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500 Hz Test Protocol Distinguishes TRXLPE Performance

**Fall 2010 IEEE/PES/ICC Meeting
Subcommittee A: Cable Construction and Design**

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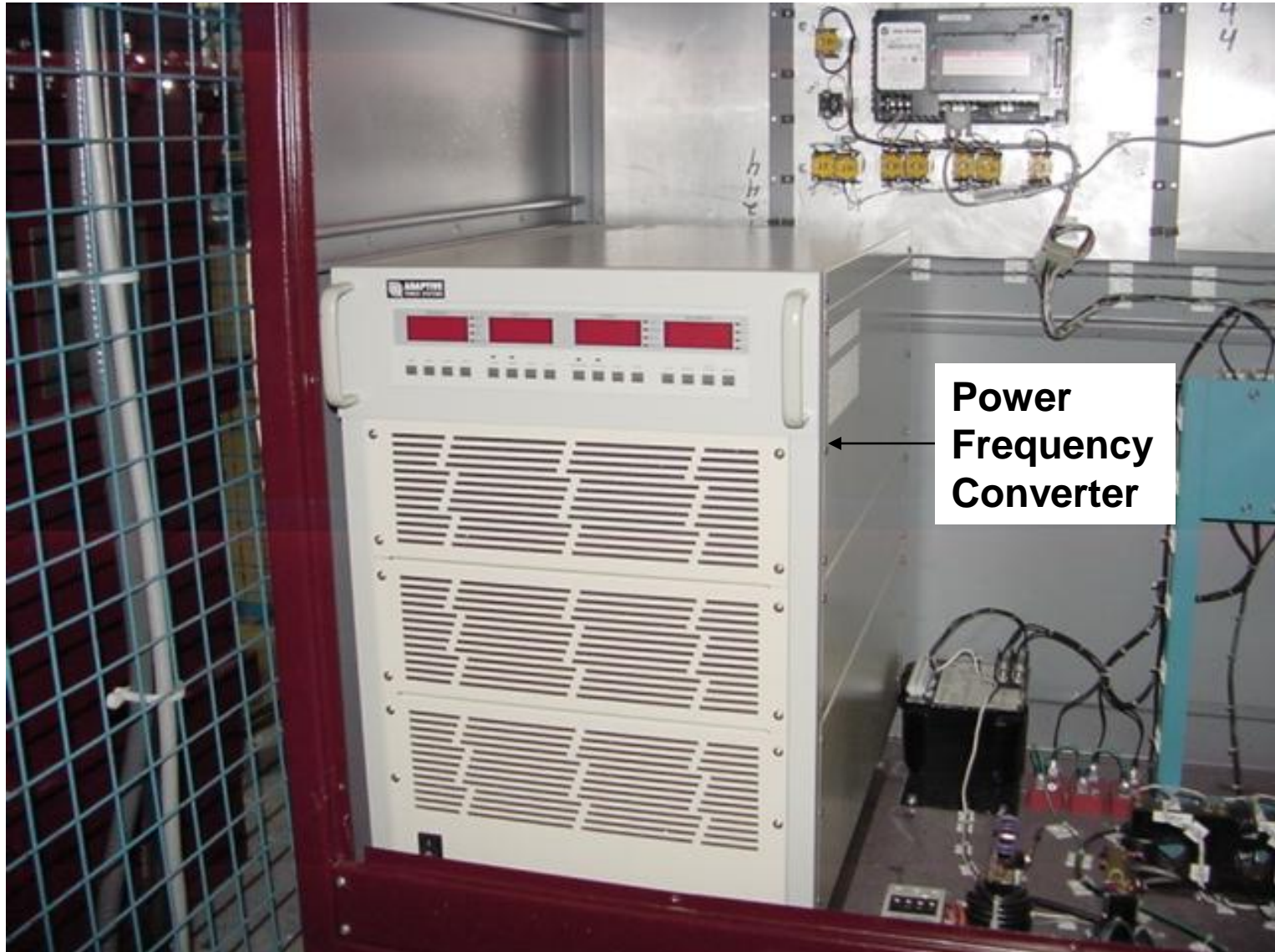
Test Protocol, Specification, Sample Length and Preconditioning

- **British Standards Institute - BS 7870-2:1999**
LV and MV Polymeric Insulated Cables for Use by Distribution and Generation Utilities
Section 5.4 “Long Term Voltage Test”
- **CENELEC HD 605 S2** Section 5.4.6 “Long Duration Test”
 - 60m active sample length if aging performed at 500 Hz
 - Prior to aging: preconditioning for 500 hours in 55°C tap water bath to remove cross-linking by-products and allow insulation and screens to absorb moisture

BS 7870-2:1999/HD 605 Test Protocol – Aging Procedure

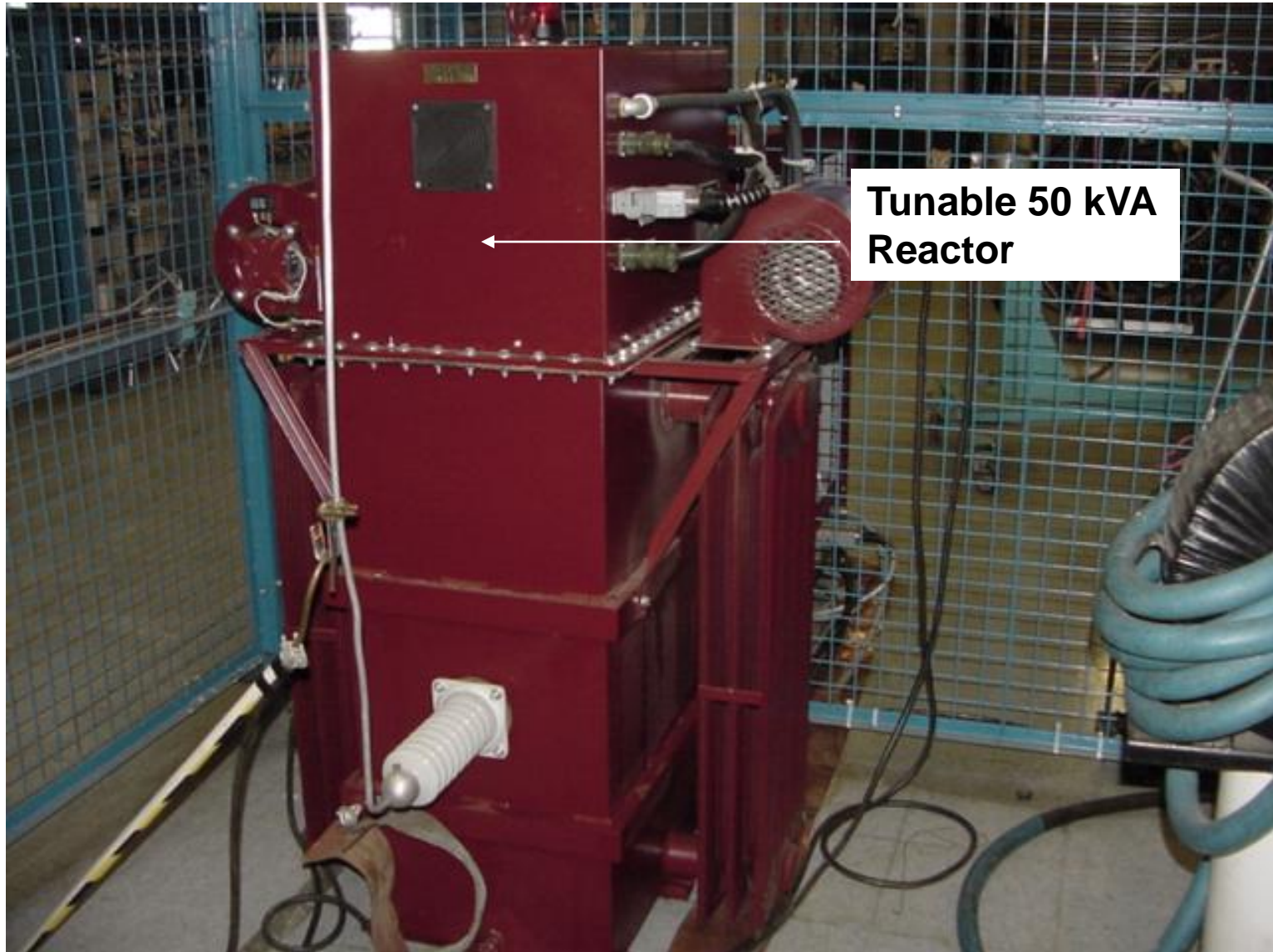
- 40 °C water bath with at least 0.5m² surface area open to atmosphere to ensure oxygenation
- Cable core ends protruding from water
- Water earthed by means of a metallic electrode
- Outer semi-conducting screen earthed
- Voltage of 18kV, 27kV or 36 kV for 3.4mm, 4.5mm and 5.5mm nominal insulation thickness, respectively
- Aging time:
 - Power frequency:
 - One 60m length - 8750 hours
 - One 60m length -17,500 hours
 - OR:
 - 500 Hz: one 60m length - 3000 hours

500 Hz Test Set



Power
Frequency
Converter

500 Hz Test Set



BS 7870-2:1999 Test Protocol – Aging Assessment

- Sample cut into 6 x 10m lengths – do not include area from 150mm below the water line and above
- Core wrapped with concentric neutral wires or tape
- Power-frequency voltage step test:
 - Start at 18, 27 or 36 kV for 3.4, 4.5 and 5.5 mm nominal insulation thickness, respectively
 - Voltage raised in 6, 9 or 12 kV steps every 5 minutes for 3.4, 4.5 and 5.5 mm nominal insulation thickness, respectively
- Pass/Fail based on all six (6) specimens' power-frequency voltage step test results meeting 18kV/mm maximum stress **or** a statistical approach: all withstand 14kV/mm, at least 4 samples withstand 18kV/mm, at least 2 samples withstand 22 kV/mm

Medium Voltage Cable Qualification

ICEA S-94-649-2004 vs. BS 7870-2:1999

ICEA AWTT

- Dry preconditioning for 14 days with 8 hours of conductor heating each day. Conductor must reach 130°C during last 4 hours of each heat cycle
- 49-61Hz aging voltage @ 26.2kV for 175-mil insulation
- Wet aging with daily 8-hour load cycles in uncontrolled water temperature in a pipe. Insulation shield in water must reach 45°C ± 3°C for last hour of load cycle
- Tap water in conductor strands
- Withstand values determined after 120, 180 and 360 days of wet aging
- Pass/Fail based on all specimens meeting nominal (V/mil) withstand requirements

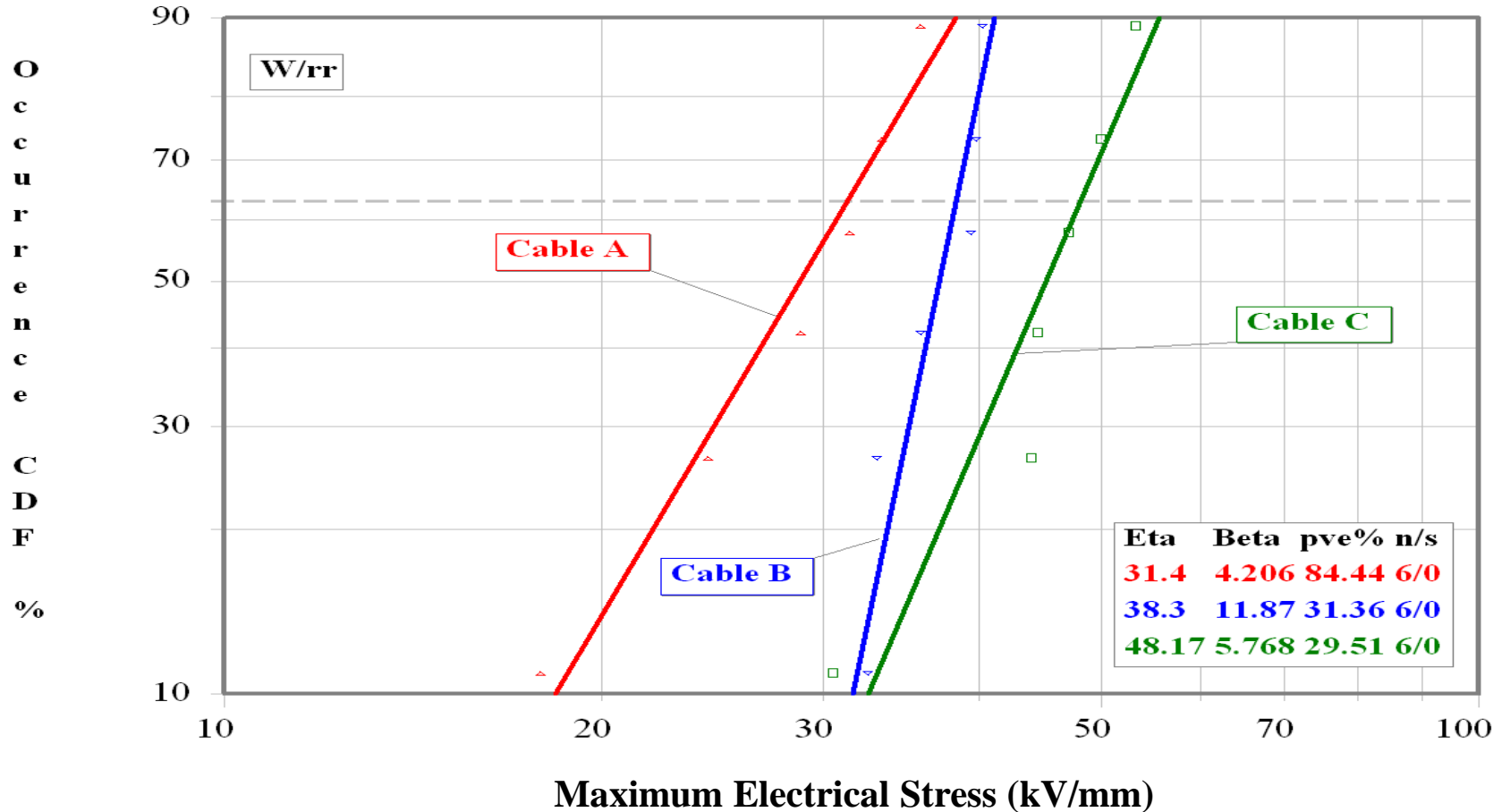
HD Harmonized Long Duration Test

- Wet preconditioning in temperature controlled water bath at 55°C for 500 hours
- 500Hz aging voltage @ 27 kV for 4.5mm insulation
- Wet aging in 40°C temperature controlled water bath with no load cycles
- No water in conductor strands
- Breakdown values determined after 3000 hours (125 days) of wet aging
- Pass/Fail based on all meeting **maximum stress** (kV/mm) breakdown values or statistical approach

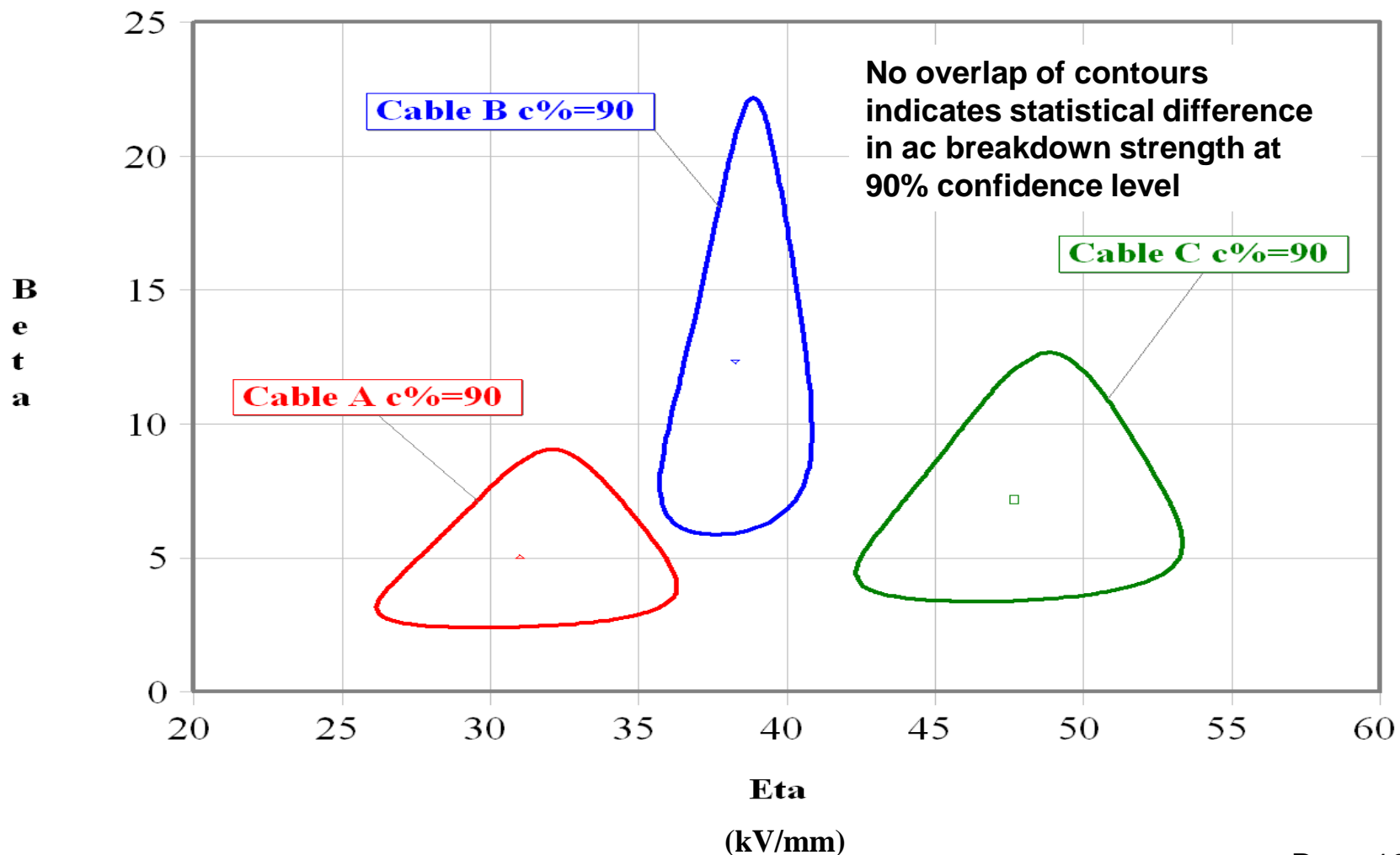
Cables Tested to HD 605 Alternative 500Hz Aging Protocol

- ✓ Cable A :3.4mm TRXLPE - A
- ✓ Cable B: 3.4mm TRXLPE - B
- ✓ Cable C: 4.5mm TRXLPE - C

HD 605 LONG TERM VOLTAGE TEST: ALTERNATE METHOD RESULTS 2 PARAMETER WEIBULL PLOTS



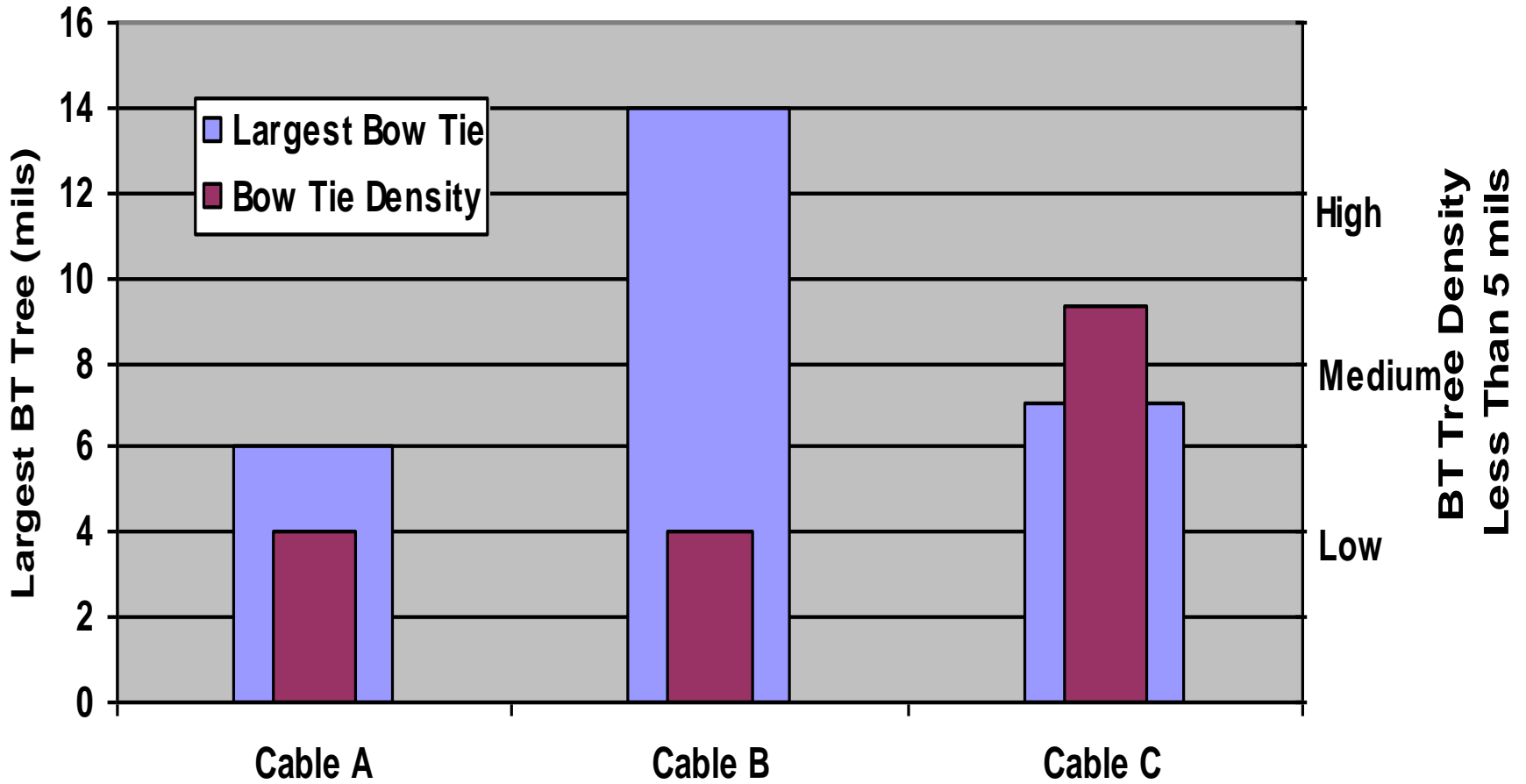
HD 605 LONG TERM VOLTAGE TEST RESULTS: JOINT 90% CONFIDENCE CONTOUR PLOTS



Treeing Analysis

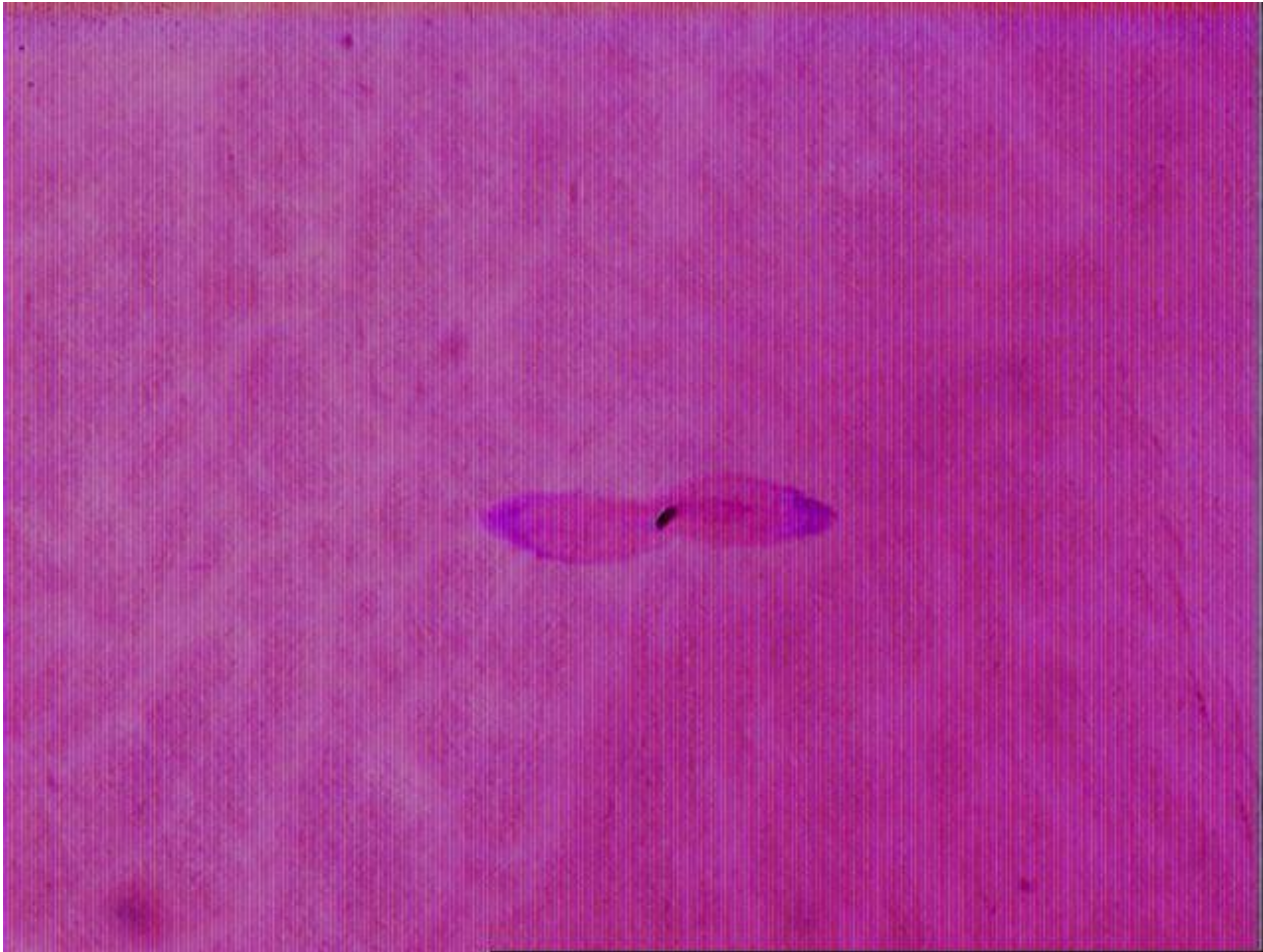
- 7 to 8 wafers cut from each breakdown site using a microtome. The ~25 mil thick wafers dyed and inspected for water trees
- Trees categorized as Bow-Tie (BT), Vented Conductor Shield (CS) and Vented Insulation Shield (IS)
- Largest tree observed and tree density recorded
- Tree density categorized as
 - None
 - Low: BT = 1-50 per wafer, Vented = 1-5
 - Medium: BT = 51 to 1000 per wafer, Vented = 6 to 10
 - High: BT = >1000 per wafer, Vented = >10

Bow Tie Trees

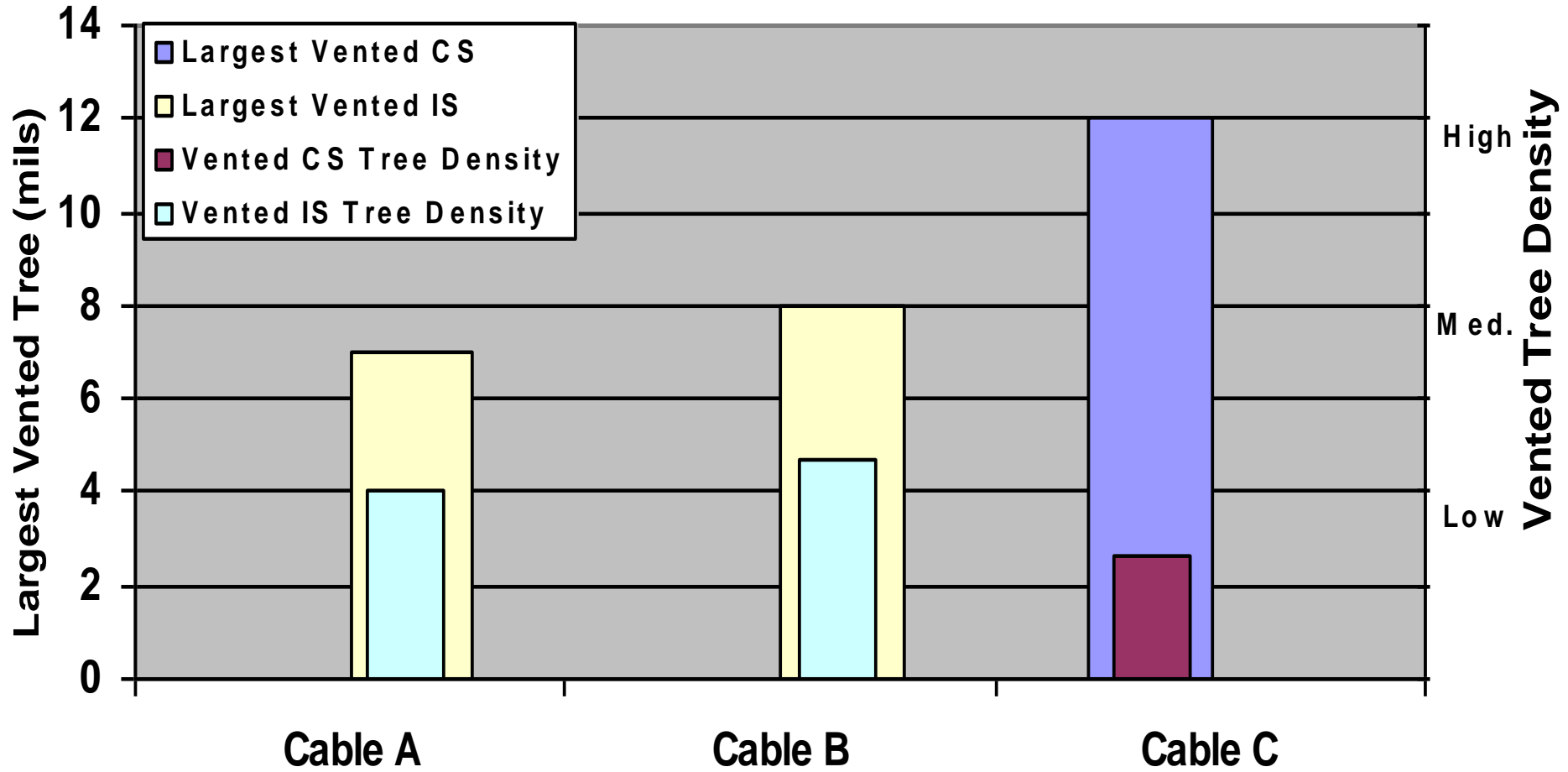


Bow Tie Trees

Largest Tree Found in Cable B – 14 mils

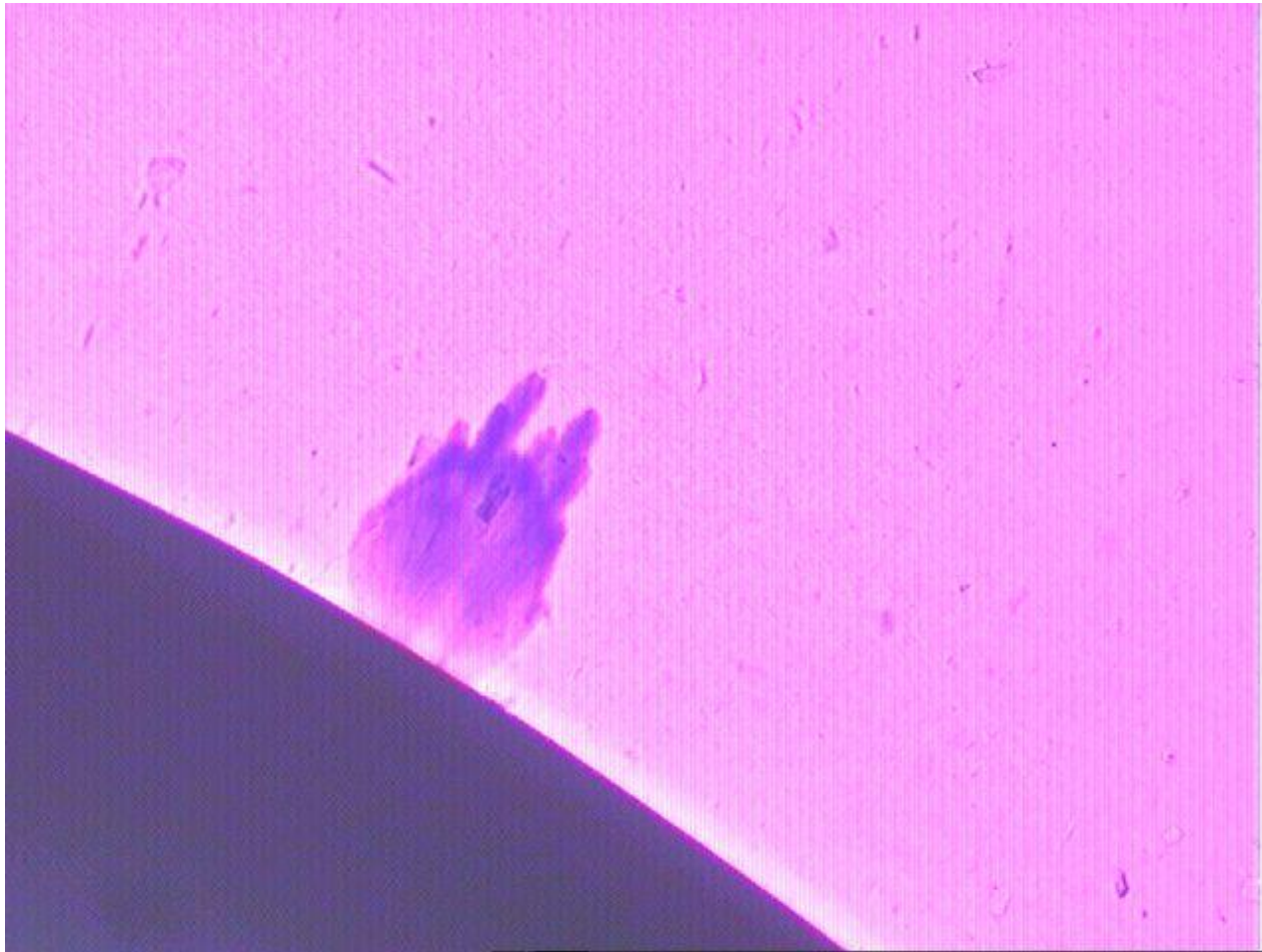


Vented Trees



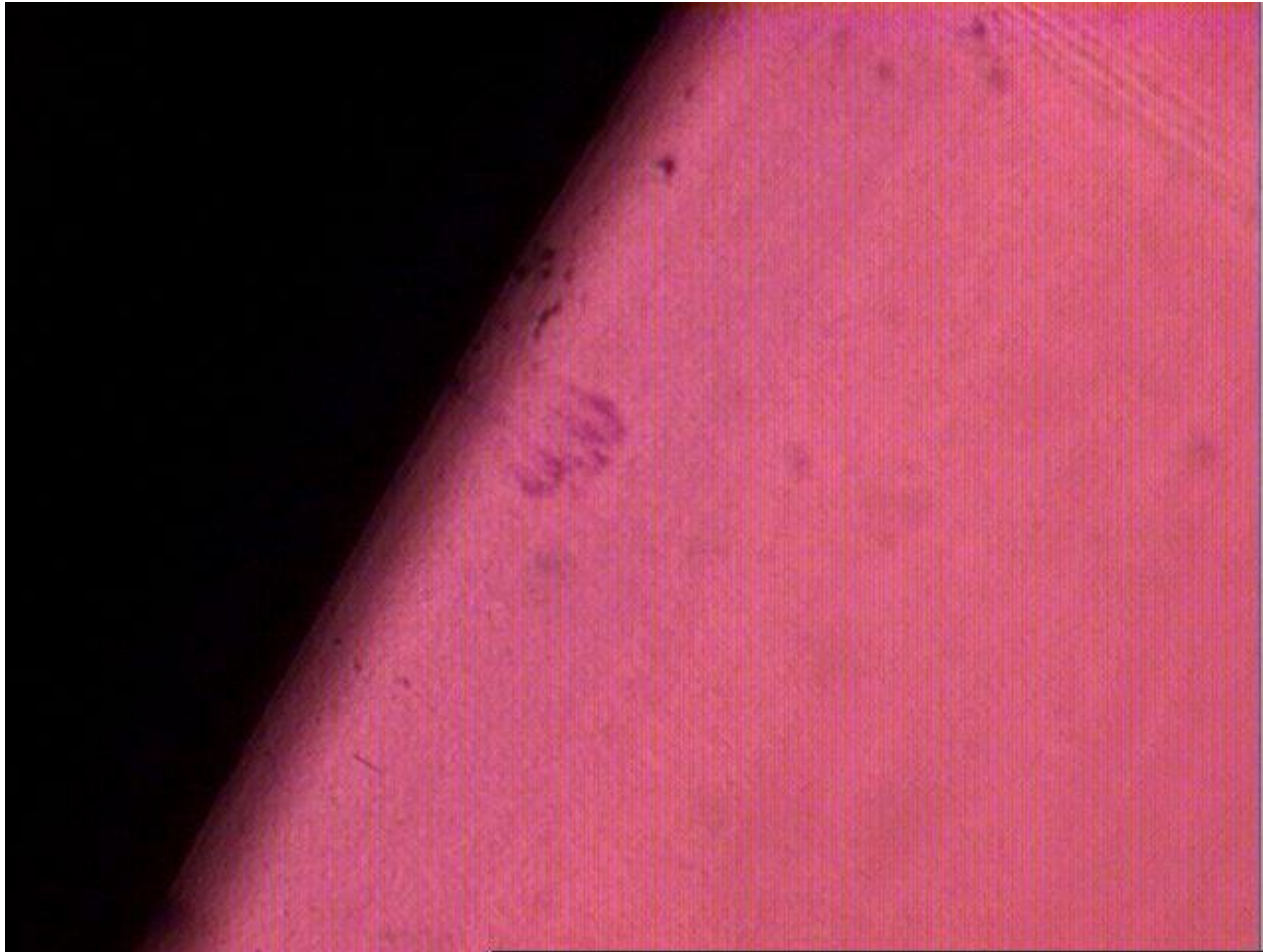
Vented Trees

Largest Vented CS Tree in Cable C – 12 mils

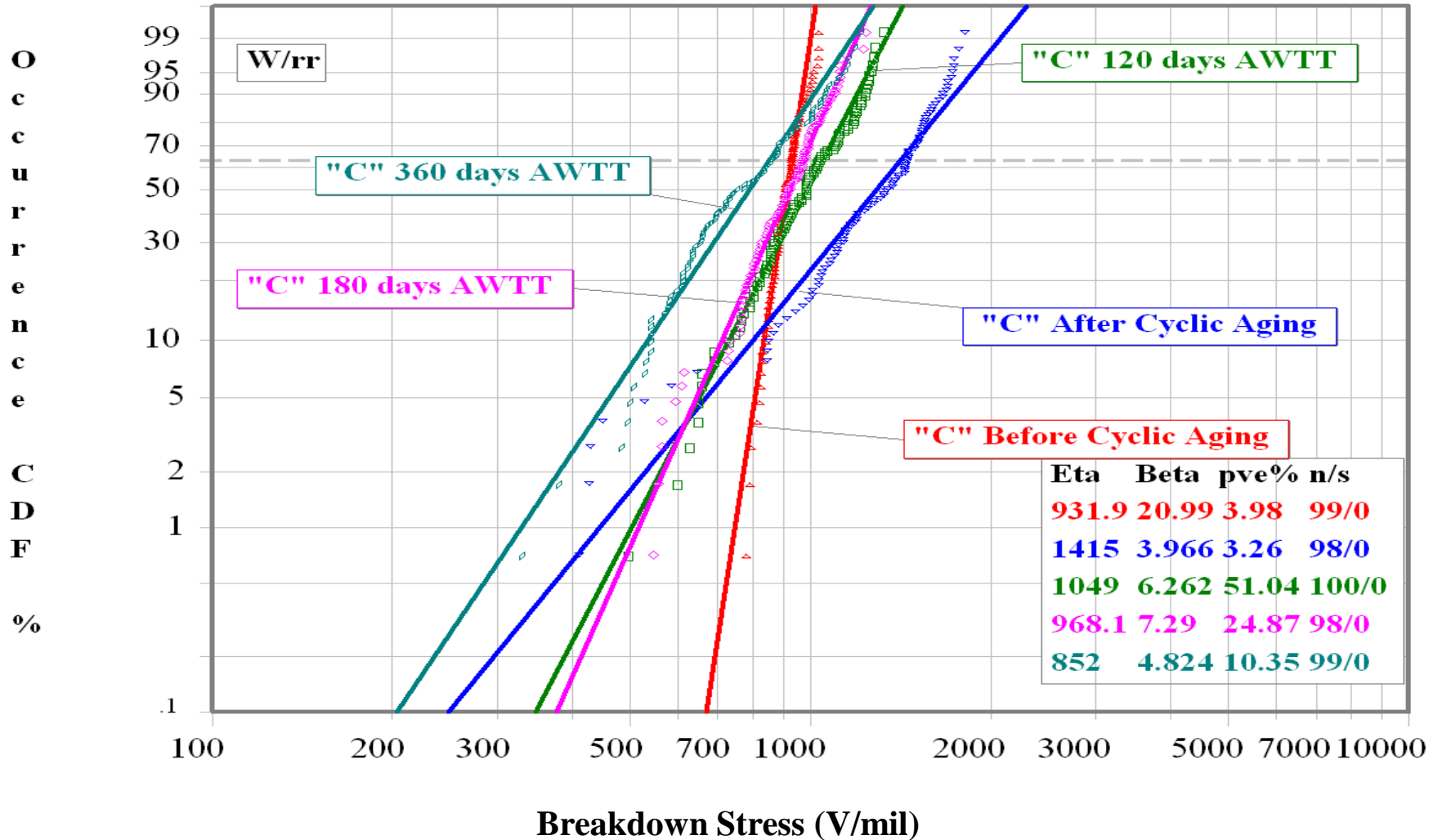


Vented Trees

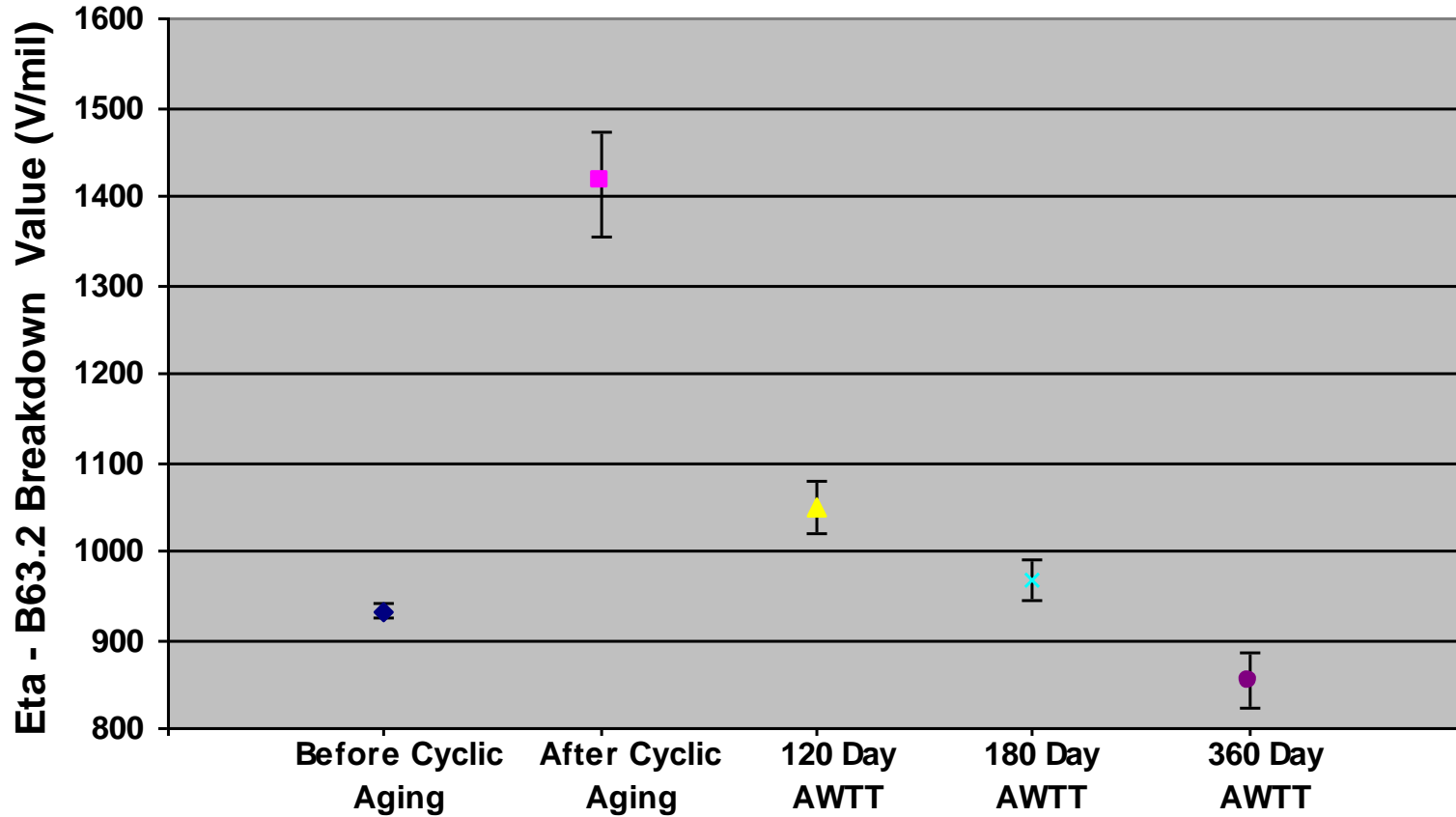
Largest Vented IS Tree Found in Cable A – 7 mils



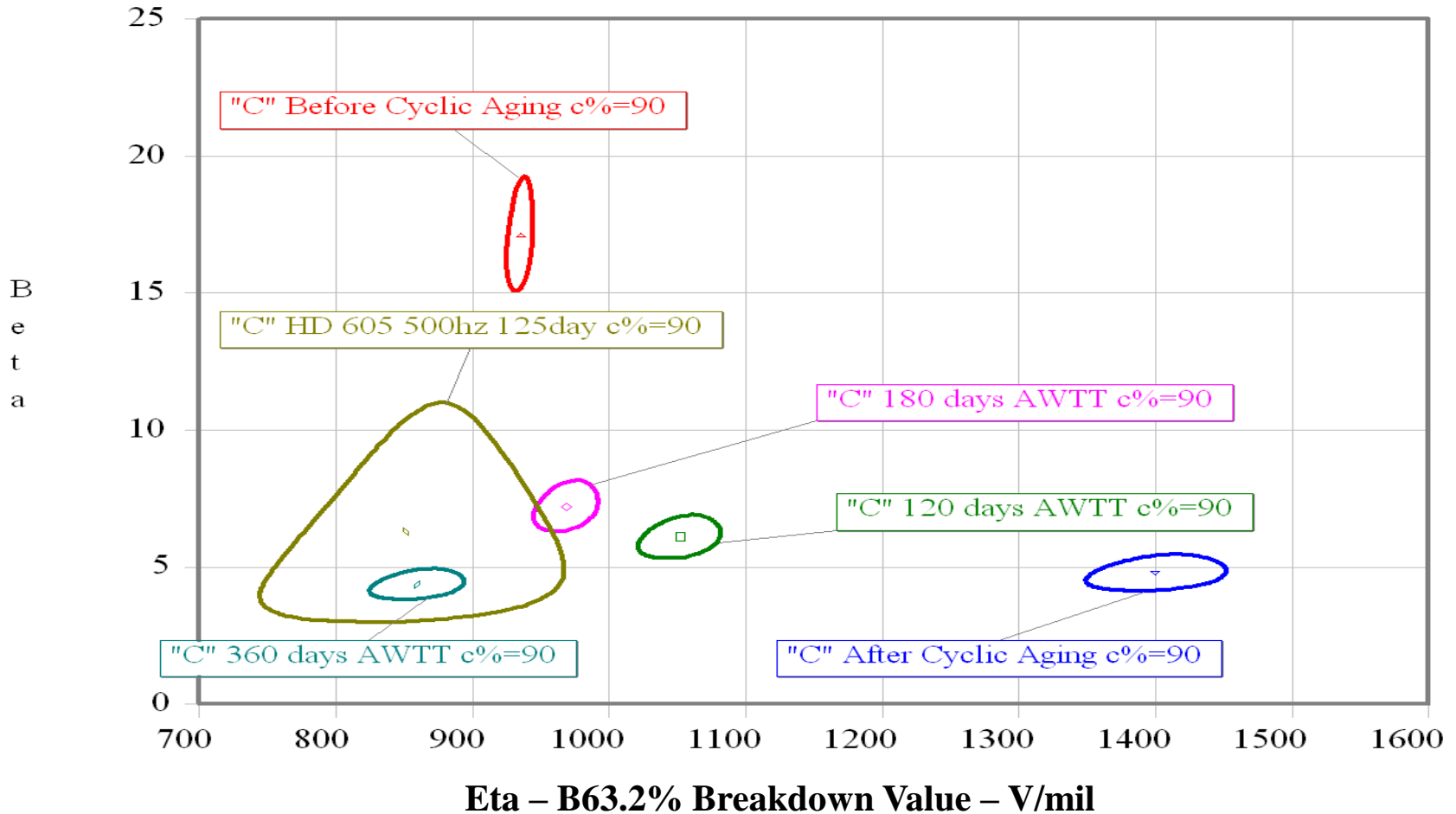
2-Parameter Weibull Plots of ICEA S-94-649 AWTT HVTT Results: TRXLPE "C"



ICEA S-94-649 AWTT HVTT Results: TRXLPE "C"



HD 605 vs. ICEA S-94-649 AWTT Breakdown Results: TRXLPE "C"



500 Hz Long Term Voltage Test Summary

- Protocol has been used in non-USA markets to qualify MV power cables since 1997
- Protocol reduces wet ageing time from 12 months (ICEA) to 4 months (CENELEC HD-605)
- Protocol reduces equipment needed to qualify MV cables when compared to ICEA S-94-649 since no inductive heating is required
- Motor-Generator sets no longer required for generation of 500 Hz test voltage
- Based on these preliminary results:
 - 125 days of aging at 500 Hz is equivalent to 360 days of aging at 60 Hz if the entire HD 605 protocol is followed
 - Protocol can statistically differentiate insulation performance on small sample size test populations
- Additional testing will increase confidence level (statistical precision) of these findings