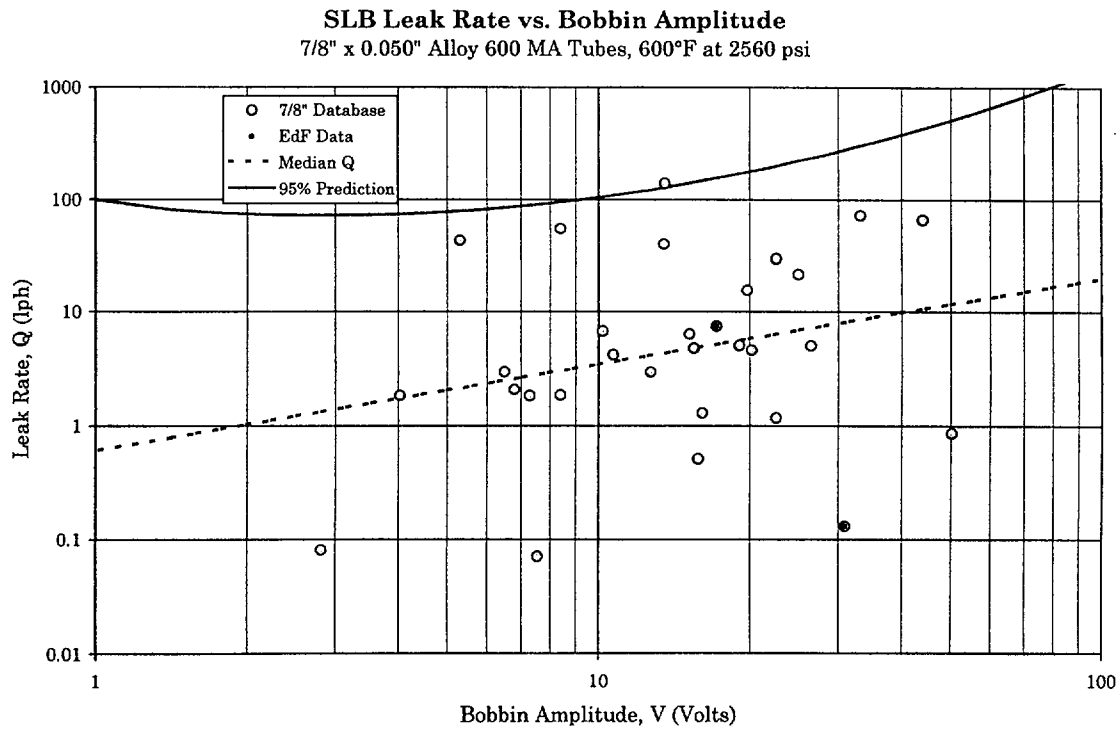
- The spread of the data for the 3/4" tubes is about two decades.

- There is a large body of data for small amplitudes.
- The slope of the log-log regression is about 3 and the *p* value is quite low.
- Cut-off at 15 V: b_3 = -1.8; b_4 = 3.1; *p* = Very Small.

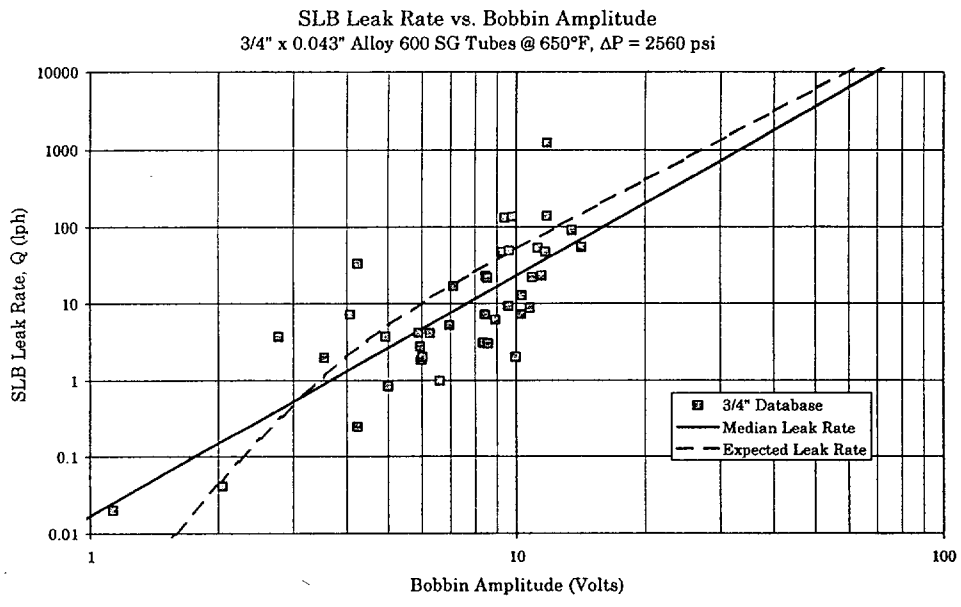


Data for 7/8" Tubes

- The spread of the data for the 7/8" tubes is about three decades.
- There are limited data for small amplitudes.
- The slope of the log-log regression is about 1 and the *p* value is in the range of 3 to 8%.
- Cut-off at 15 V: b_3 = -1.8, b_4 = 2.7; *p* = 2.1%.

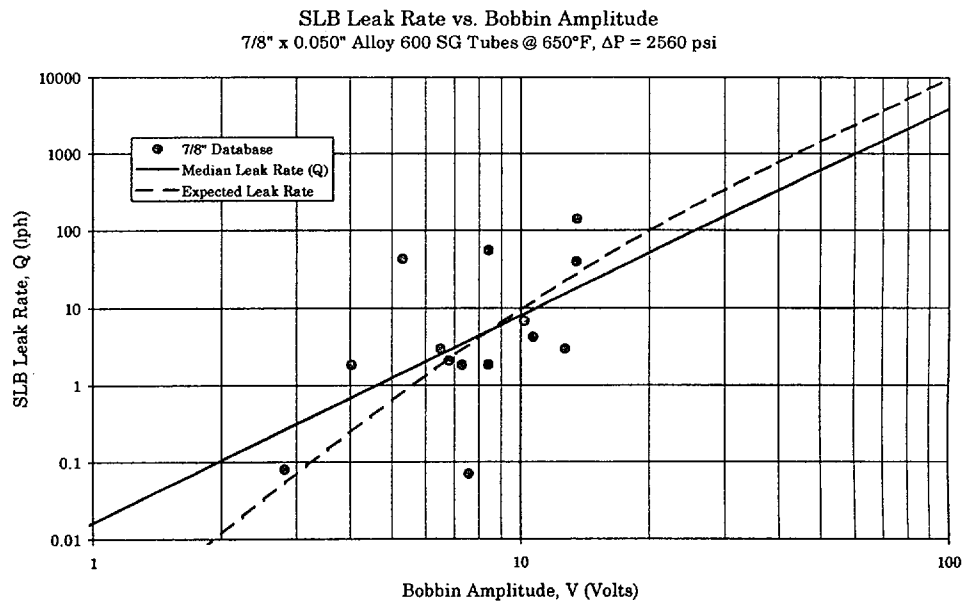


Regression for < 15 Volts, 3/4" & 7/8" Tubes



- They both have *p* values that are less than 5%
- Slopes and intercepts likely drawn from the same population

- The intercepts are similar.
  - They would not be expected to be identical.
- The slopes are similar.



"Don't Forget Nonstatistical Knowledge"

- The bobbin amplitude and the leak rate are both measures of the severity of degradation.
  - It is expected that they are correlated.
- The results of the 3/4" evaluation are more in line with expectation than the results of the 7/8" evaluation if all of the data is used.
  - Both sets of results are in line with expectation over the range of interest of application, i.e., ≤15 Volts.
- It is unreasonable to continue to use the slope for all simulations only if it has a 1 in 20 chance of not being zero when the leak rate is also reported at the 1 in 20 level.

Discussion

- The simulation methodology already accounts for the possibility that there is no correlation.
  - The current implementation applies a statistical test twice, the first to use the correlation and the second to bound the predicted leak rate.
- As data is added to the analysis, it is expected that the *p* value will fluctuate.
  - Sometimes < 5% and sometimes > 5% for 7/8".
  - It is inappropriate to require this fluctuation.
- Plants with SLB limits of 2405 psi would still get to use the correlation while plants with a higher limit would not.

Decision Rule and Error Background

- The application of the *p* value test is a decision rule.
  - The decision rule is based on comparing one hypothesis against another.
    - Null Hypothesis: H_0 is that the slope β_4 is zero.
    - Alternate: H_1 is that the slope β_4 is > zero.
  - The *p* value is the probability of rejecting H_0 when it is true.
- Potential Errors
  - Type I error occurs when H_0 is rejected and it is true.
    - Probability is denoted as α.
  - Type II error occurs when H_0 is not rejected and it is false.
    - Probability is denoted as β (not a parameter).

Power of a Test

- Power = Probability that the null hypothesis will be rejected.
  - The null hypothesis is that there is no effect, it is usually desired to reject it.
  - Reasonable to design experimental tests with high power.
  - Function of the magnitude of the variable, the standard deviation and the number of data.
- The power in the 7/8 inch case is low, about 40%.
- Probability β for a Type II error is about 60%.
  - Not rejecting the null hypothesis when it is false is likely in the case of the 7/8" diameter tubes.
- Analysis of field tubes is not a laboratory experiment and the statistics alone should not be the basis for not rejecting H_0.

Analysis Refinement

- Eliminate the potential for zero and negative slopes to be used.
  - A zero slope from the regression has a lower standard deviation than the case of no correlation.
- Evaluate the intercept and slope regardless of the *p* value.
  - If the slope is ≤ 0 discard the intercept and slope values and simulate the SG indications using the population mean and standard deviation.
    - ▸ Conservative relative to zero slope.
  - If the slope is > 0 proceed with the simulation using the regression line and the population standard error about the regression line.
- Increases the conservatism when a correlation is being used.

Effect of the Analysis Refinement

- Utilizing the uncorrelated leak rate produces excessive conservatism.
- The effect is conservative when a correlation is used for a SLB ΔP=2560 psi.

Test Case	Correlation *p* Value	Uncorrelated Leak Rate (GPM)	Sampled *p* Leak Rate (GPM)	Unsampled *p* Leak Rate (GPM)
7/8 - 1	3.5%	N/A	6.2	5.6
7/8 - 2	3.5%	N/A	0.51	0.49
7/8 - 3	3.5%	N/A	0.96	1.0
7/8 - 1	7.9%	34.3	14.5	14.1
7/8 - 3	7.9%	7.6	2.5	2.5

Summary

- The analysis refinement for the simulation approach can be interpreted to be within the guidance of GL 95-05.
  - The net effect is to not simulate the regression line for about *p* fraction of the simulations of the total SG.
- The change is technically supportable and relies on <u>both</u> statistical and scientific information.
  - The current approach is statistical only and ignores other pertinent information.
  - Conservatism is increased relative to using the correlation alone.
- The refinement makes the treatment of 3/4" and 7/8" tubes consistent regardless of SLB pressure.

Merging of 3/4" and 7/8" SLB Leak Rate Data

NRC/Industry Meeting
February 21, 2002

Presented By:
T. A. Pitterle
Westinghouse Electric Company Consultant

ATTACHMENT 4

Merging of 3/4" and 7/8" SLB Leak Rate Data

Objectives

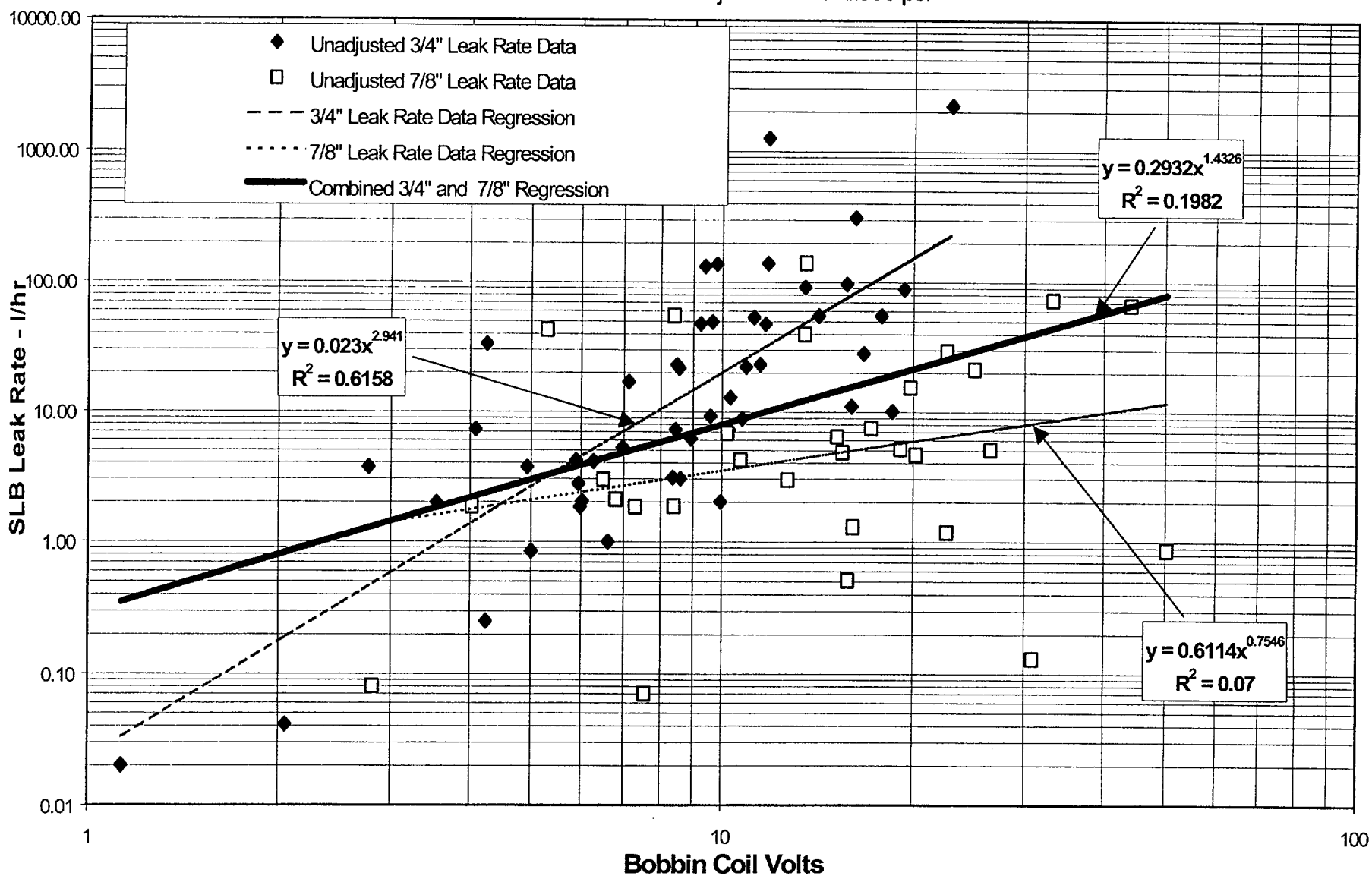
- Assess limitations of 7/8" leak rate database
  - Address ACRS NUREG-1750: "The databases for 7/8" tubes need to be greatly improved to be useful"
  - Assess causes for major differences between 7/8" and 3/4" databases
  - Conservative merging 3/4" data with 7/8" data
- Recommend method for defining 7/8" SLB leak rate correlation

Differences Between 7/8" and 3/4" Database and Correlations

- Unexpected difference in slopes between correlations
  - Slope of 7/8" correlation much smaller than the 3/4" data, which show a strong leak rate correlation
  - For leak rate versus throughwall length correlations, the slopes are nearly the same for both tube sizes
    - o Use of voltage as correlating parameter would not be expected to cause a large difference in slopes between tube sizes (confirmed by assessments presented later)
- Differences in voltage range between 3/4" and 7/8" databases
  - 7/8" database has 50% of leak rate indications above 15 volts (30% above 20 volts)
  - 3/4" database has 15% of leak rate indications above 15 volts (2% above 20 volts)
  - Identified as major cause for differences in leak rate correlations

Combined Unadjusted Leak Rate Correlation - 7/8 and 3/4 Data - All Data

Combines Data without Adjustments at 2560 psi



Potential Causes for Differences in Leak Rate Correlations

Potential Errors in 7/8" Leak Rate Measurements

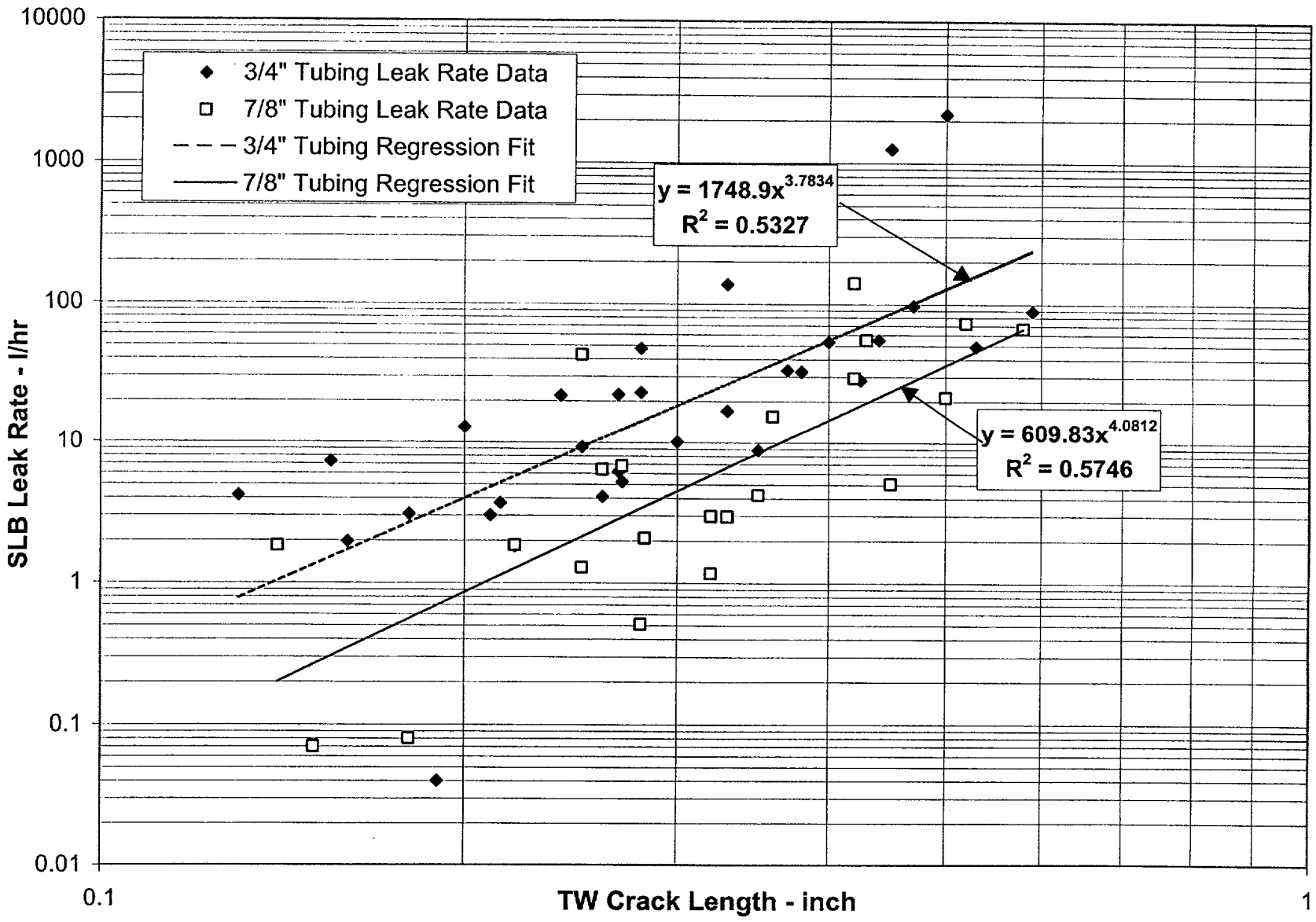
- Large fraction of database leakage measurements performed in same facility by nearly the same personnel
  - All model boiler leakage measurements performed at Westinghouse in same facility and by same personnel
  - Large fraction of pulled tube leakage measurements also performed at Westinghouse with nearly the same personnel
  - Leakage measurement differences not a likely cause of correlation differences

Potential for Deposits Reducing Leakage in 7/8" Data

- Same water composition used in 3/4" and 7/8" model boiler leakage measurements
- Effects of deposits in cracks
  - Deposits can potentially have significant effects on short crack leak rates
  - For long (greater than about 0.3 to 0.4") cracks at SLB conditions, the crack openings are sufficient to pass deposits with negligible effects on leak rates
  - If present in 7/8" data, a steeper slope would be expected on leak rate versus throughwall length trends
    - o No significant differences in slope between 3/4 and 7/8" data - both ODSCC datasets have expected slopes near exponent of four on TW crack length
- Deposit effects may be a contributor to a few lower than expected leak rates in both 3/4" and 7/8" data but trends with TW length do not support effects on a large fraction of the data

Axial ODSCC SLB Leak Rate versus Throughwall Crack Length

ARC Leak Rate Database > 0.1 inch



Potential Causes for Differences in Leak Rate Correlations

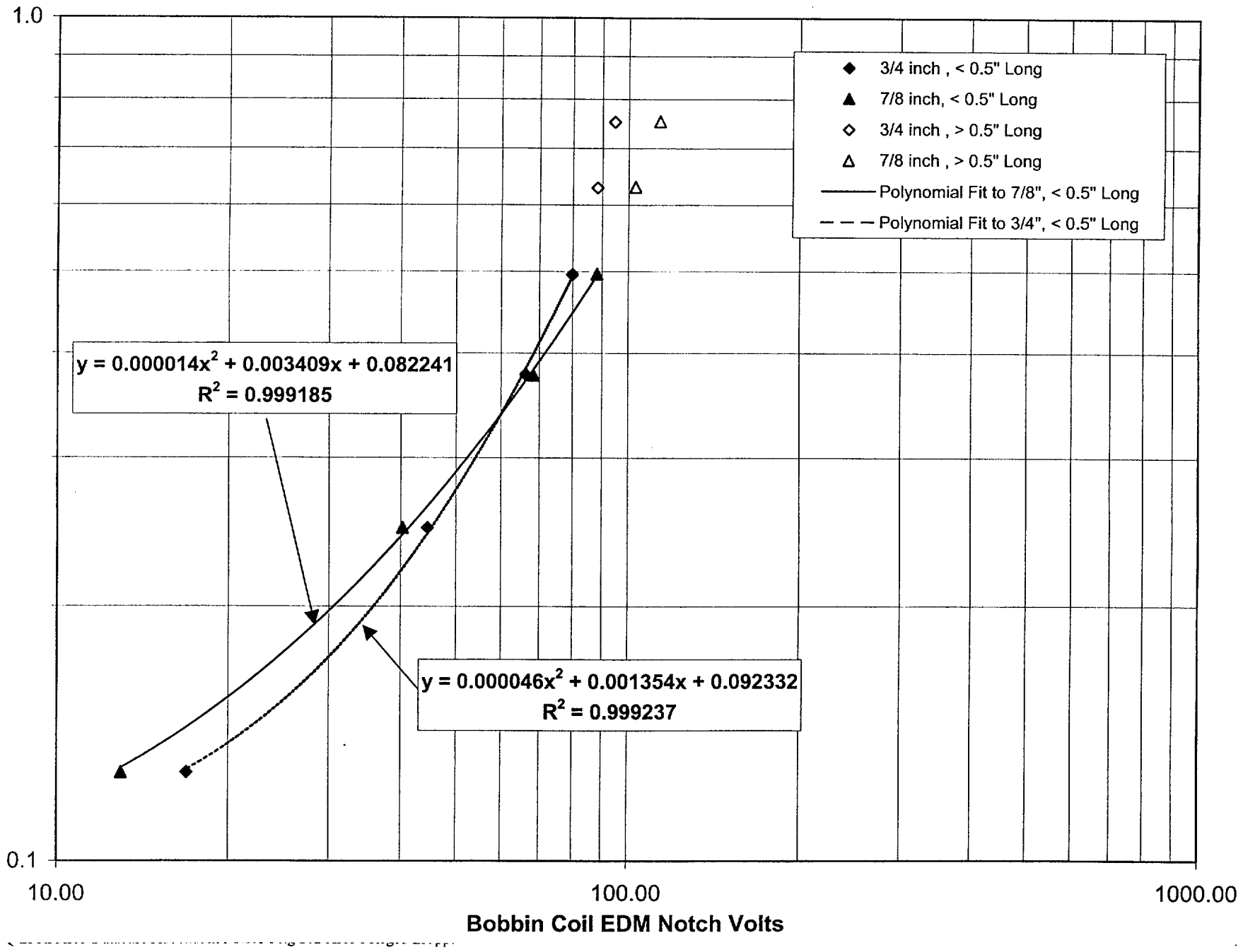
Potential Differences in Bobbin Voltage Responses Between 3/4" and 7/8" Tubing

- Potential voltage differences can be assessed by comparing TW length versus volts responses for the two tubing sizes

3/4" and 7/8" TW Length to Voltage Relations

- Based on TW EDM notches from 1/8" to 3/4" long
- Bobbin coil voltages cross calibrated to ARC reference standards
- Averages of 10 repeat voltage calibrations and measurements
- Regression analyses to correlate TW length with bobbin voltage
  - Correlation cut off at 0.5" TW length which represents range of database indications
  - Correlations used in quantitative assessments for merging data
- A constant voltage ratio between 3/4" and 7/8" tubing does not exist
  - Data cannot be adequately merged based on a constant voltage ratio
- 3/4" voltages saturate with TW length faster than 7/8" as length tends to exceed the effective coil field length, which leads to a crossover point in the correlations
- Differences in voltage are small (about 20% at 0.2" TW) compared to leakage measurement uncertainties and would not have a dominant effect on combining the data sets

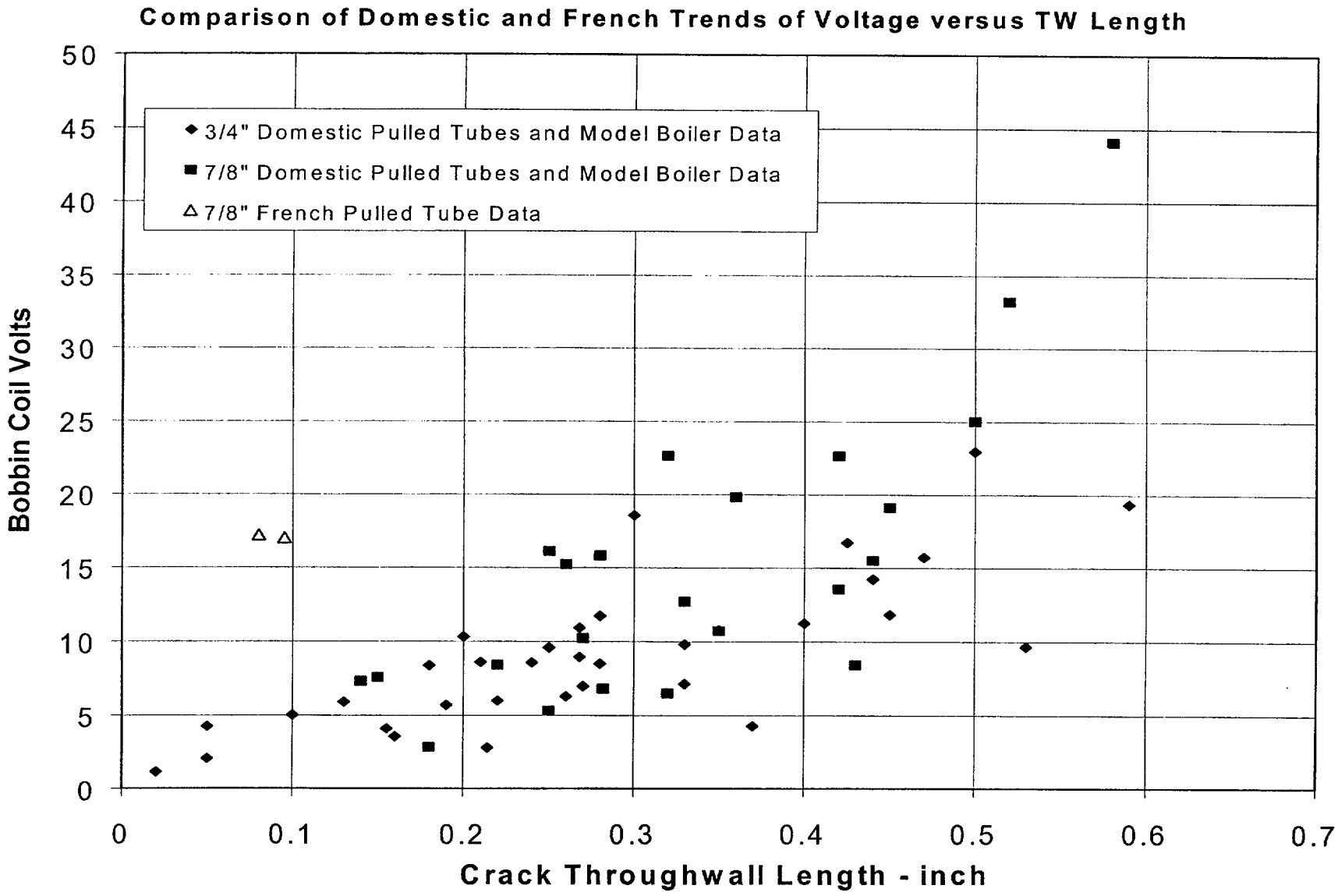
Throughwall Length vs. Bobbin Coil EDM Notch Amplitude



High Voltage Indications as Causative Factor

Contributors to High Bobbin Voltage Indications

- Long TW lengths
  - Voltages tend to increase exponentially with depth and then again exponentially with TW length
    - o TW length effects potentially important for leakage considerations
  - Extreme effects limited by voltage saturation with length but this effect is beyond the TW lengths of interest to ARC correlations
  - For indications with a dominant single crack, the voltages are < 20 volts for TW lengths up to 0.59"
- Multiple deep cracks around circumference of tube
  - Multiple deep cracks (TW or near TW) needed to obtain high voltages such as > 15 to 20 volts within range of TW lengths encountered in ARC (≤ 0.5" for pulled tubes, < 0.6" for model boiler specimens)


Comparison of Domestic and French Trends of Voltage versus TW Length
3/4" Domestic Pulled Tubes and Model Boiler Data
7/8" Domestic Pulled Tubes and Model Boiler Data
7/8" French Pulled Tube Data
Bobbin Coil Volts
50
45
40
35
30
25
20
15
10
5
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
Crack Throughwall Length - inch

Application of Data Cutoff at 15 Volts

15 Volt Cutoff

- Based upon differences in crack morphology > 15 volts compared to < 15 volts
  - Supporting data given in responses to NRC RAI on exclusion criterion 2c
- Based upon limiting data to < 15 volts that bounds range needed for ARC applications up to at least 3 volts
  - Domestic pulled tubes are dominantly (one ¾" exception) < 15 volts

Extent of Multiple Deep Cracks in Model Boiler and French Data Indications > 15 Volts is Atypical of Data < 15 Volts

- Multiple deep crack morphology > 15 volts increases bobbin voltages above the contributions attributable to TW lengths affecting leakage
  - Effect more dominant in 7/8" leak rate correlation as 50% of indications exceed 15 volts (30% >20 volts) compared to about 15% for 3/4" correlation (2% >20 volts)
  - Number and maximum depths of model boiler and French data are comparable, but French data show much lower POL apparently due to short TW lengths in French data
- Pulled tubes and model boiler indications < 15 volts do not show multiple deep indications

Conclusion from Crack Morphology Comparisons

- SLB leak rate database should be limited to < 15 volts reflecting the range of interest for ARC applications

Combined 3/4" and 7/8" Data < 15 Volts

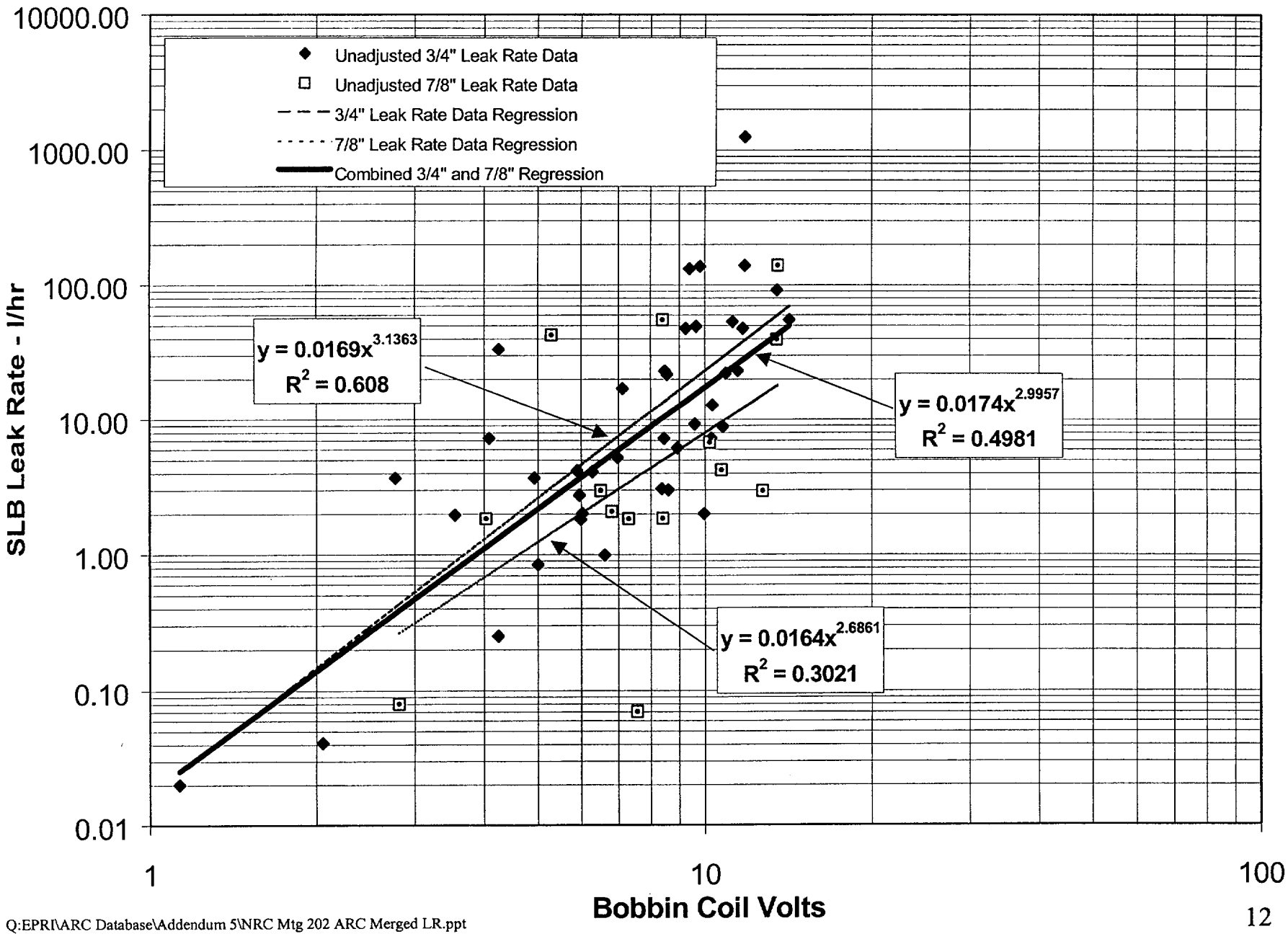
Effects of Cutoff at 15 Volts

- Good agreement between 3/4" and 7/8" data
- Nearly same slope for both sets of data
- 3/4" inch leak rates biased higher than 7/8" data
- Provides a basis for merging data sets

Conservative Correlation for 7/8" Data

Combined Unadjusted Leak Rate Correlation - 7/8 and 3/4 Data <15 Volts

Combines Data without Adjustments at 2560 psi



Methods for Adjusting and Merging Data

Methodology

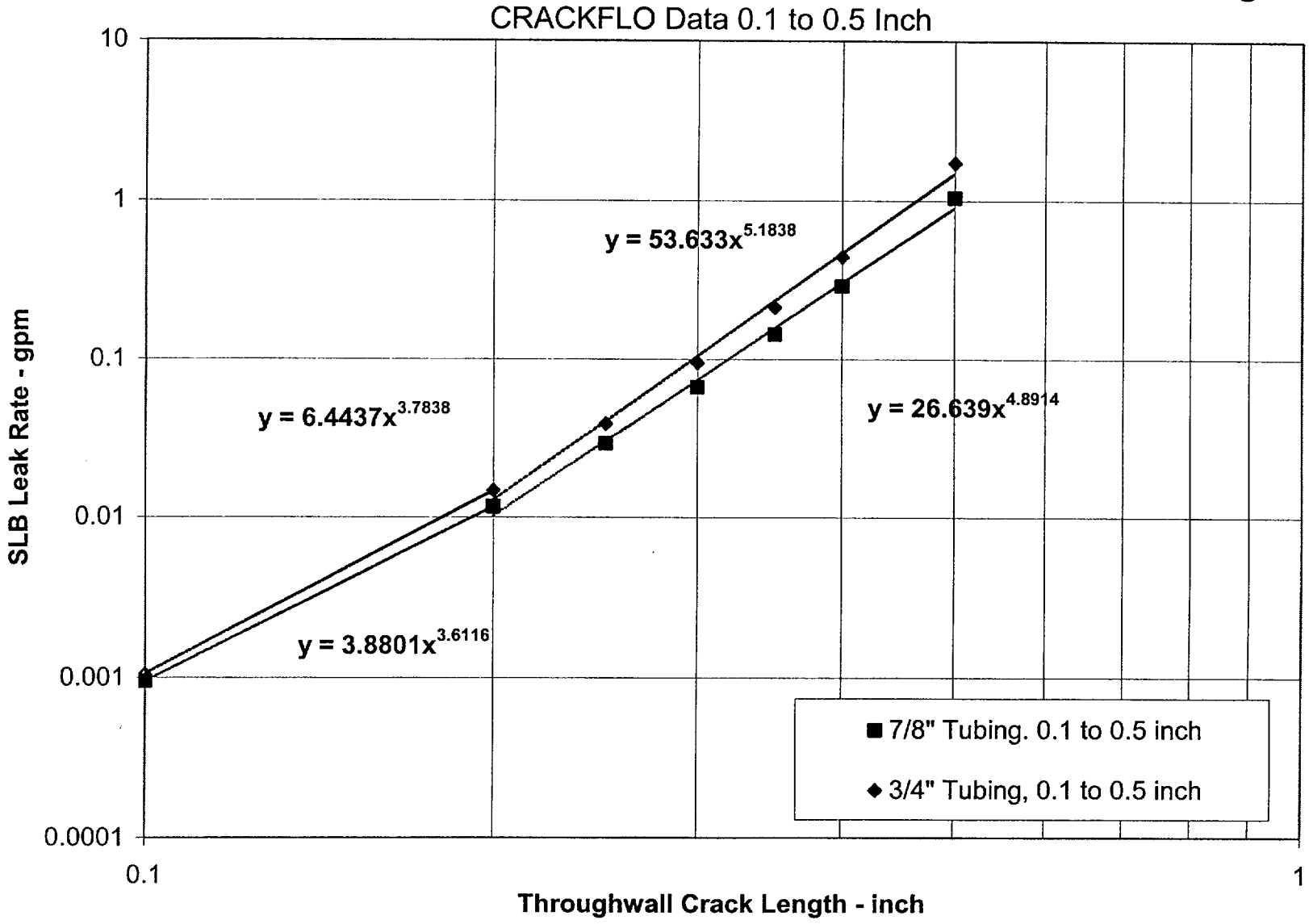
- TW length versus EDM Voltage regression analysis
  - Utilize TW EDM notches to obtain separate analyses for 3/4" and 7/8" tubing
- Leak Rate (LR) versus TW length regression analysis
  - Utilize calculated (CRACKFLO code) leak rates for 3/4" and 7/8" tubing
- Combine above to obtain Leak Rate versus EDM Voltage for 3/4" and 7/8" tubing
- From LR vs V relations, obtain ratio of 3/4" to 7/8" leak rates as a function of 3/4" leak rates
  - Ratio applied to eliminate EDM slot voltages
- Apply 3/4" to 7/8" leak rate ratio to 3/4" ARC leak rate data to obtain 3/4" leak rates adjusted to 7/8" data and combine with 7/8" data
- Apply regression analysis to combined data to obtain 7/8" SLB leak rate correlation

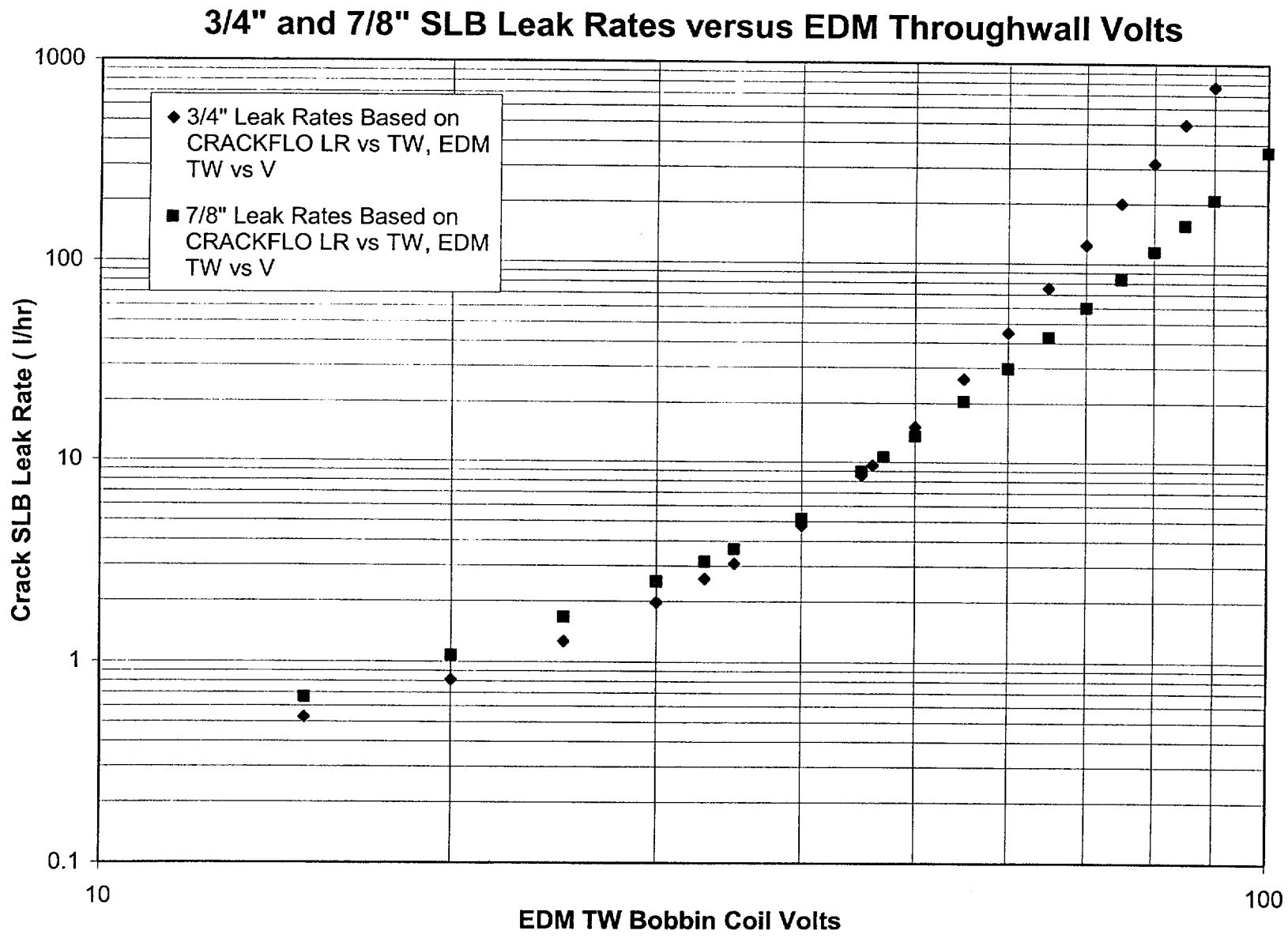
Method Limited to Leak Rate Correlations

- Dependency on TW length cannot be applied to POL or burst correlations
- Voltage ratios between tubing sizes not feasible due to non-linearity of voltage ratios

Comparisons of SLB Leak Rates for 7/8" and 3/4" Diameter Tubing

CRACKFLO Data 0.1 to 0.5 Inch




3/4" and 7/8" SLB Leak Rates versus EDM Throughwall Volts
3/4" Leak Rates Based on CRACKFLO LR vs TW, EDM TW vs V
7/8" Leak Rates Based on CRACKFLO LR vs TW, EDM TW vs V
Crack SLB Leak Rate (l/hr)
1000
100
10
1
0.1
10
100
EDM TW Bobbin Coil Volts

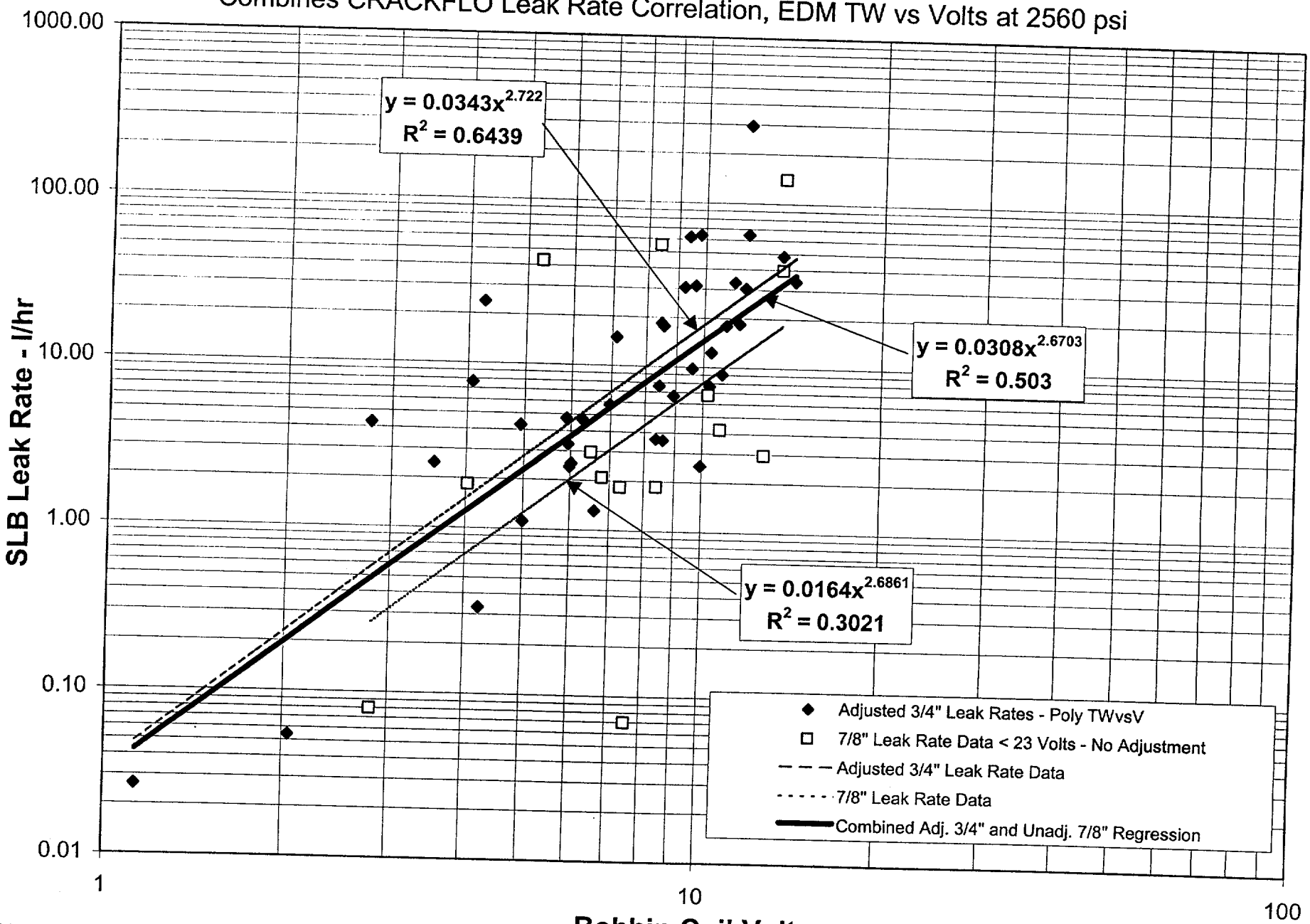
Merged Adjusted 3/4" and 7/8" Leak Rate Correlation

Results of Adjustments to 3/4" Data

- Adjustments provide modest improvement on correlation compared to combined data with no adjustments
- Adjustments to 3/4" data lead to essentially same slopes for adjusted 3/4" and 7/8" data

7/8" Leak Rate Correlation - 7/8 Data and Adjusted 3/4 Data <15 Volts

Combines CRACKFLO Leak Rate Correlation, EDM TW vs Volts at 2560 psi



SLB Leak Rate and POL Correlations

All Merged Leakage Correlations Satisfy the p-value Requirement for a Correlation with Substantial Margin

Influence on SLB Leak Rate Correlations from Including Data > 15 Volts

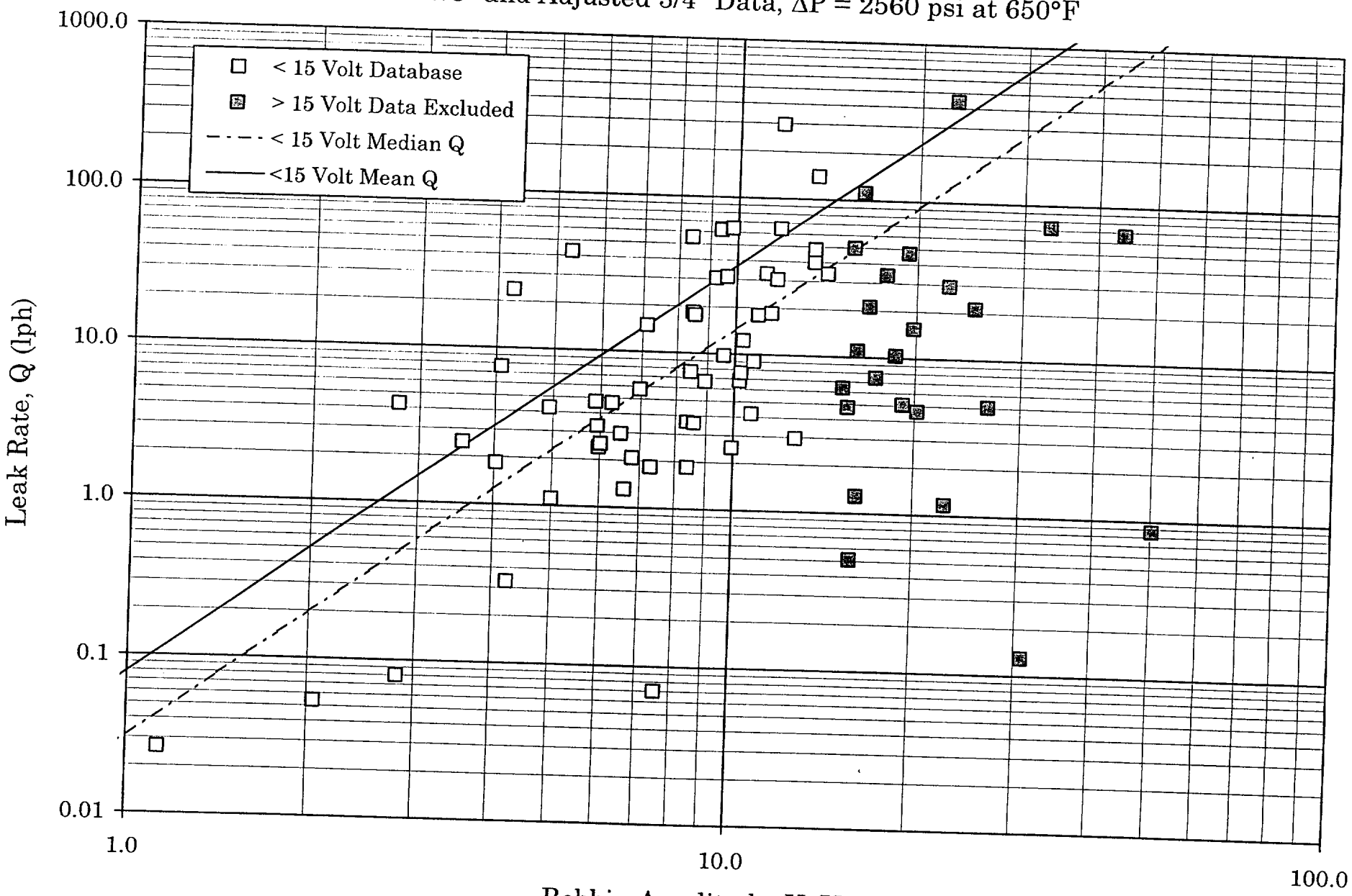
- High voltage indications reduce slope of SLB leak rate correlations to less than expected and increase uncertainty in the correlations
- Would increase leak rates for plants having low voltage indications (< 6 volts) and decrease leak rates for plants with high voltage indications
  - Contrary to expected behavior and a resulting penalty for the desired low voltage indications

Influence on POL Correlations from Including Data > 15 Volts

- For 7/8" tubing, the low leakage probability of the French data decreases the POL above about 3 volts and increases the POL below 3 volts
  - Like the leak rate correlation, the high voltage indications increase leak rates for low voltage indications and decrease leak rates for high voltage indications
  - Retaining the French data (not accepting exclusion criterion 2c) < 15 volts has a similar and larger effect on the POL correlation
- For ¾" tubing, the effect of the 15 volt cutoff on the POL correlation is negligible

7/8" SLB Leak Rate vs. Bobbin Amplitude

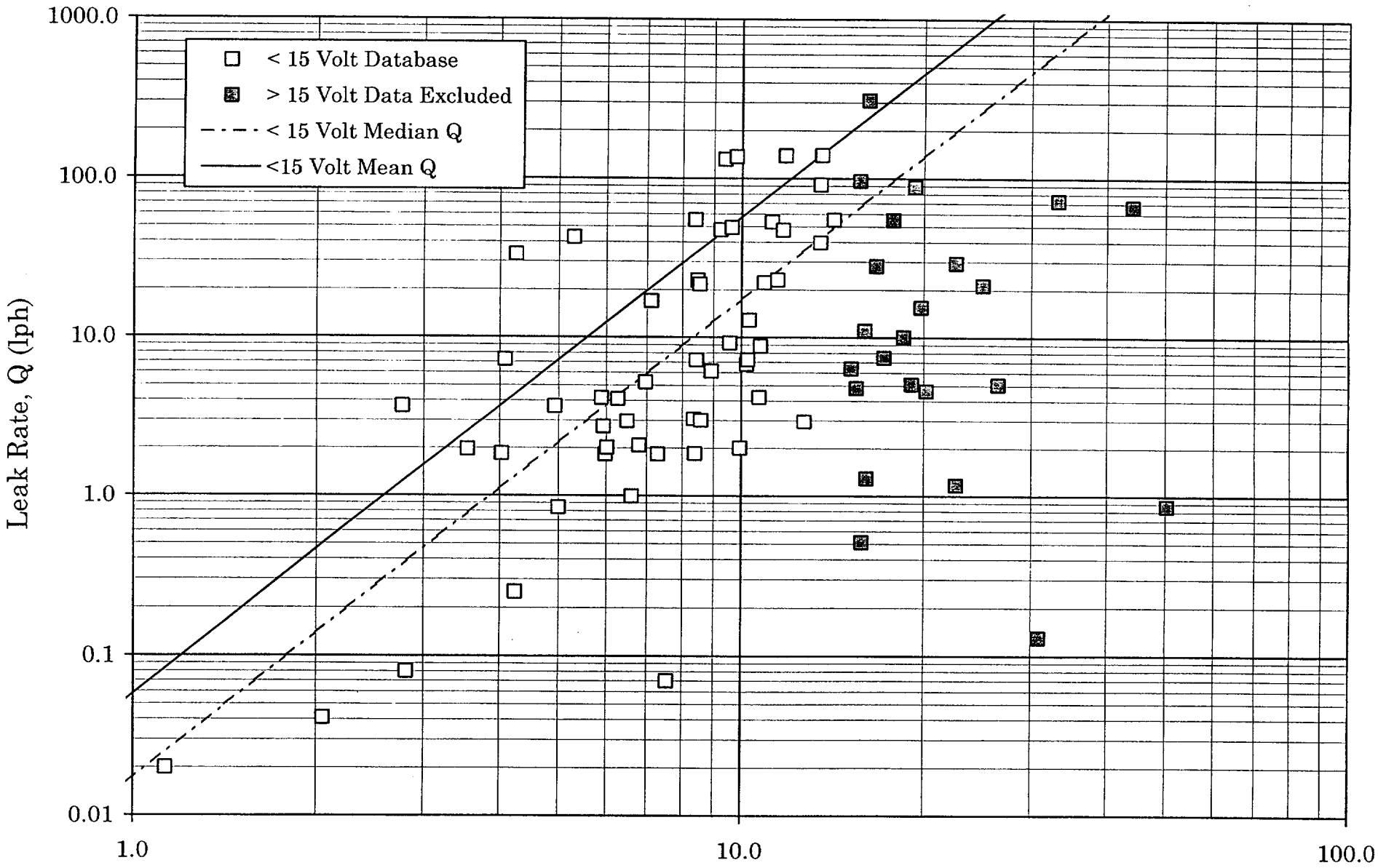
Combined 7/8" and Adjusted 3/4" Data, ΔP = 2560 psi at 650°F



Q:EPRI\ARC Database\Addendum 5\NRC Mtg 202 ARC Merged LR.ppt

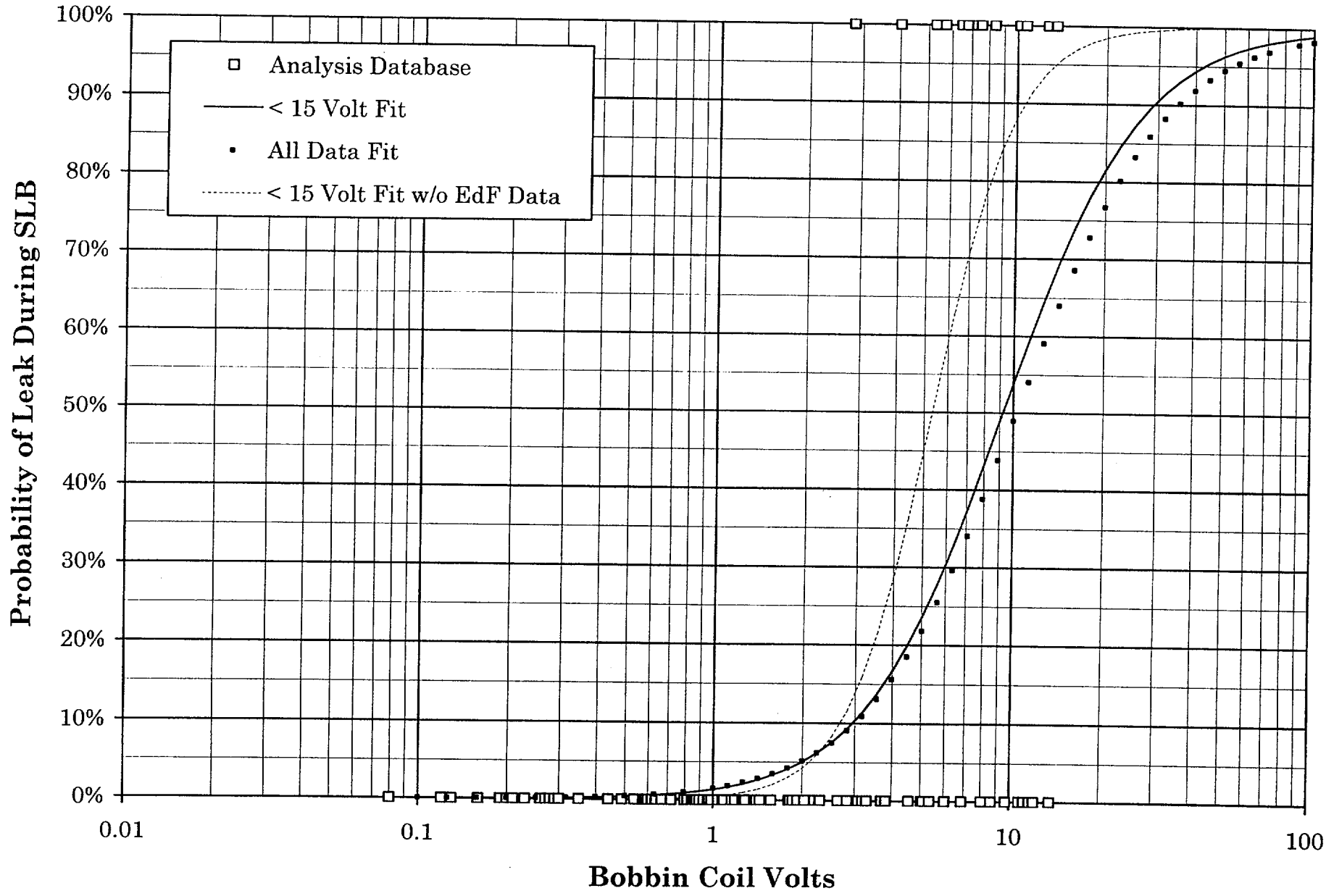
SLB Leak Rate vs. Bobbin Amplitude

Combined 7/8" and 3/4" Data Without Adjustments, ΔP = 2560 psi at 650°F



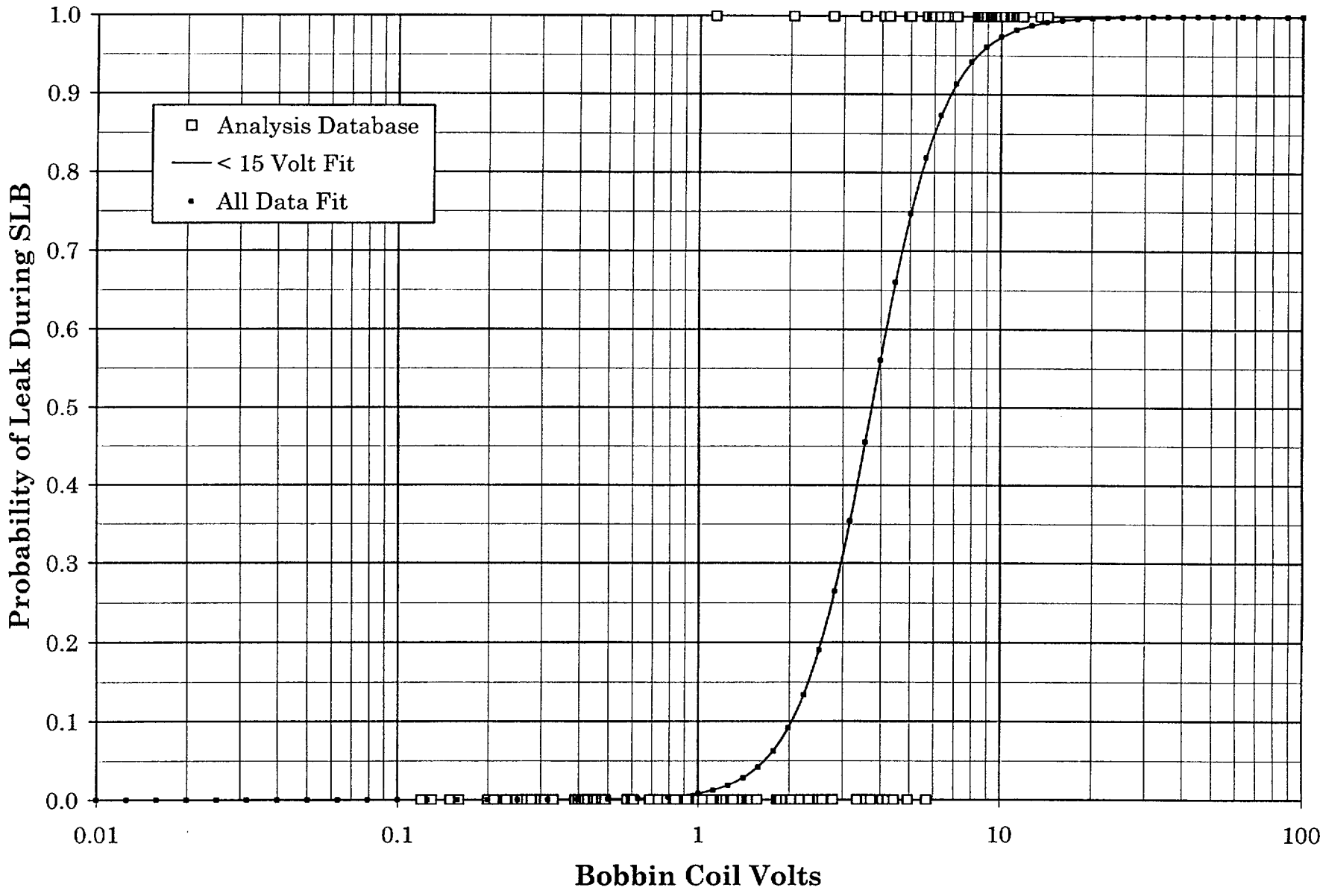
7/8" Probability of Leak vs. Bobbin Amplitude

7/8" x 0.050" SG Tubes @ 650°F, ΔP = 2560 psi



3/4" Probability of Leak vs. Bobbin Amplitude

3/4" x 0.043" SG Tubes @ 650°F, ΔP = 2560 psi



Application of Combined Correlations

2560 psi Leak Rate Data

SG SLB Leak Rate Calculation Results (gpm)				
Tube Size	Current All Data	Current Data < 15 Volts	Merged Data < 15 Volts	
			No Adjustment	Adjusted 3/4" Data
7/8"	14.1	4.12	0.169 0.153 (POL w/o EdF Data)	0.173
3/4"	0.392 22.8	0.389 23.0	0.413	

Conclusions on Merging Leak Rate Data

Leak Rate Data Must be Limited to 15 Volts to Obtain Acceptable Leak Rate Correlation

- Spans range of interest for ARC applications
- Eliminates high voltage indications resulting from multiple deep cracks around tube circumference; a morphology not significantly present in < 15 volt indications

Merging of the 3/4" Data into the 7/8" Correlation Significantly Improves the 7/8" Leak Rate Correlation

Recommendations

- Merged database should be applied for 7/8" leak rate correlation
  - Merged data without adjustments to 3/4" data recommended to simplify correlation development
    - o Although the adjusted 3/4" data provides minor improvements, the complexity of the analysis does not appear to be warranted
    - Can be applied for consistency to 3/4" correlations but not necessary due to adequacy of the 3/4" database
- Databases for leak rate, POL, and burst correlations should be cut off at 15 volts for consistency of crack morphologies within a bounding range for ARC EOC voltage indications
- Data exclusion criterion 2c should be applied to improve the 7/8" POL correlation consistency with domestic data independent of applying a cut off voltage

Responses to NRC RAI of 1/3/02 on ARC Data Exclusion Criterion 2c

NRC/Industry Meeting
February 21, 2002

Presented By:
T. A. Pitterle
Westinghouse Electric Company Consultant

ATTACHMENT 5

1. Adequacy of Combining 3/4" and 7/8" Data in Applying Exclusion Criterion 2c

Comparison of 3/4" and 7/8" Voltages for EDM Notches

- Throughwall Indications
  - 3/4" volts higher than 7/8" by about 20% (e.g., 0.2" TW) in the range of interest
- Partial Depth Indications
  - 3/4" volts lower than 7/8" by about 10% up to about 90% depth
  - Data at 90% could indicate a crossover point
- 3/4" to 7/8" voltage ratio varies between about 0.9 and 1.2

Worst Case for Criterion 2c Combined Data

- Criterion combines all data above 5 volts
- Worst case to assume 3/4" voltages lower by 1.2 factor
  - Combine 3/4" data above 4 volts with 7/8" data above 5 volts
  - Would add two leaking tubes to domestic pulled tube with no impact on Criterion 2c conclusions

Conclusions

- Application of criterion 2c not sensitive to voltage differences between 3/4" and 7/8" tubing

Figure 1

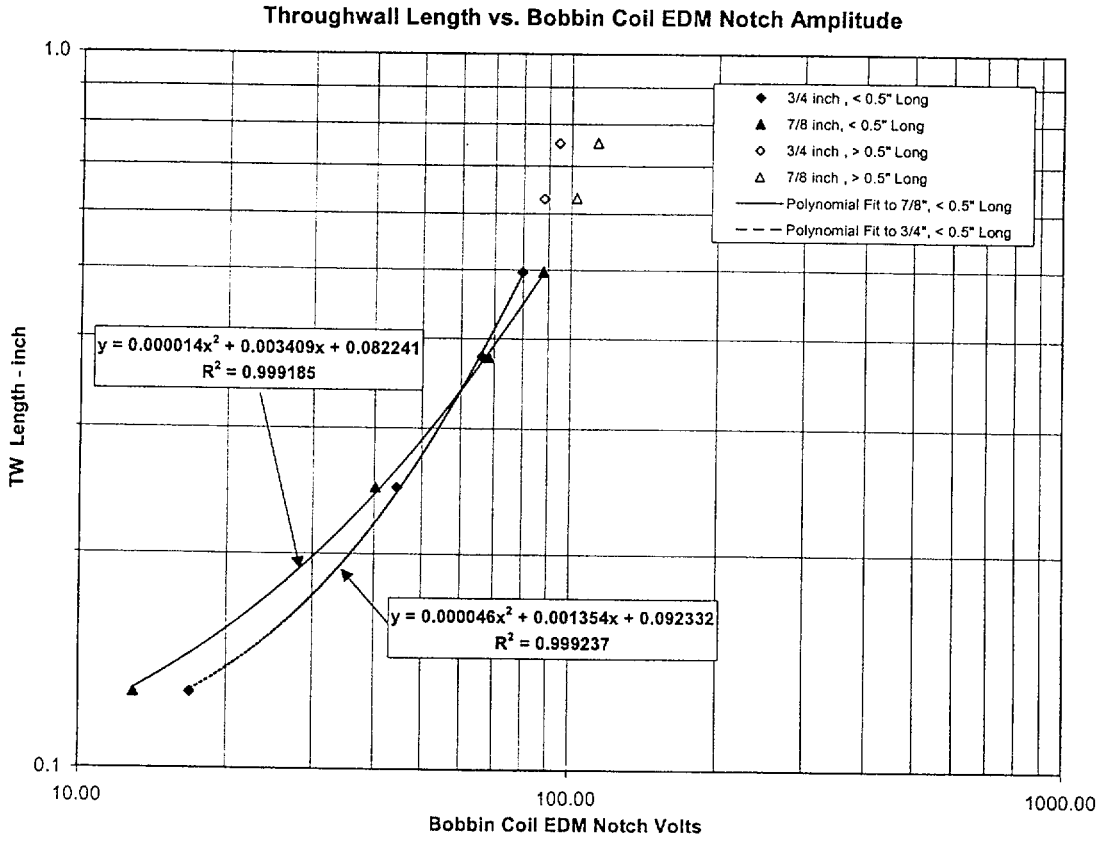
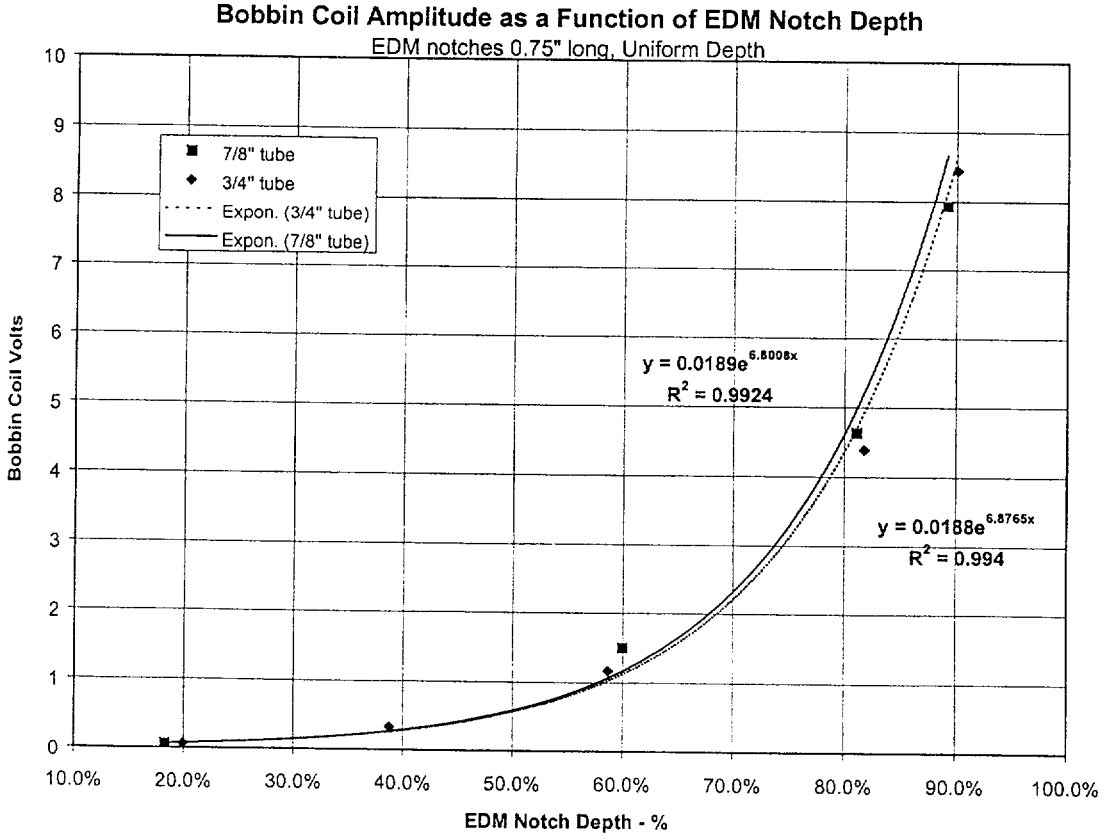


Figure 2



2-1) Compare Amount of Time French Indications Left in Service Compared to Domestic Pulled Tubes

"Time" related to formation of oxide films and increased cracking around tube circumference (part of RAI)

The important time element is the time from crack initiation to repair (or removal for examination)

- French reporting limit about 2.4 US volts compared to typical reporting of 0.2 to 0.3 volt indications domestically
  - The time required for the French indications to grow to 2.4 volts (above US ARC repair limits) cannot be obtained but could exceed US time to repair for comparable growth
- French had no required repair limit in the time frame of French Plant J-1 pulled tubes
  - No repair limit permits time for multiple deep cracking around the tube circumference and oxide formation to occur while US indications would be repaired before multiple deep cracking occurs

Conclusions

- Differences in repair limits are more influential on differences in extent of cracking than absolute time
- Plant J-1 is reported to have had thicker oxide films than other French units - chemistry may be more influential than time
- Oxide films may be a contributor to differences but is less important than extent of cracking around tube circumference

2-2) Compare Oxide Films for French Pulled Tubes with Domestic Pulled Tubes and Model Boiler Specimens

Oxide film thickness is typically not measured in tube exams so limited detail for comparisons

Plant J-1 reported to have thicker oxide films than other French SGs

- Plant J-1 data dominates the French data in the ARC database

Plant J-1 crack face deposits reported to be up to 1 um

- In some instances, easily observed on crack face SEM pictures

Domestic plants have reported oxide film thicknesses in the range of 0.01 to 0.5 um

Conclusion

- Plant J voltages would appear to be increased more by oxide film thickness than domestic plants

2-3) Compare Cracking Around Circumference Between Domestic and French Pulled Tubes

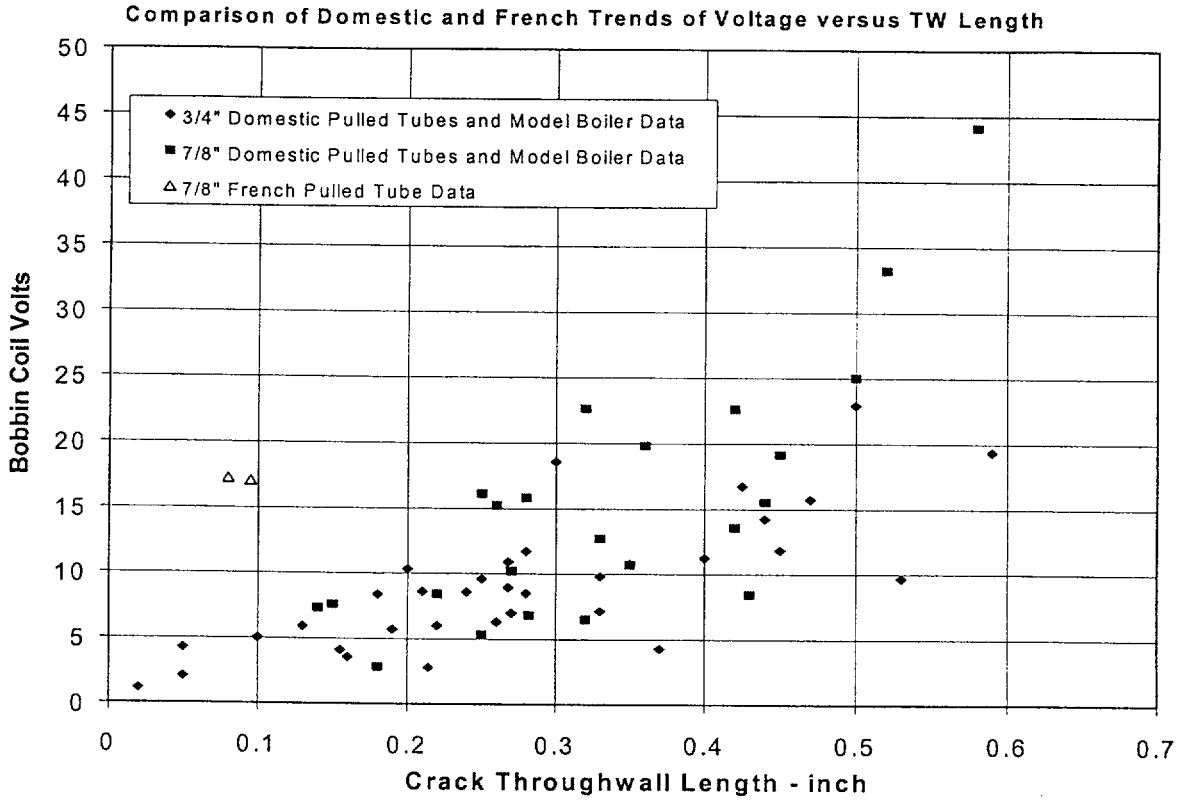
High bobbin voltages can occur from long TW indications and/or from multiple deep indications

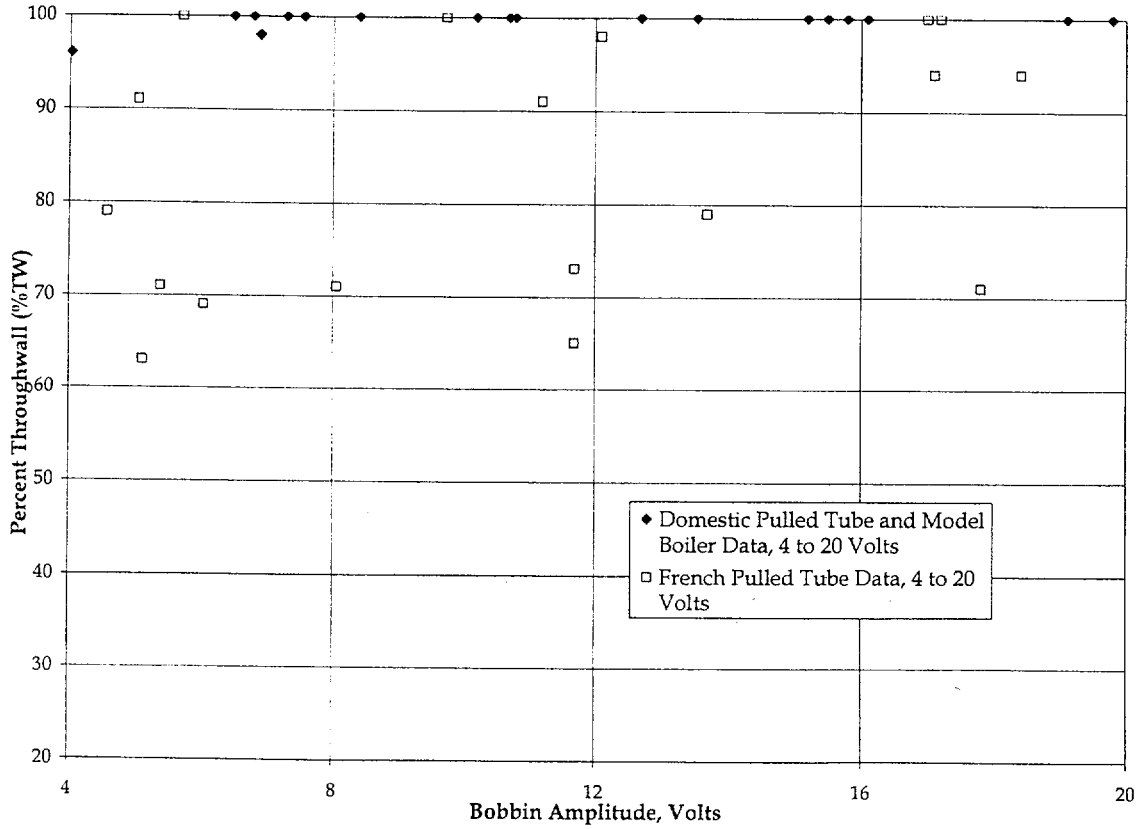
- Multiple deep indications evaluated based on transverse metallography results for domestic pulled tubes, model boiler indications and available French data
- Higher likelihood for short TW cracks in French data based on leakage potential since TW length data limited for French indications

Potential for significant (leakage) TW lengths

- ARC database shows strong trend for voltages to increase significantly with throughwall length
  - ARC indications > 10 volts have TW lengths >0.2" and leak
- French data have high voltages for short TW (<0.1" @ 17 volts) and maximum depths as low as 70% up to about 17 volts
  - High voltages for short TW and non-TW can only be attributable to multiple cracking around the tube circumference

Figure 3


Comparison of Domestic and French Trends of Voltage versus TW Length
3/4" Domestic Pulled Tubes and Model Boiler Data
7/8" Domestic Pulled Tubes and Model Boiler Data
7/8" French Pulled Tube Data
Bobbin Coil Volts
Crack Throughwall Length - inch
0
5
10
15
20
25
30
35
40
45
50
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7


Percent Throughwall (%TW)
Bobbin Amplitude, Volts
Domestic Pulled Tube and Model Boiler Data, 4 to 20 Volts
French Pulled Tube Data, 4 to 20 Volts
20
30
40
50
60
70
80
90
100
4
8
12
16
20

Crack Morphology for 3/4" Tubing Indications

Largest voltage pulled tube indications

- Indications pulled as largest voltage indications rather than based on single dominant crack (2nd criterion for tube removal)
- Indications and voltages dominated by single throughwall crack
- Only R28C41 (11.8 volts) shows significant secondary cracking over about a 60° sector

Model boiler specimens between 14 and 20 volts

- Indications and voltages dominated by single throughwall crack
- Only 596-3 (14.2 volts) shows a significant secondary crack that was TW
- No 3/4" model boiler indications above 18.5 volts

Conclusions

- 3/4" ARC database dominated by one or two TW cracks with TW length most influential on high voltage indications (< 23 volts)
- Dominant single crack morphology for higher voltage indications helps to support the good SLB leak rate correlation for 3/4" tubing

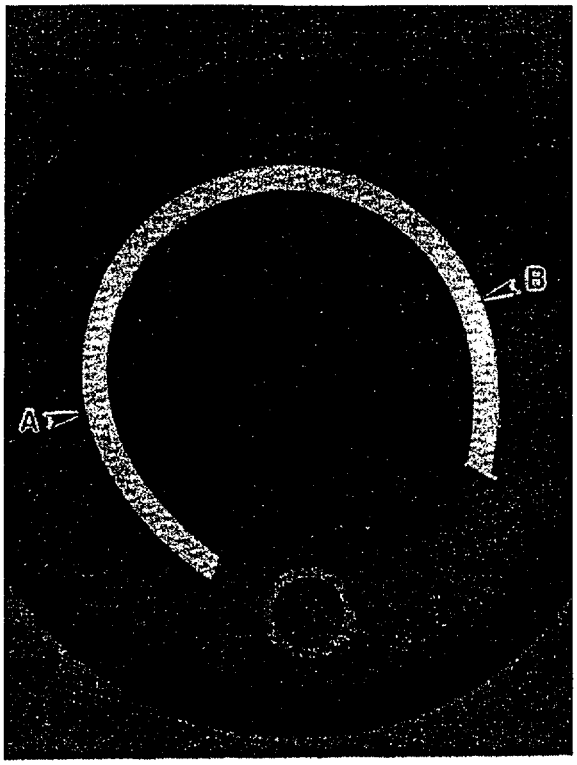


Figure 4a. Plant S, R42C43 (FDB), 22.9 Volt, 2 TW cracks ~0.5" at cutout of section. Highest voltage domestic pulled tube.

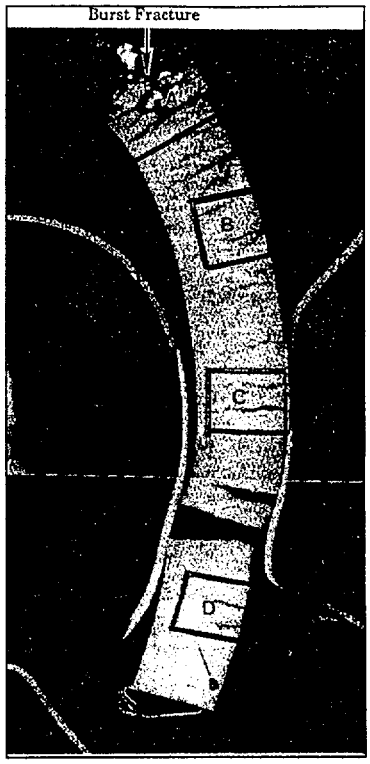


Figure 4b. Plant S, R28C41 (FDB) 11.8 volt, 0.45" TW (~0.1" TW secondary cracks), ~60° section with cracking, no other significant cracks around tube

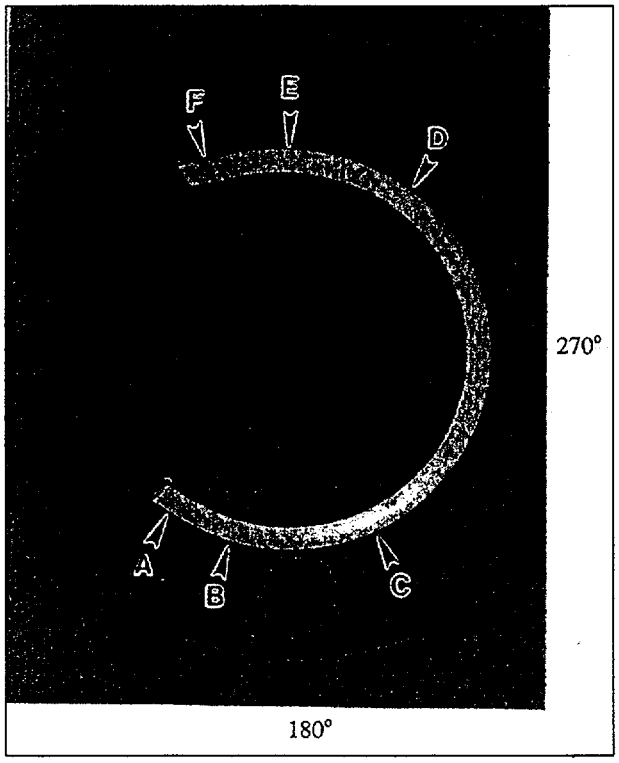


Figure 4c. Plant AB-1, R20C07 TSP3, 10.9 volt, 2 TW cracks ~0.26".

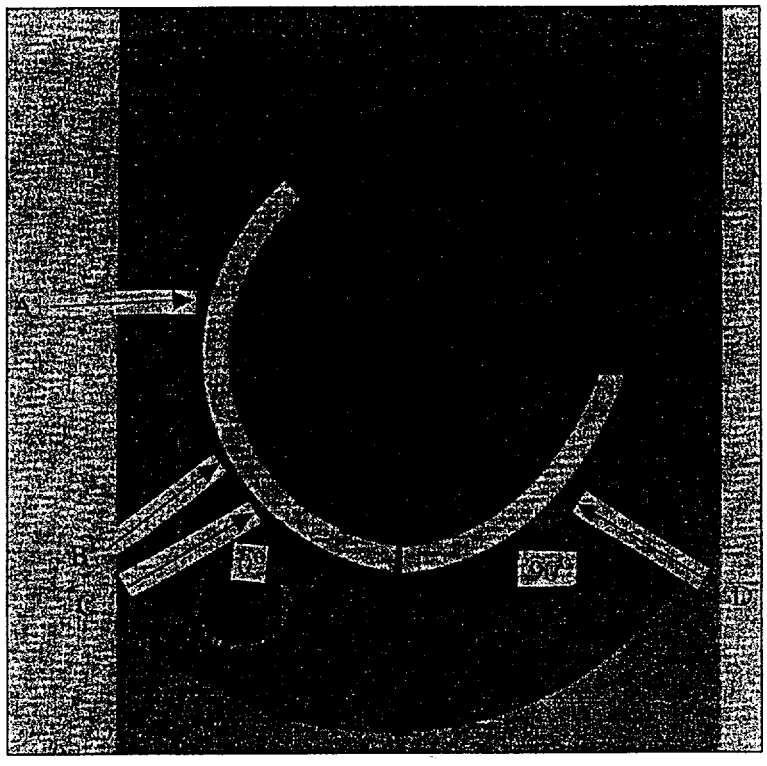


Figure 4d. Plant AA-1, R37C34 TSP5, 10.3 volt, 0.2" TW, second separation is a cut for axial metallography.

Figure 4. ¾" Pulled Tubes: Modest secondary cracking up to 23 volts (largest voltage ¾" pulled tube.

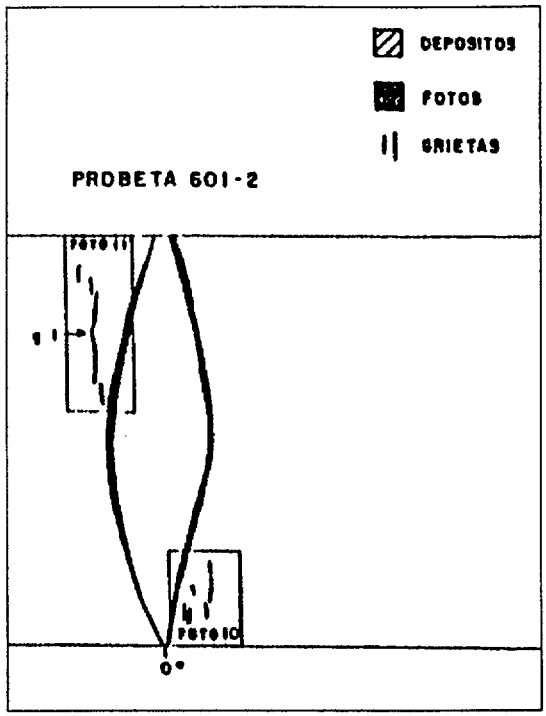


Figure 5a. Model Boiler 601-2, 19.33 volt, 0.59" TW, negligible secondary cracking.

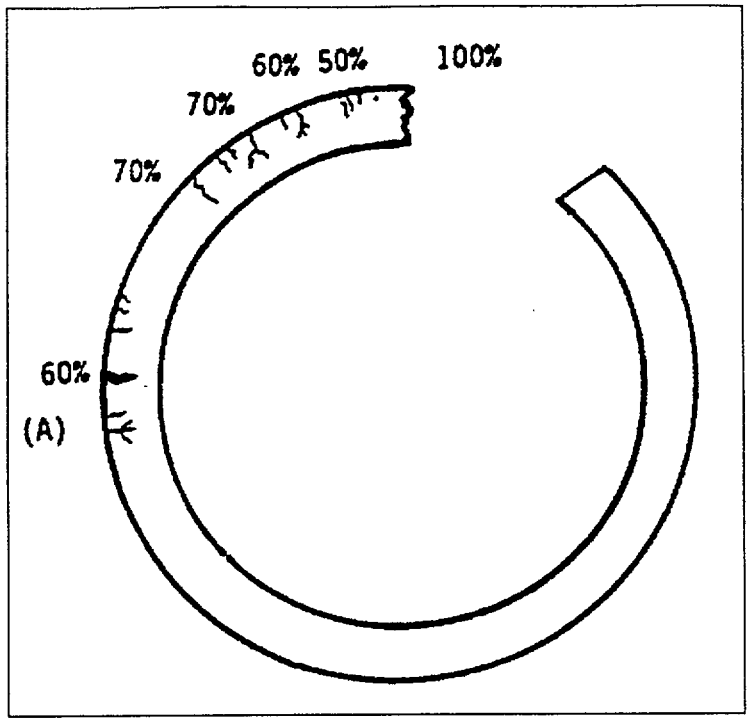


Figure 5b. Model Boiler 590-2, 18.53 volts, 0.30" TW.

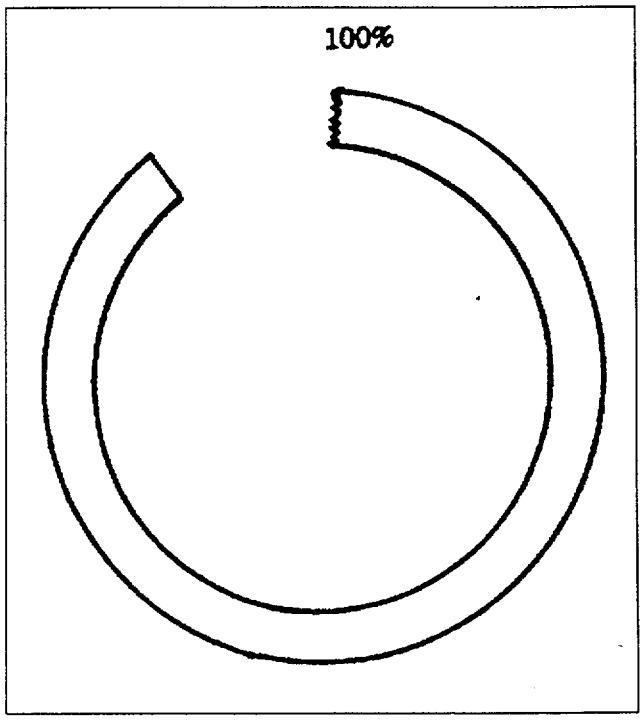


Figure 5c. Model Boiler 595-1, 16.71 volts, 0.43" TW, no secondary cracking.

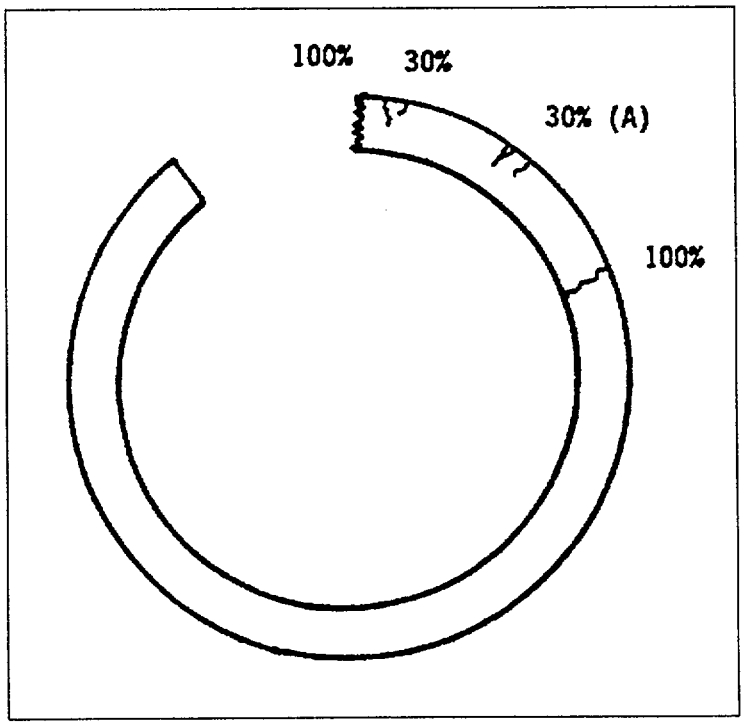


Figure 5d. Model Boiler 596-3, 14.2 volt, 0.44" TW.

Figure 5. ¾" Model Boiler Specimen: Examples showing modest secondary cracking up to 20 volts.

Crack Morphology for 7/8" Tubing Indications

Highest voltage pulled tube indications (all < 14 volts)

- Indications pulled as highest voltage indications
- Indications and voltages dominated by single throughwall crack
- Secondary cracking is shallow with modest influence on voltages for indications < 15 volts

Model boiler specimens up to 15 volts

- Modest secondary cracking similar to pulled tubes < 15 volts

Model boiler specimens > 15 volts

- Indications with voltages above 15 to 20 volts become strongly influenced by multiple deep cracks
- For 7 indications between 15.5 and 22.6 volts, metallography is not available for 5 indications
  - 528-1 (19.1 volts) had 0.45" TW with secondary cracks up to 60%
  - 510-1 (19.8 volts) had 0.36" TW, a second TW and other shallow cracks
  - Leak rates well below mean value support the likelihood of multiple deep cracks for the indications without metallography

Conclusions

- Pulled tube and model boiler indications less than 15 volts are dominated by single deep crack
- Multiple deep cracks dominate indications above 15 to 20 volts

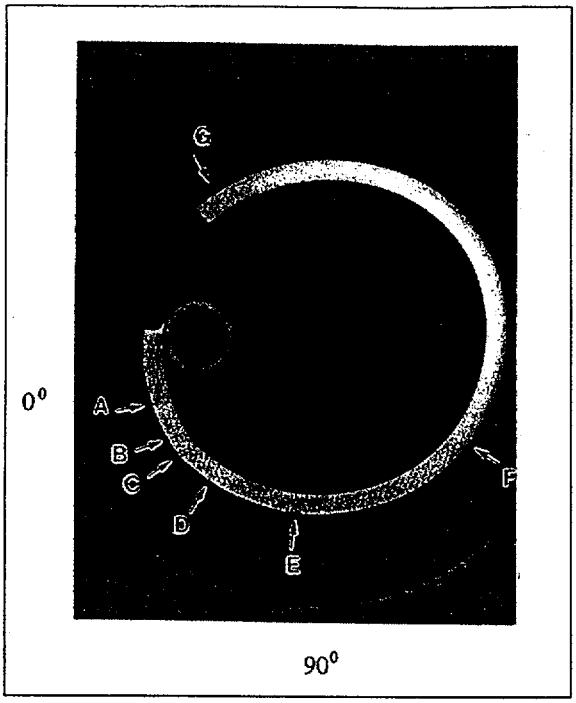


Figure 6a. Plant A-1, R2C85 TSP1, 13.55 volt, TW-0.42", maximum secondary crack depth = 74%.

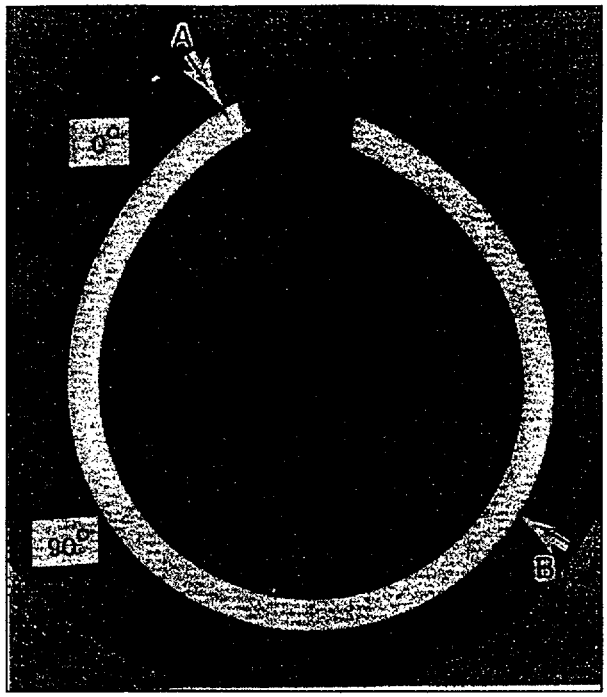


Figure 6b. Plant A-1, R21C22 TSP1, 7.56 volt, 0.15" TW, secondary crack depth = 65%, IGA on crack face, deplugged tube.

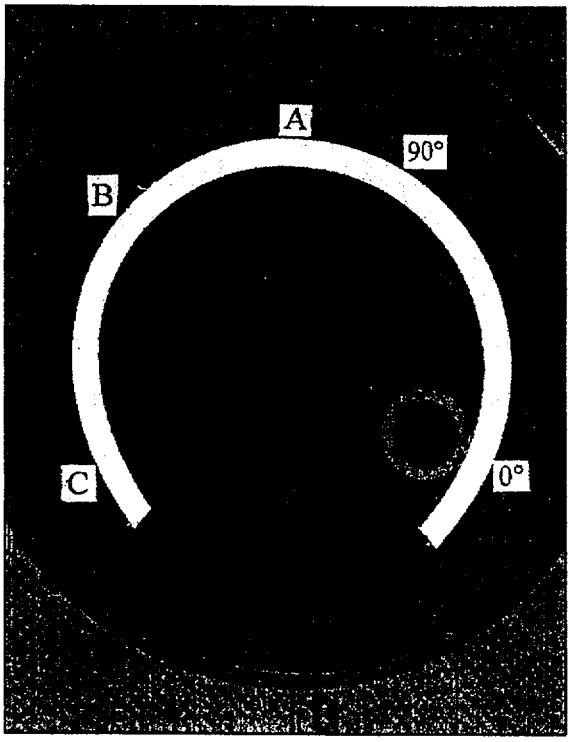


Figure 6c. Plant A-2, R34C53 TSP1, 6.8 VOLT, 0.28" TW, maximum secondary crack depth = 18%.

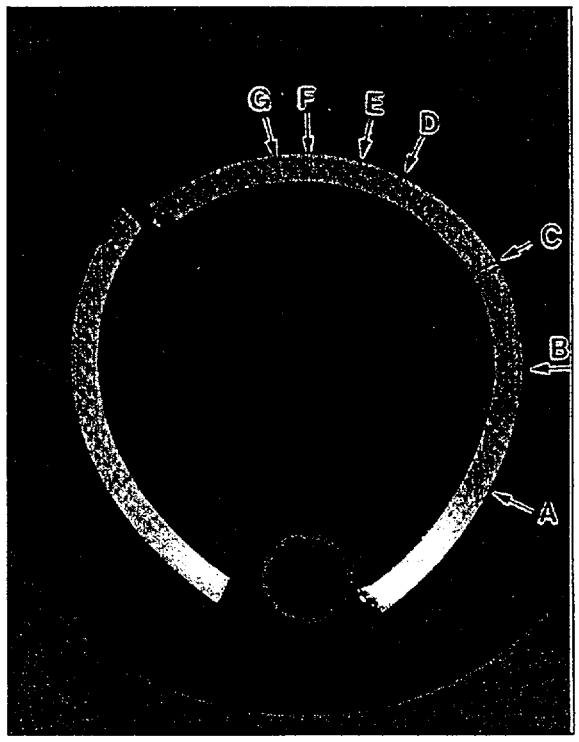


Figure 6d. Plant A-1, R28C35 TSP1, 4.03 volt, 96% maximum depth at burst crack and secondary crack.

Figure 6. 7/8" Pulled Tubes: Modest secondary cracking up to 14 volts (largest voltage 78" pulled tube.

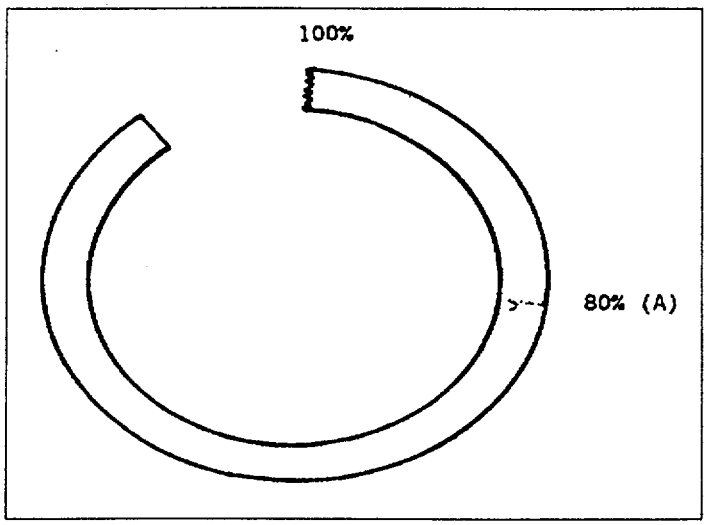


Figure 7a. Model Boiler 509-2, 15.2 volts, 0.26" TW.

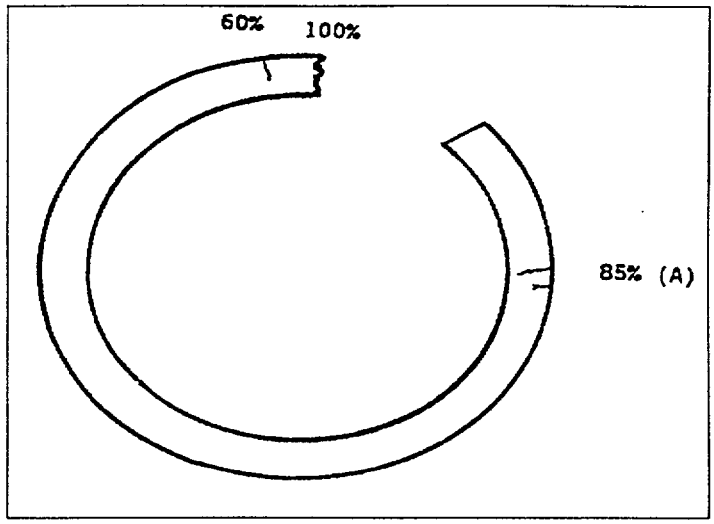


Figure 7b. Model Boiler 509-3, 10.8 volts, 0.16" TW.

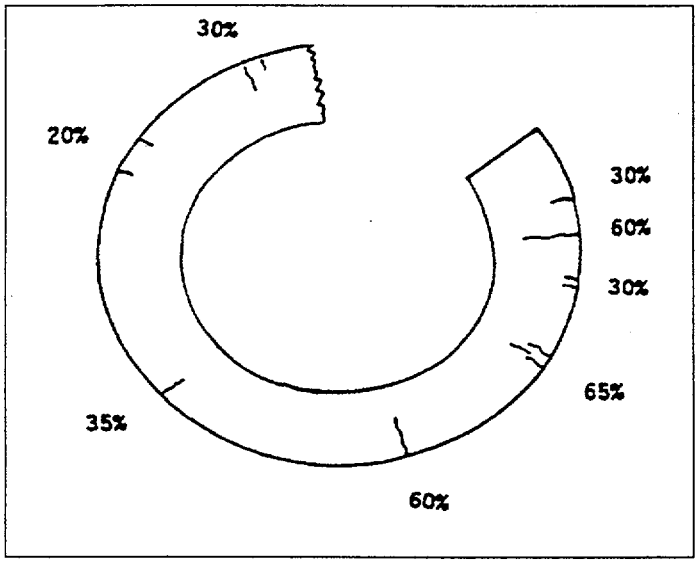


Figure 7c. Model Boiler 533-4, 7.3 volt, 0.14" TW.

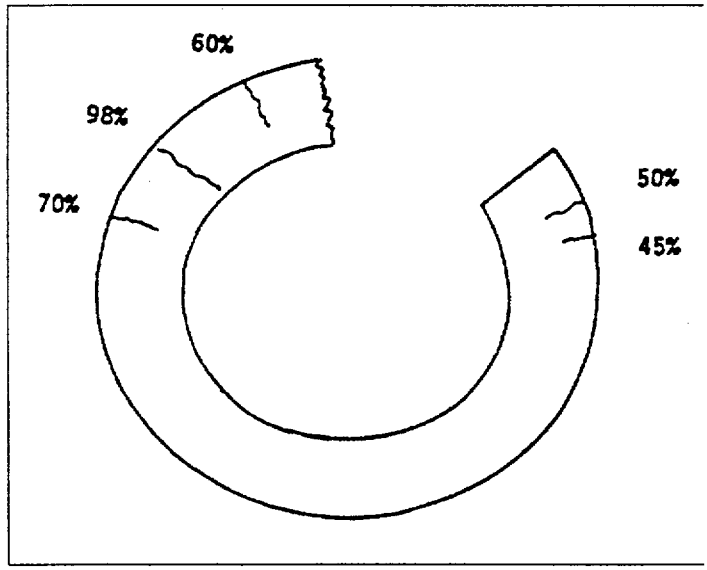


Figure 7d. Model Boiler 543-4, 6.9 volt, 98% maximum depth.

Figure 7. 7/8" Model Boiler Specimens: Examples showing modest secondary cracks up to ~15 volts.

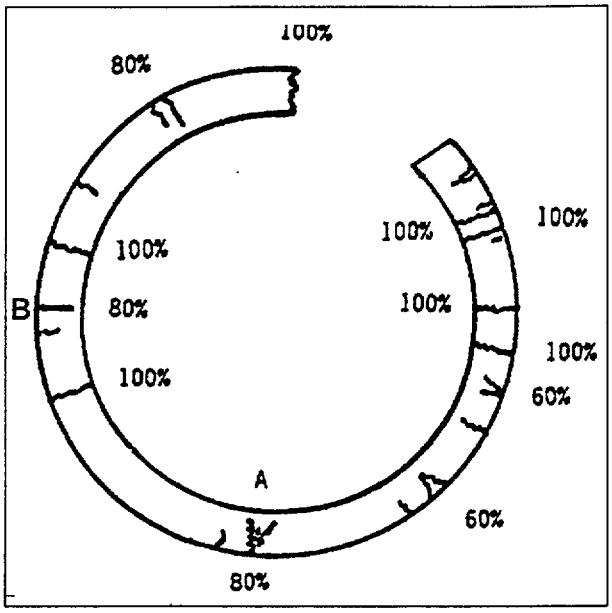


Figure 8a. Model Boiler 532-2, 44.1 volt, 0.58" TW.

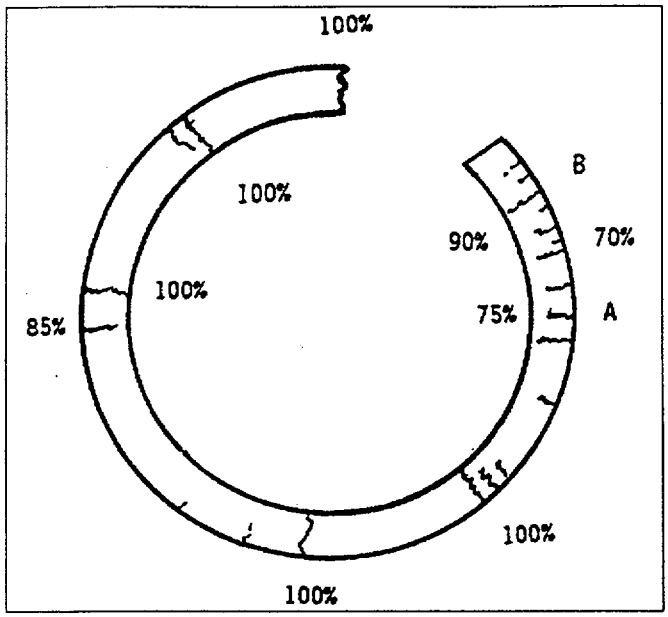


Figure 8b. Model Boiler 532-1, 33.2 volt, 0.52" TW.

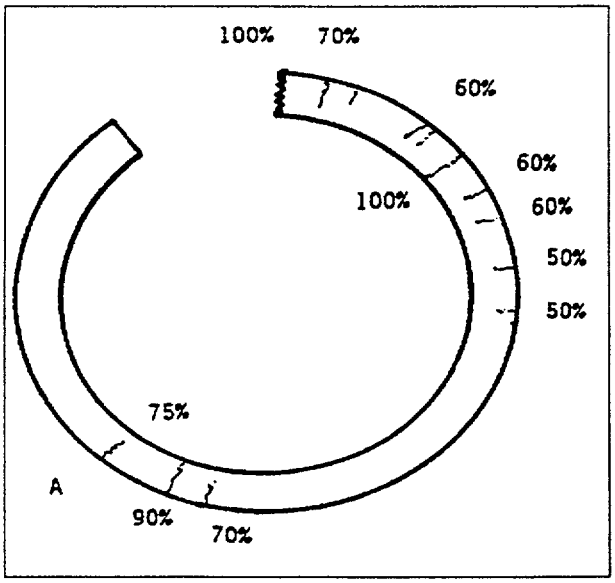


Figure 8c. Model Boiler 528-2, 25.0 volt, 0.50" TW.

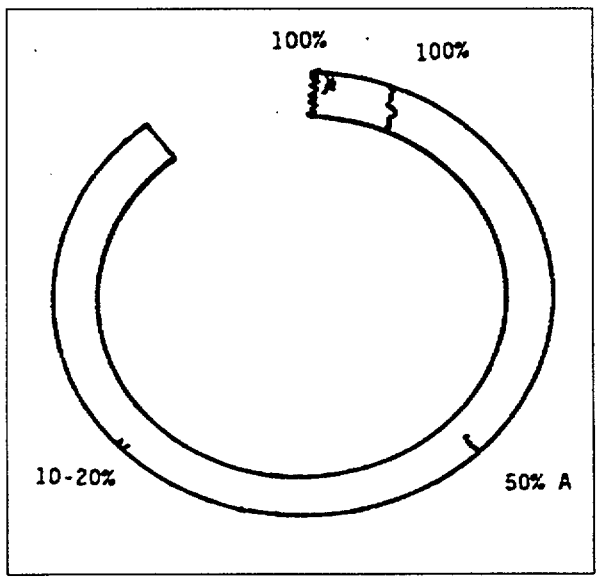


Figure 8d. Model Boiler 555-3, 22.6 volt, 0.42" TW.

Figure 8. 7/8" Model Boiler Specimens: Examples showing extensive secondary cracking as volts exceed 15-20 volts.

Crack Morphology for French Pulled Tube Indications

Transverse metallography available for only two indications from Plant J-1

- Both indications of 30.9 and 39.4 volts show at least five TW indications
- R8C74 shows more extensive IGA than found in domestic pulled tubes or model boiler specimens
- Extent of deep cracking similar to model boiler specimens in 30 to 40 volt range
- Two 17 volt indications had TW lengths < 0.1" and did not leak

Conclusions

- Multiple deep cracks for high voltage indications similar between French data and model boiler specimens
- Low probability of leakage for French indications compared to model boiler specimens implies that a large fraction of the French indications have short TW lengths

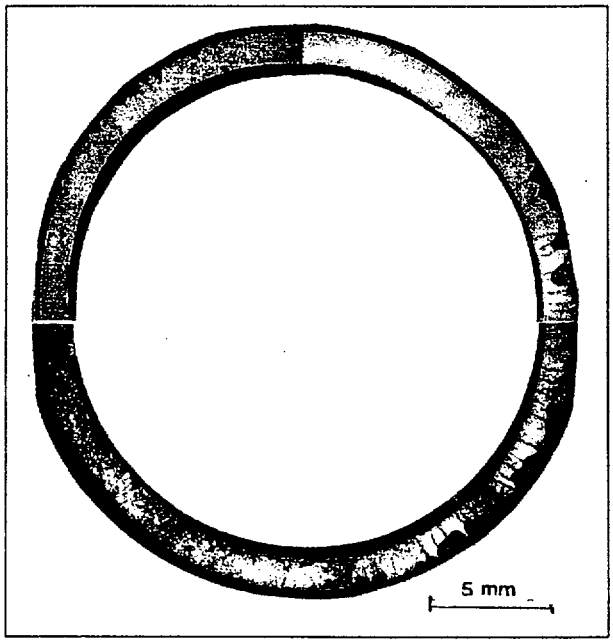


Figure 9a. Plant J-1, R5C28, 39.4 volt, LR exceeded test capacity.

Figure 9b. Plant J-1, R8C74, 30.9 volt, LR=0.13 l/hr = 0.00057 gpm

Figure 9. French Plant J-1 Pulled Tubes R5C28 and R8C74 crack mMorphology showing extensive secondary cracks for high voltage indications

2-3) Conclusions on Crack Morphology

Extent of multiple deep cracks in model boiler and French indications above about 15 volts differs significantly from domestic pulled tubes principally < 15 volts

- Domestic indications above 15 volts not expected for ARC repair limits up to 3 volts

High voltages for multiple deep cracks lead to low leak rate points on the leak rate versus voltage correlation

- Big effect for 7/8" correlation for which 50% of indications are > 15 volts (30% > 20 volts) compared to 3/4" correlation (15% > 15 volts, 2% > 20 volts)

Number and maximum depths of French and model boiler data are similar at high voltages but French data show a much lower POL

- Lower POL attributable to high voltage non-TW indications and short TW lengths

SLB leak rate correlations need to be limited to an upper voltage limit about 15 volts for consistency with domestic pulled tube crack morphology

- A 15 volt upper limit is adequate to encompass range of interest for ARC applications

2-4) Discuss Influence of Time on Domestic Indications and Need to Limit Time for ARC Applications

The responses to questions 2-1) and 2-2) address "time" and oxide film considerations, respectively

Lower ARC repair limits prevent extensive multiple, deep cracks around tube circumference that occur at high voltages (i.e., > 15 volt)

Both oxide film and multiple cracks (potential "time" effects) will result in increased voltages and earlier removal from service

No need to place restrictions on amount of time the alternate repair criteria are applicable

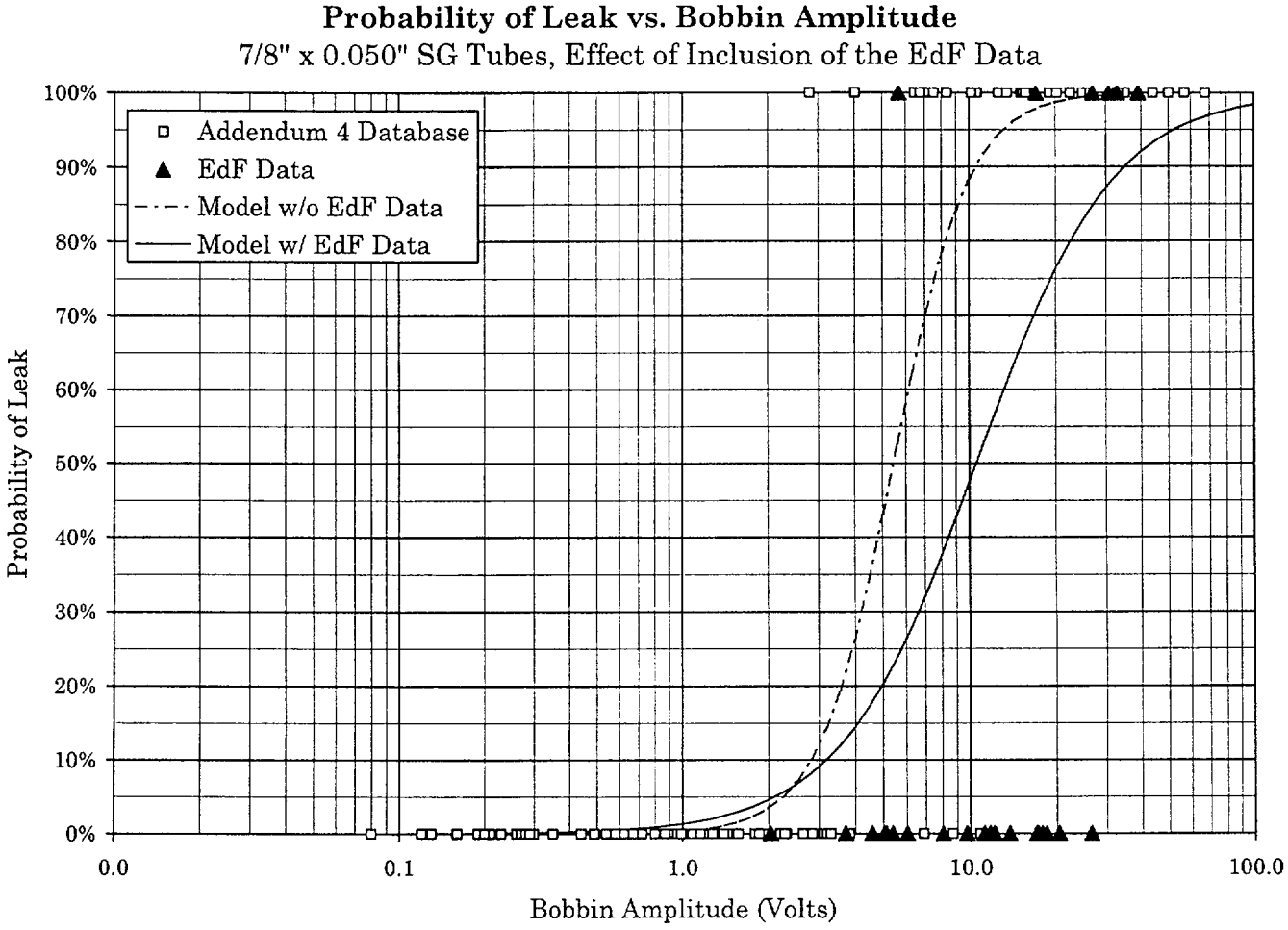
2-5) Discuss Additional Data that French Indications Leak Less than Domestic Data at a Given Voltage

Exclusion criterion 2c is based on probability of leak (POL) rather than on differences in leakage when leakage occurs

- Inclusion of French data leads to a large shift in the POL curve to higher voltages
- Only 13 of 25 French indications above 5 volts are > 95% deep while all domestic pulled tubes and model boiler specimens above 5 volts are > 95% deep.
- All model boiler specimens above 15 volts have TW cracks long enough to leak while 7 of 13 French indications > 15 volts show no leakage including three reported TW indications
  - Although high voltage model boiler and French data have similar number and max depth indications, they differ significantly in leakage potential
- Criterion 2c does not imply that the French indications consistently provide high voltages for "shallow" flaws, but rather implies that 12 of 25 < 95% depth leads to a low POL

Implications of French data on POL

- French data increases POL above about 2.5 volts and significantly increases leakage potential for indications below 2 volts.
  - Inclusion of the French data penalizes the desired ARC condition of low volt indications and helps the high voltage indications representing potential challenges to leakage integrity


Probability of Leak vs. Bobbin Amplitude
7/8" x 0.050" SG Tubes, Effect of Inclusion of the EdF Data
Addendum 4 Database
EdF Data
Model w/o EdF Data
Model w/ EdF Data
Probability of Leak
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0.0
0.1
1.0
10.0
100.0
Bobbin Amplitude (Volts)

3. Discuss Whether Current 7/8" Data Adequately Account for Potential Variability in the Leak Rate

Elements for consideration in adequacy of 7/8" correlation

- Slope of the correlation
- Data variability or uncertainty in the correlation

Correlation slope

- 3/4" leak rate correlation
  - Strong correlation
  - Slope proportional to $V^{2.94}$ which is consistent with expected slope magnitude from combining TW vs V and LR vs TW data
- 7/8" correlation
  - Slope proportional to $V^{0.75}$ including all data and $V^{1.02}$ excluding French data
  - Slope proportional to $V^{2.69}$ with cutoff at 15 volts
    - o Indications in range of interest yield expected slope magnitude
    - o Database < 15 volts includes only 14 data points
      - Leads to desire to merge 3/4" data with 7/8" data to enhance the database supporting the 7/8" leakage correlation

Data variability

- Leak rate range of 7/8" indications in 1 to 10 volts is ≈ 0.1 to 50 l/hr
- Leak rate range of 3/4" indications in 1 to 10 volts is ≈ 0.01 to 100 l/hr
- Data variability of 7/8" data is adequate but obtained with fewer data points than for 3/4" correlation

Conclusions

- Leak rate correlation should be limited to < 15 volts to limit data to range of interest for ARC applications, obtain expected slope magnitude and obtain crack morphologies typical of pulled tubes
- Merging 3/4" with 7/8" data would improve correlation database

4. Discuss the Extent that Domestic Data is Biased to Single Indications and Effects on Exc. Criterion 2c

Dominant reasons for pulling tubes with > 5 volt indications was based on selecting highest voltage indications

- First criterion for industry and for GL 95-05
- Selection guideline for tube removal based on RPC signatures of a single dominant crack is used to select between tubes with similar voltages
  - Typical of selection basis for lower voltage indications although only two < 5 volt leakers have been found in 7/8" tubing
- Industry removal guideline (Database Addendum 3, 1999) emphasis on selecting tubes for removal to increase the leak rate database has not yet influenced a tube selection since highest voltage indications have been removed

Conclusions

- Database is not biased to single indications based upon selection criteria for tube removal
- Morphology of one or two dominant cracks in < 15 volt indications is present in both pulled tube and model boiler specimens