



Efficient Accelerated Cable Life Testing (ACLT) - Reduce the Time and Still Get Reliable Data

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Educational Didactic - Fall 2004 ICC Meeting

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Why the Need for Accelerated Test Protocols?

- **Laboratory Test Evaluations of Cable Systems or Cable Products at Normal Use Conditions Take Too Long (tens of years) to Get the Answers Needed for Engineering Design Decisions**
- **Testing at Conditions Much Higher (Accelerated Test Conditions) Than Use Conditions Shortens Life or Reduces the Performance Level of the Cable Systems or Products, Thereby Shortening the Time Required (by 1 - 2 orders of magnitude) to Get Useful Data for Making Comparative Life or Performance Estimates of Cable Systems' or Products**
- **For Accelerated Cable Life Testing (ACLT) of Cable Materials Systems or Products Which are Designed to have Significantly Improved Performance at Use Conditions, It is Desirable to Have Results as Fast as Possible Without Changing the Failure Mode of the Cable System or Product Under Evaluation.**
- **This Presentation Discusses Statistical Sampling, Analysis and Test Plan Techniques Which Can Provide ACLT Results in Much Shorter Timeframes, with Savings in Testing Time and Costs**

Techniques Which Significantly Reduce Test Protocols

- **Sudden Death Test Plans**
 - **Sample Population Divided Into Sub-Groups or Sub-Populations**
 - **Involves Cessation of Testing of Remaining Specimens in a Sub-Population Group at the Time that First Specimen Failure of the Sub-Group Occurs**
 - **Specimens Stopped are Treated as Suspensions in Analysis of the Full Population**
- **Population Truncation Test Plans**
 - **Involves Cessation of Testing of Remaining Specimens in a Population after some Cumulative Number of Population Failures have Occurred**
 - **Specimens Stopped are Treated as Suspensions in the Analysis**
- **Small Sample Populations**
 - **Comparison With Control Population or Previous Historical Data Having the Same Failure Mechanism**

Sudden Death Test Plans

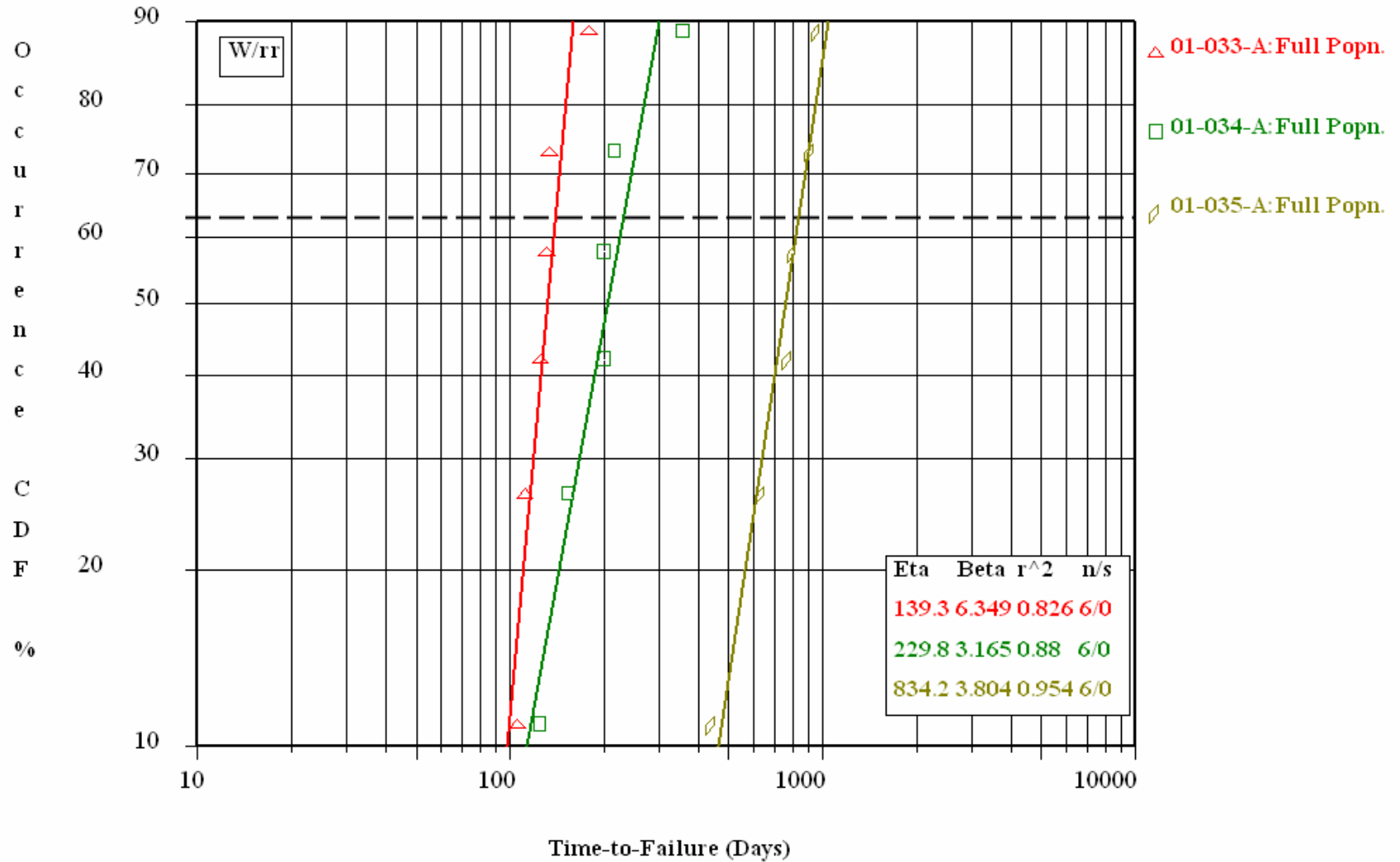
#2 AWG 44 ACLT - CCS/XLPE: FAILED CABLE SAMPLES

01-033-A Sample ID	Timer Days		01-034-A Sample ID	Timer Days		01-035-A Sample ID	Timer Days	
	Full	Sudden Death		Full	Sudden Death		Full	Sudden Death
G06*3912	105.5	105.5	H01*4701	123.9	123.9	J04*4710	442.8	442.8
G02*3908	111.3	111.3	H02*4702	152.8	152.8	J01*4707	633.8	633.8
G01*3907	124.8	124.8	H04*4704	198.2	214.8	J03*4709	776.8	776.8
G05*3911	130.5	130.5	H05*4705	199.0	198.2	J05*4711	803.0	803.0
G03*3909	133.6	133.6	H03*4703	214.8	199.0	J06*4712	912.6	912.6
G04*3910	178.1	178.1	H06*4706	355.8	355.8	J02*4708	958.1	958.1

Three (3) Sub-Groups Having 2 Sample Specimens for each group. 1 Failure/1 Suspension per Sudden Death Group; $n/s = (2/1)*3 = 6/3$; $n = 6, F = 3, S = 3. n/s = 6/3$

Sudden Death Test Plans

#2 AWG 44 ACLT:CCS/XLPE



F_F

Sudden Death Test Plans

Weibull Log Likelihood (LL) Comparison: Set Quantity = 3

Difference = Extreme

>99.9999 % pff-Value Confidence

Set 1-3-5 Difference Significance

(>99.9999 % p-Value With Standard mle Test Bias)

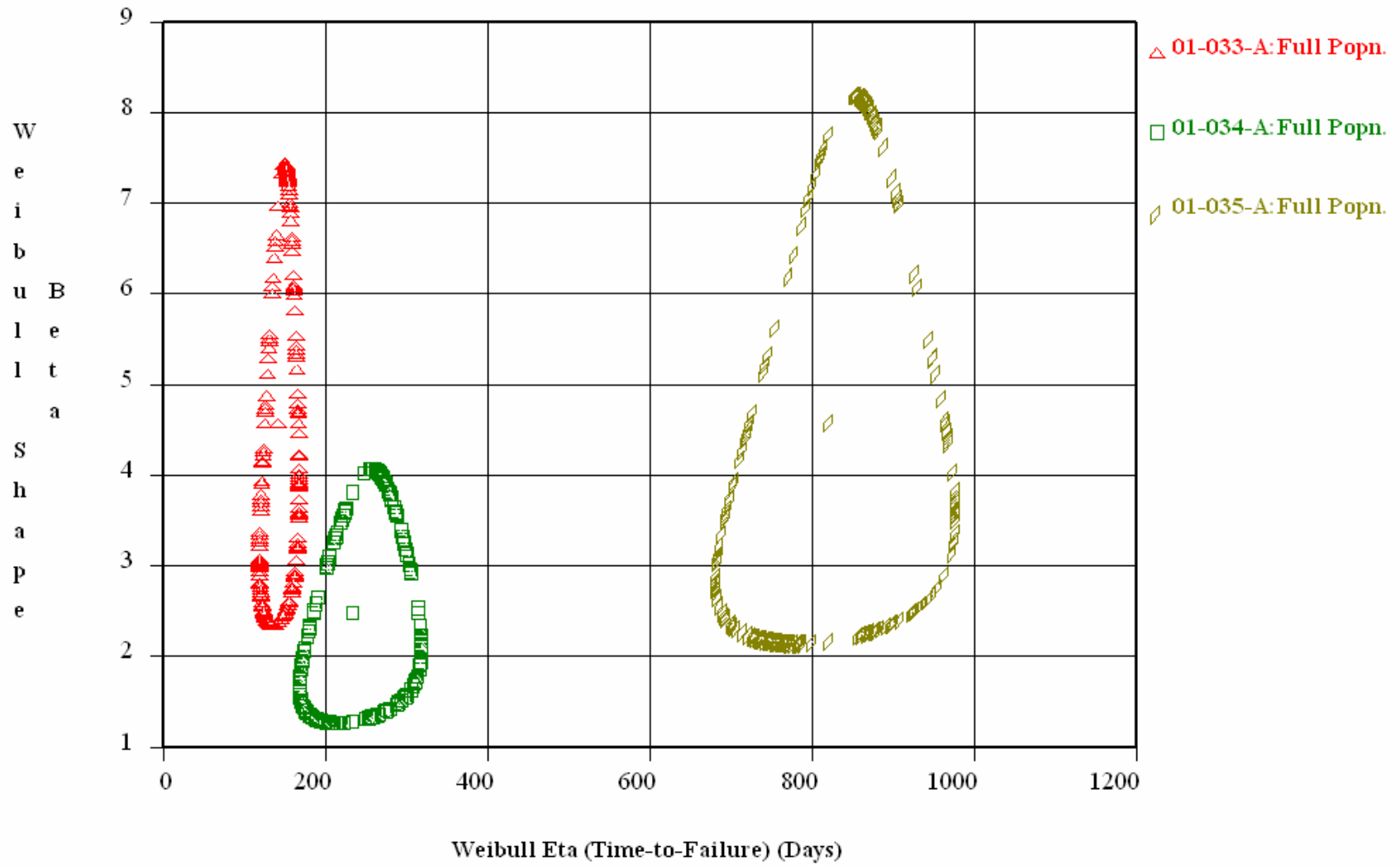
(LL3 Set Quantity 3 = -101.2886)

(LL1 All 1 Set = -123.2219)

(LL3-LL1 = 43.86654 / 2)

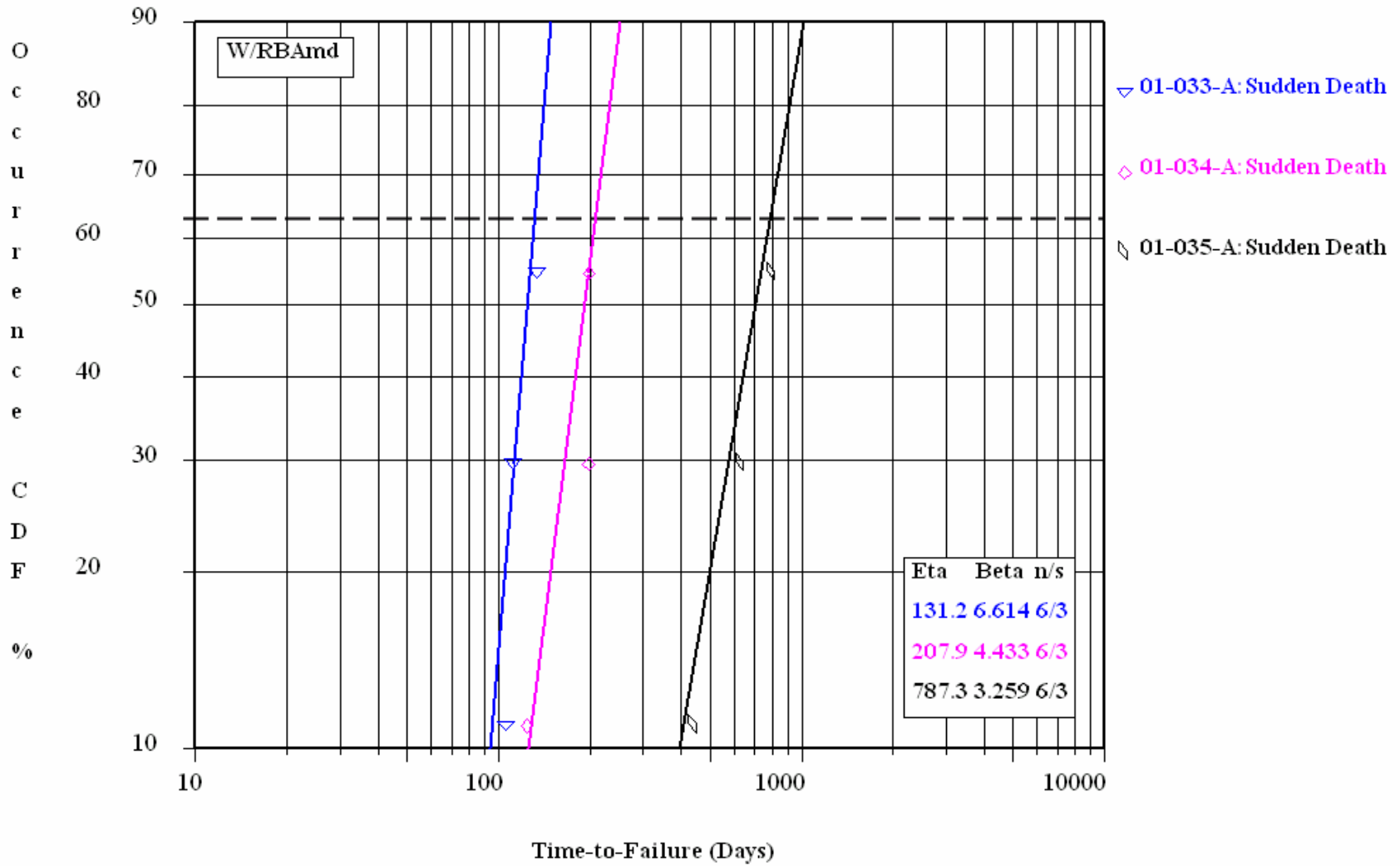
Sudden Death Test Plans

#2 AWG 44 ACLT:CCS/XLPE



Sudden Death Test Plans

#2 AWG 44 ACLT:CCS/XLPE



Sudden Death Test Plans

Weibull Log Likelihood (LL) Comparison: Set Quantity = 3

Difference = Extreme

99.63 % pff-Value Confidence

Set 2-4-6 Difference Significance

(>99.9999 % p-Value With Standard mle Test Bias)

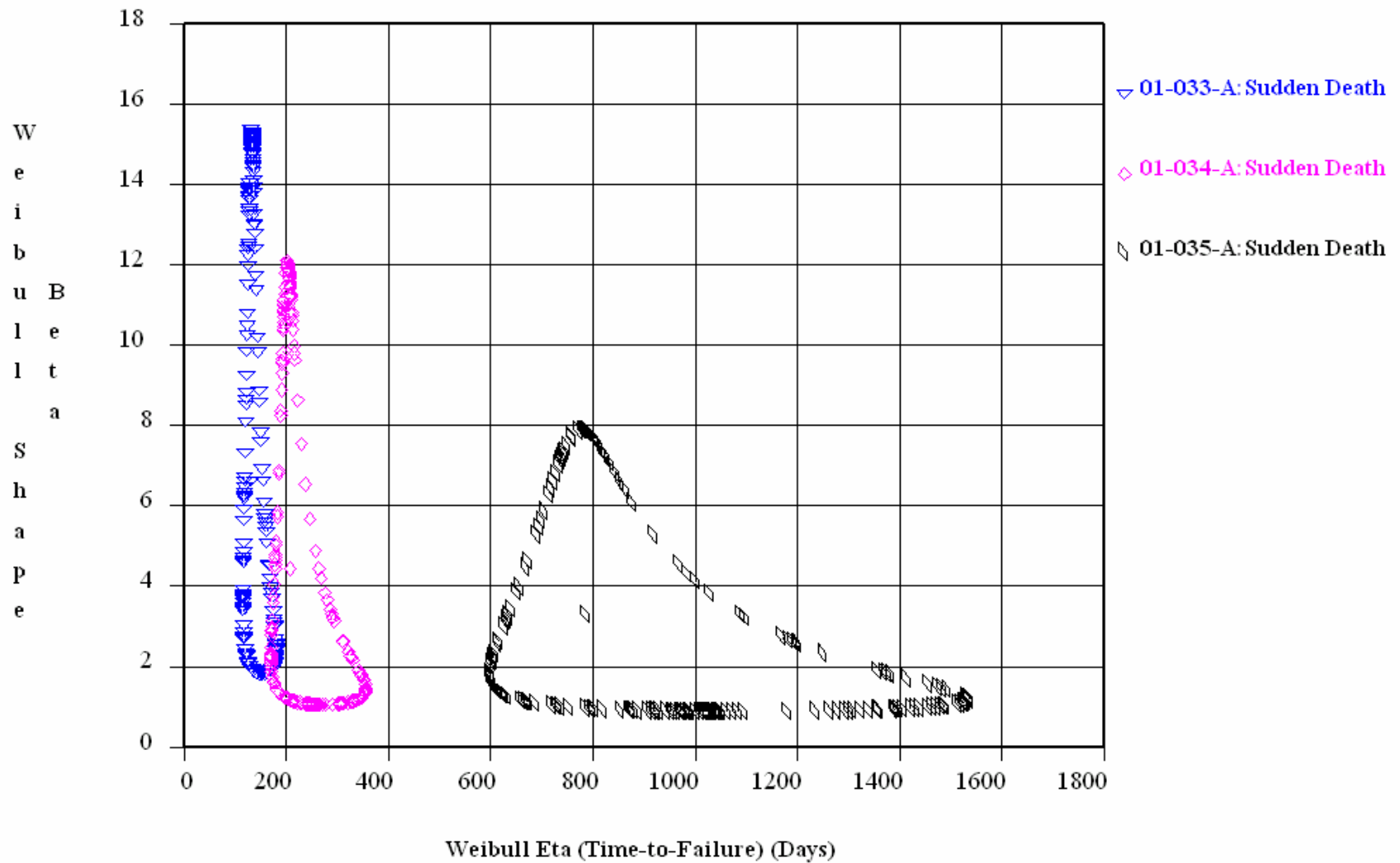
(LL3 Set Quantity 3 = -52.05836)

(LL1 All 1 Set = -66.11456)

(LL3-LL1 = 28.1124 / 2)

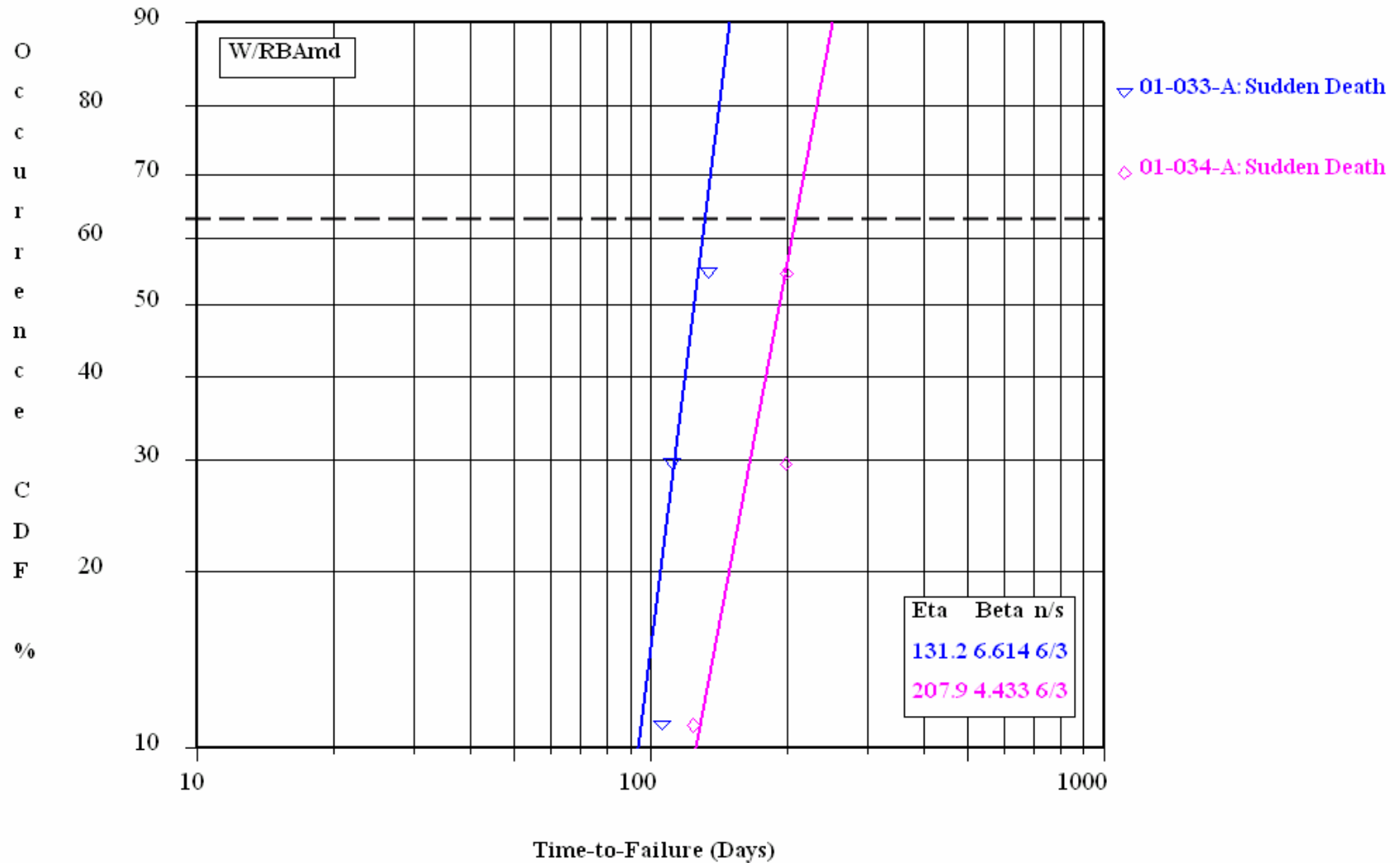
Sudden Death Test Plans

#2 AWG 44 ACLT:CCS/XLPE



Sudden Death Test Plans

#2 AWG 44 ACLT:CCS/XLPE



Sudden Death Test Plans

Weibull Log Likelihood (LL) Comparison: Set Quantity = 2

Difference = Possible ... With Additional Data

88.18 % pff-Value Confidence

Set 2-4 Difference Significance

(97.9 % p-Value With Standard mle Test Bias)

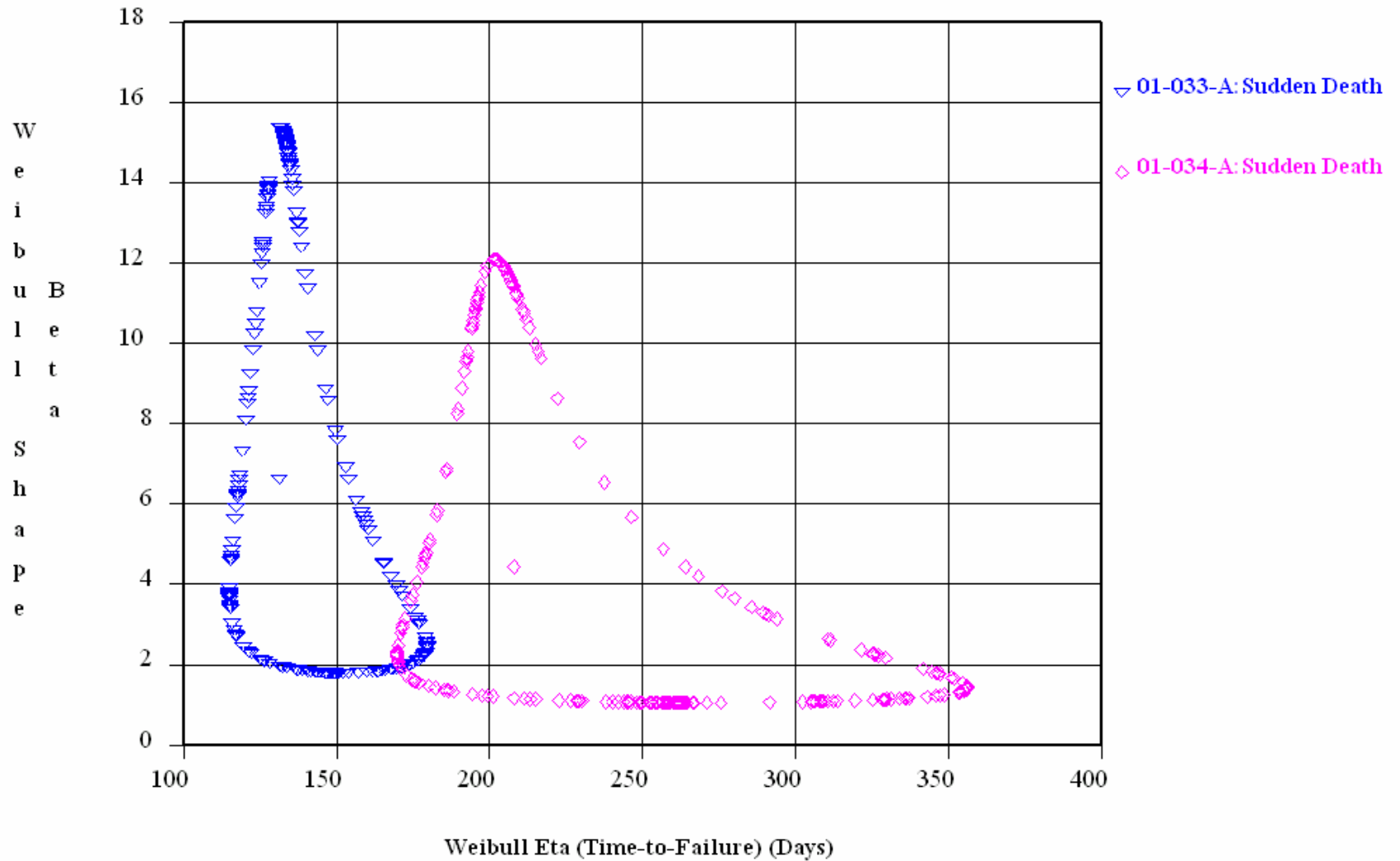
(LL2 Set Quantity 2 = -30.79412)

(LL1 All 1 Set = -34.65722)

(LL2-LL1 = 7.726199 / 2)

Sudden Death Test Plans

#2 AWG 44 ACLT:CCS/XLPE



Sudden Death Test Plans Time Savings

#2 AWG 44 ACLT CCS/XLPE: FAILED CABLE SAMPLES								
01-033-A	Timer Days		01-034-A	Timer Days		01-035-A	Timer Days	
Sample ID	Full	Sudden Death	Sample ID	Full	Sudden Death	Sample ID	Full	Sudden Death
G06*3912	105.5	105.5	H01*4701	123.9	123.9	J04*4710	442.8	442.8
G02*3908	111.3	111.3	H02*4702	152.8	152.8	J01*4707	633.8	633.8
G01*3907	124.8	124.8	H04*4704	198.2	214.8	J03*4709	776.8	776.8
G05*3911	130.5	130.5	H05*4705	199.0	198.2	J05*4711	803.0	803.0
G03*3909	133.6	133.6	H03*4703	214.8	199.0	J06*4712	912.6	912.6
G04*3910	178.1	178.1	H06*4706	355.8	355.8	J02*4708	958.1	958.1
Test Months Req'd	5.9	4.5		11.9	6.6		31.9	26.8
Time Saved, %		25			44			16

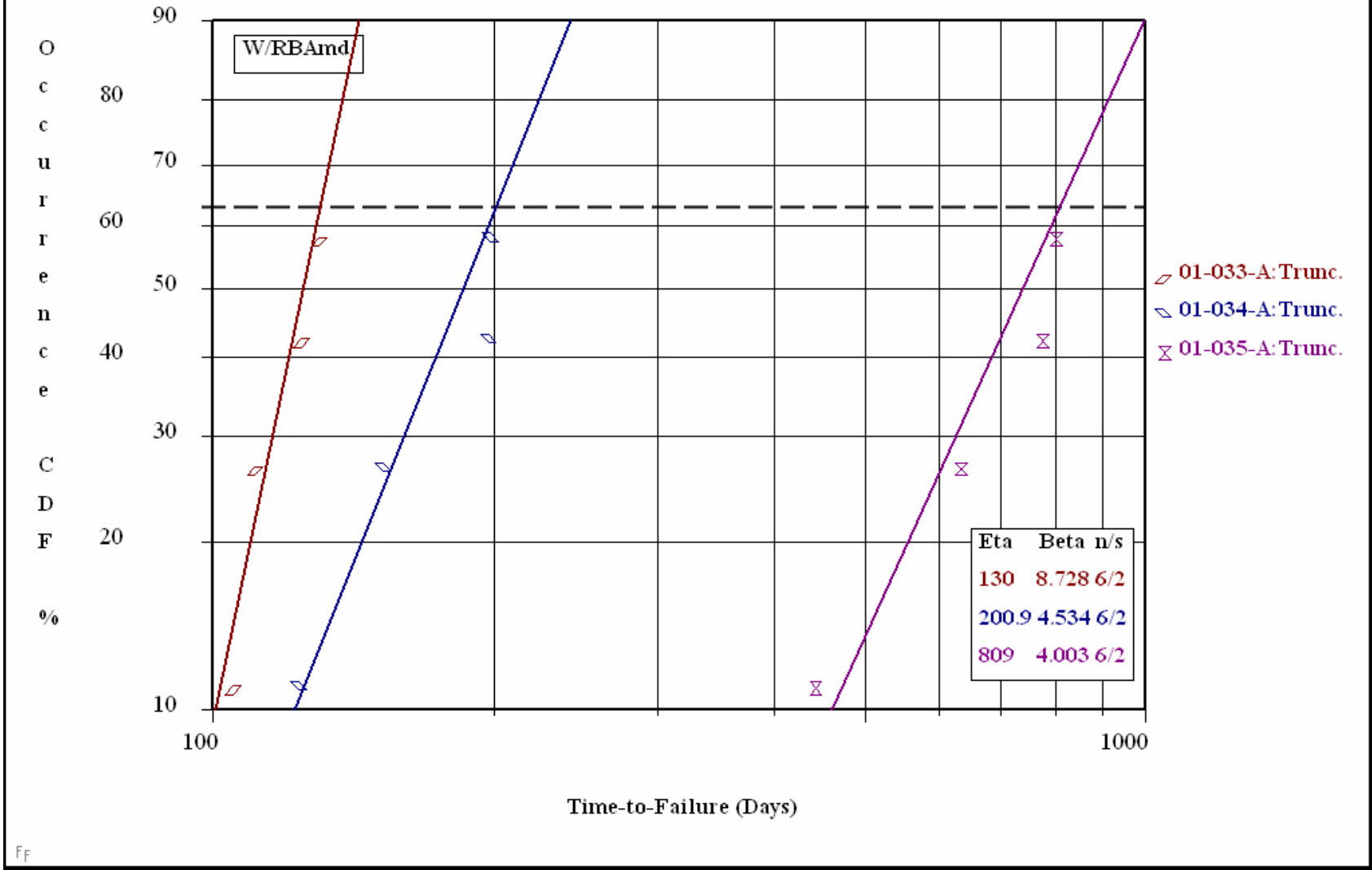
Population Truncation Test Plans

#2 AWG 44 ACLT - CCS/XLPE: FAILED CABLE SAMPLES								
01-033-A	Timer Days		01-034-A	Timer Days		01-035-A	Timer Days	
Sample ID	Full	Sudden Death	Sample ID	Full	Sudden Death	Sample ID	Full	Sudden Death
G06*3912	105.5	105.5	H01*4701	123.9	123.9	J04*4710	442.8	442.8
G02*3908	111.3	111.3	H02*4702	152.8	152.8	J01*4707	633.8	633.8
G01*3907	124.8	124.8	H04*4704	198.2	214.8	J03*4709	776.8	776.8
G05*3911	130.5	130.5	H05*4705	199.0	198.2	J05*4711	803.0	803.0
G03*3909	133.6	133.6	H03*4703	214.8	199.0	J06*4712	912.6	912.6
G04*3910	178.1	178.1	H06*4706	355.8	355.8	J02*4708	958.1	958.1

Each Population Suspended after $\frac{2}{3}$ of Samples Have Failed.

Population Truncation Test Plans

#2 AWG 44 ACLT:CCS/XLPE



Populations Suspended after $\frac{2}{3}$ Specimens Failed; $n = 6$, $F = 4$, $S = 2$. $n/s = 6/4$

Population Truncation Test Plans

Weibull Log Likelihood (LL) Comparison: Set Quantity = 3

Difference = Extreme

99.99 % pff-Value Confidence

Set 7-8-9 Difference Significance

(>99.9999 % p-Value With Standard mle Test Bias)

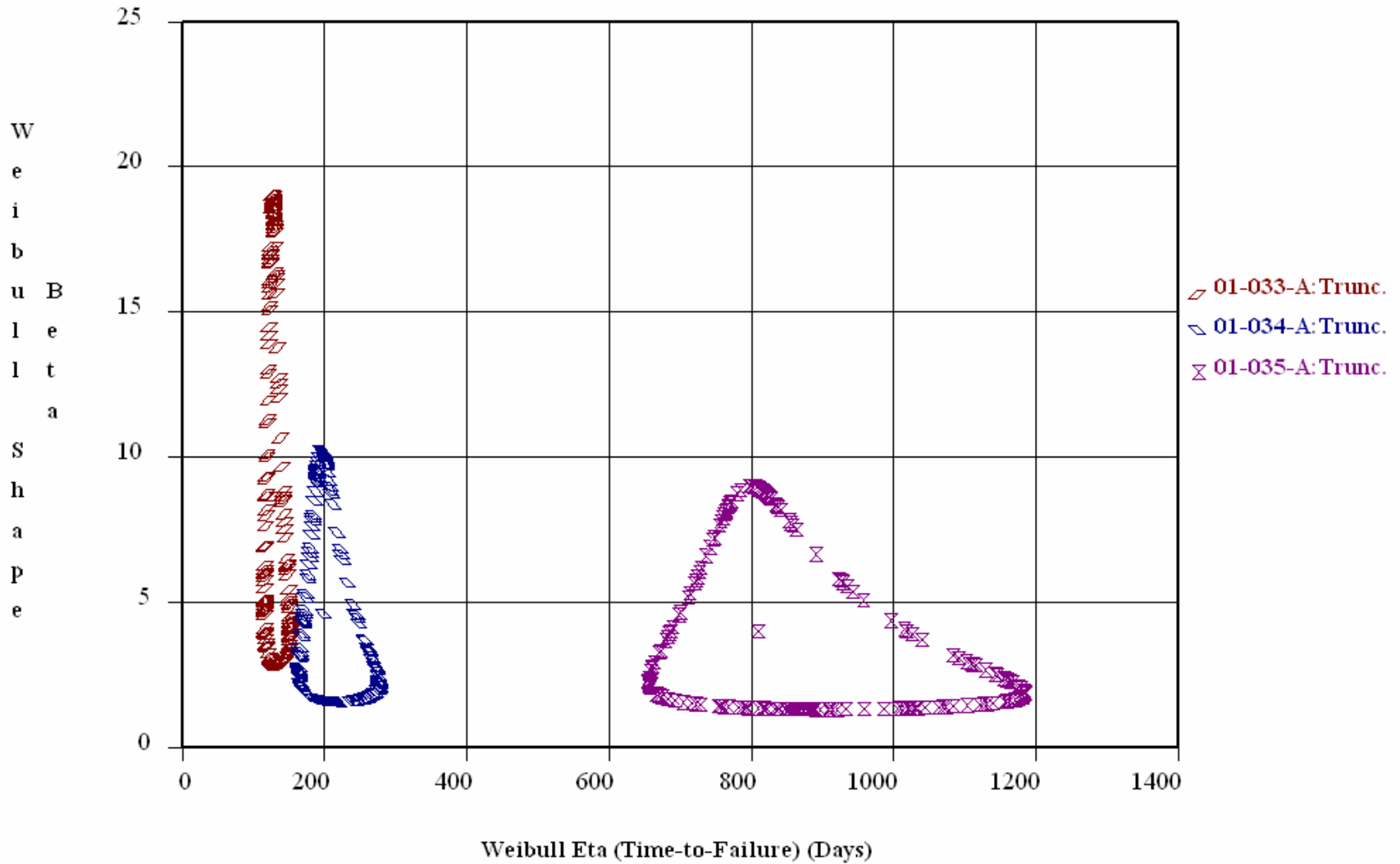
(LL3 Set Quantity 3 = -67.84519)

(LL1 All 1 Set = -86.25345)

(LL3-LL1 = 36.81652 / 2)

Population Truncation Test Plans

#2 AWG 44 ACLT:CCS/XLPE



Population Truncation Test Plans

Weibull Log Likelihood (LL) Comparison: Set Quantity = 2

Difference = Extreme

95.35 % pff-Value Confidence

Set 7-8 Difference Significance

(99.11 % p-Value With Standard mle Test Bias)

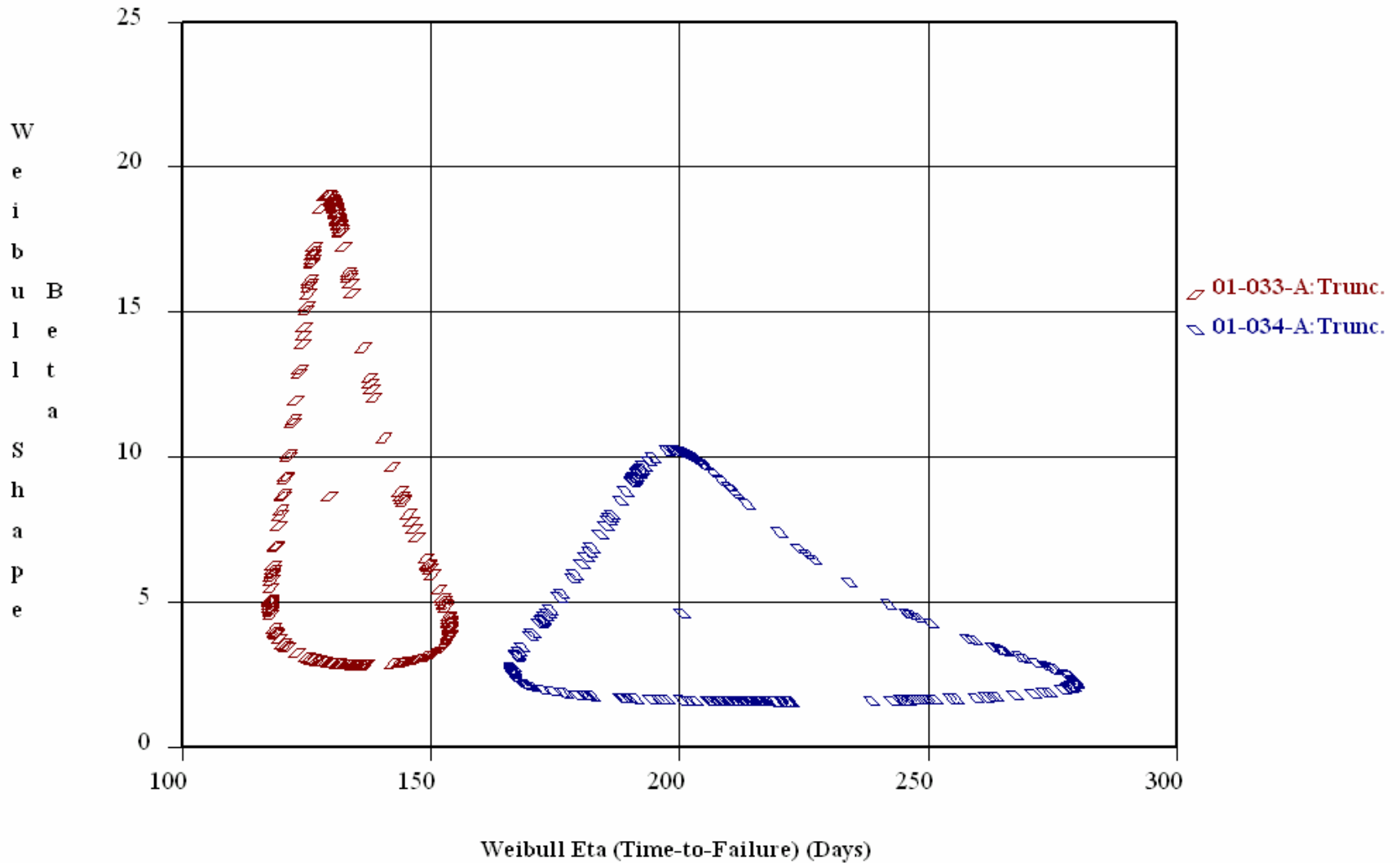
(LL2 Set Quantity 2 = -39.87969)

(LL1 All 1 Set = -44.60301)

(LL2-LL1 = 9.446639 / 2)

Population Truncation Test Plans

#2 AWG 44 ACLT:CCS/XLPE



Population Truncation Test Plans Time Savings

#2 AWG 44 CCS/XLPE: FAILED CABLE SAMPLES								
01-033-A	Timer Days		01-034-A	Timer Days		01-035-A	Timer Days	
Sample ID	Full	Trunc.	Sample ID	Full	Trunc.	Sample ID	Full	Trunc.
G06*3912	105.5	105.5	H01*4701	123.9	123.9	J04*4710	442.8	442.8
G02*3908	111.3	111.3	H02*4702	152.8	152.8	J01*4707	633.8	633.8
G01*3907	124.8	124.8	H04*4704	198.2	198.2	J03*4709	776.8	776.8
G05*3911	130.5	130.5	H05*4705	199.0	199.0	J05*4711	803.0	803.0
G03*3909	133.6	133.6	H03*4703	214.8	214.8	J06*4712	912.6	912.6
G04*3910	178.1	178.1	H06*4706	355.8	355.8	J02*4708	958.1	958.1
Months Req'd	5.9	4.4		11.9	6.6		31.9	26.8
% Time Saved		27			44			16

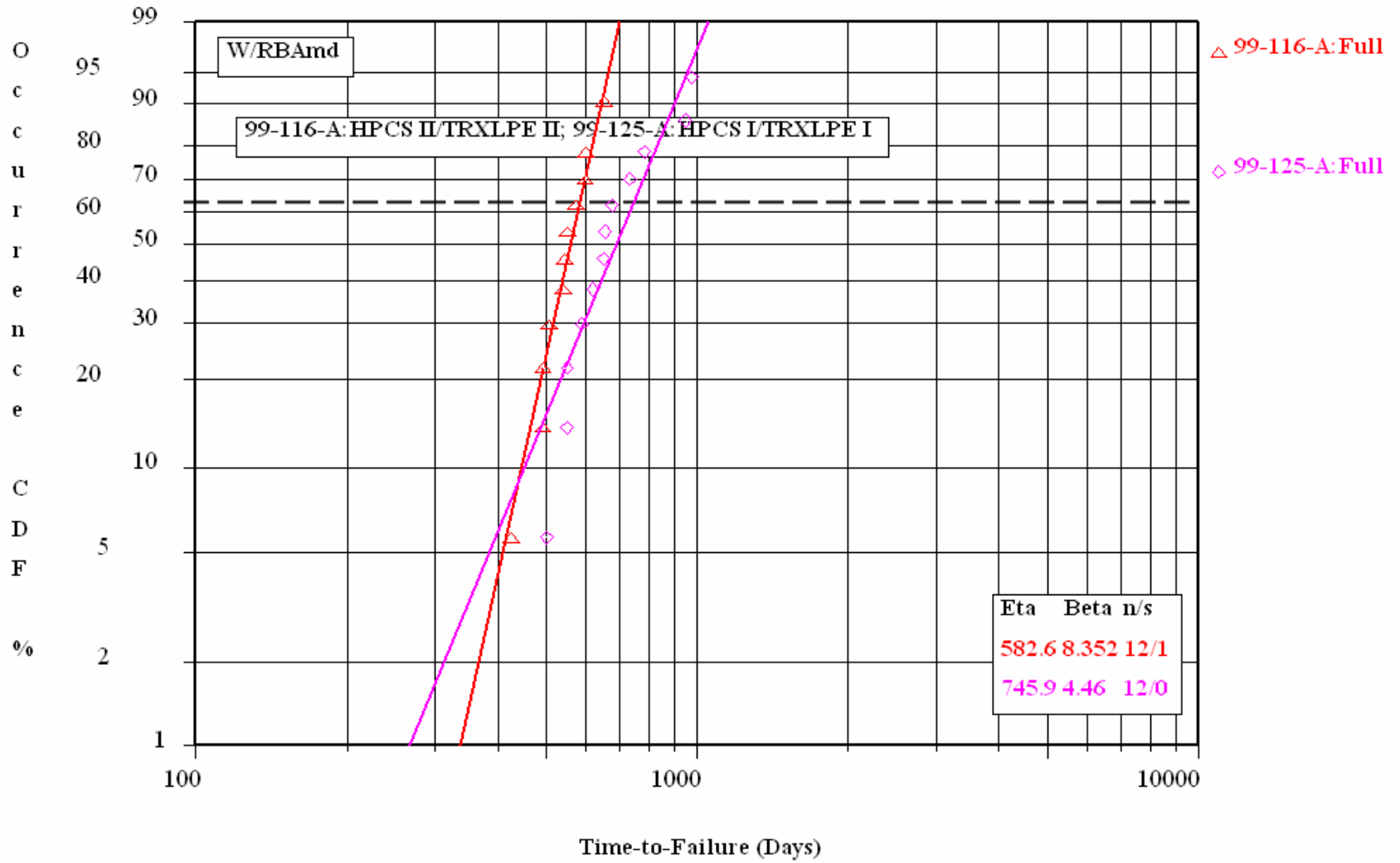
Sudden Death and Truncation Test Plans

#1/0 AWG 44 ACLT HPCS/TRXLPE: FAILED CABLE SAMPLES							
99-116-A	Timer Days			99-125-A	Timer Days		
Sample ID	Full Popn.	Sudden Death	Trunc.	Sample ID	Full Popn.	Sudden Death	Trunc.
P12*4108	425.4	425.4	425.4	U05*4205	501.2	501.2	501.2
P04*4110	492.2	492.2	492.2	U01*4201	549.6	549.6	549.6
P05*4111	492.2	492.2	492.2	U10*4210	551.0	551.0	551.0
P07*4110	507.2	507.2	507.2	U09*4209	588.4	588.4	588.4
P01*4107	539.2	539.2	539.2	U02*4202	618.3	618.3	618.3
P06*4112	544.1	544.1	544.1	U03*4203	649.5	649.5	649.5
P10*4112	550.2	550.2	550.2	U08*4208	653.7	653.7	653.7
P03*4109	572.0	572.0	572.0	U11*4211	676.0	676.0	676.0
P08*4111	597.2	597.2	597.2	U12*4212	734.2	734.2	734.2
P11*4109	599.9	599.9	599.9	U04*4204	784.9	784.9	784.9
P02*4108	652.2	652.2	652.2	U06*4206	946.0	946.0	946.0
P09*4107	-641.5			U07*4207	975.5	975.5	975.5

Four (4) Sub-Groups of 3 Sample Specimens for each Sudden Death group; $n/s = (3/2)*4 = 12/8$.
 Failure of $2/3$ Specimens Failed; $n = 12, F = 8, S = 4, n/s = 12/4$

Sudden Death Test Plans

1/0 AWG 44 ACLT:HPCS/TRXLPE



F_F

Sudden Death Test Plans

Weibull Log Likelihood (LL) Comparison: Set Quantity = 2

Difference = Extreme

99.7 % pff-Value Confidence

Set 1-4 Difference Significance

(99.88 % p-Value With Standard mle Test Bias)

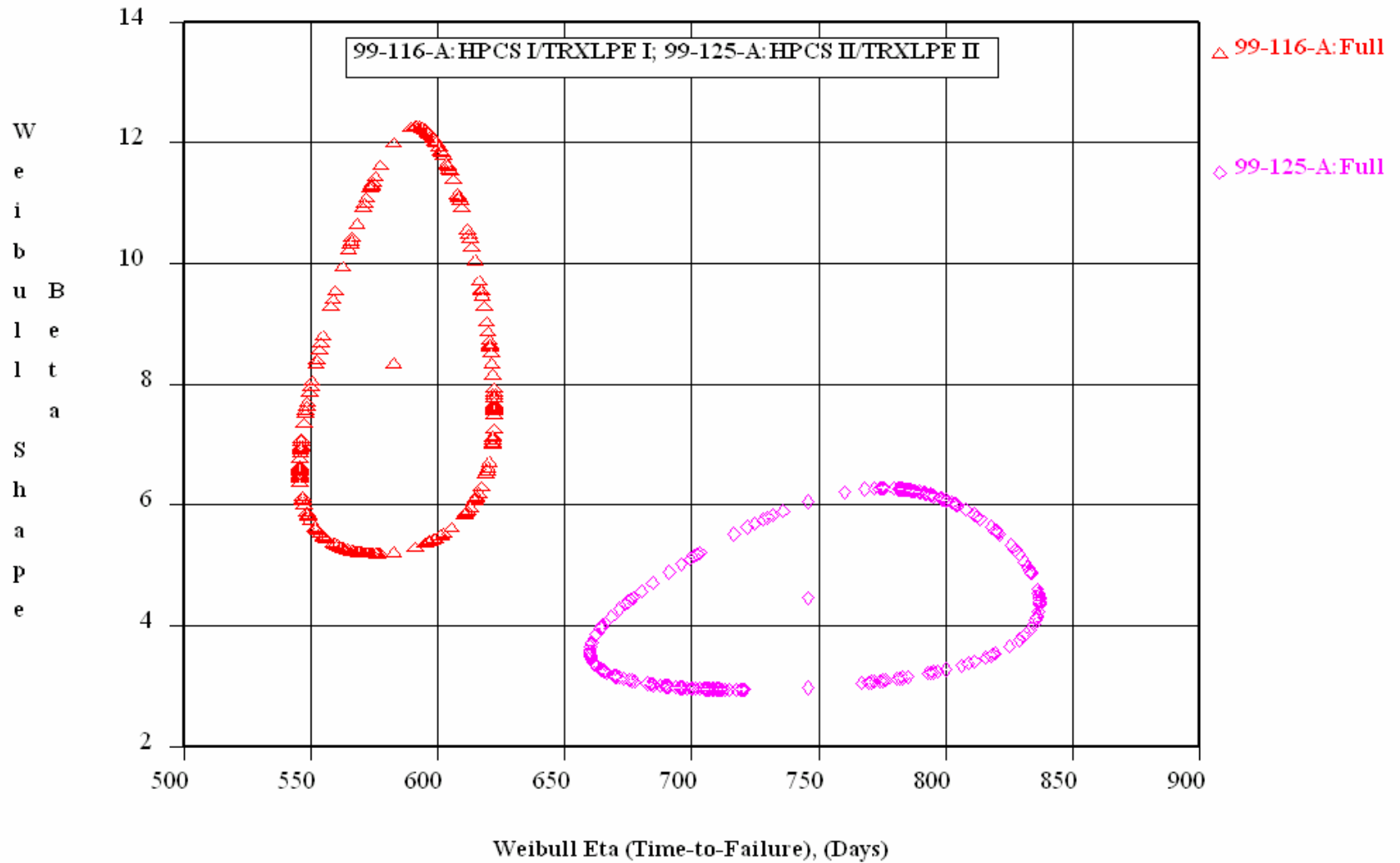
(LL2 Set Quantity 2 = -140.89)

(LL1 All 1 Set = -147.6167)

(LL2-LL1 = 13.4535 / 2)

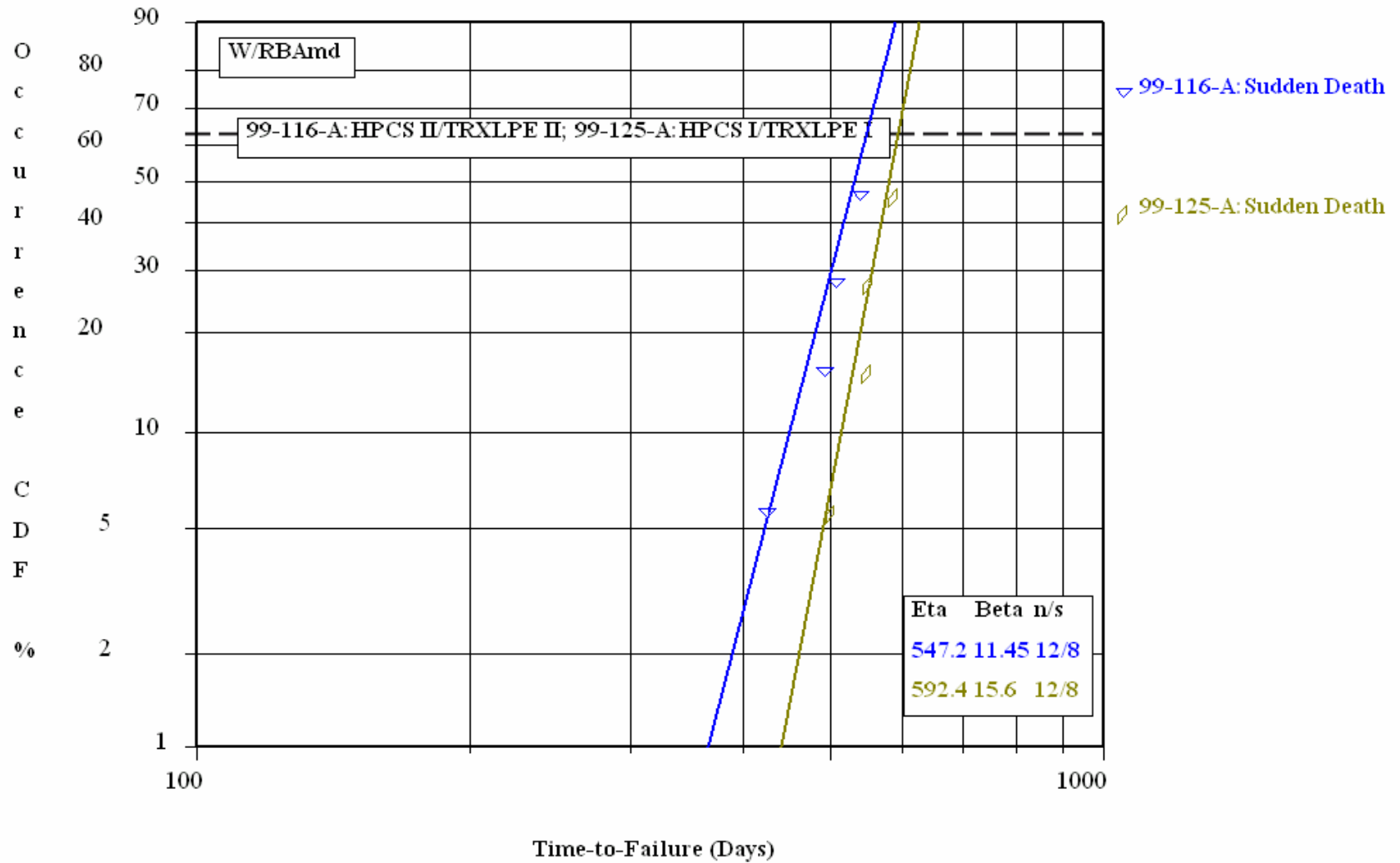
Sudden Death Test Plans

44 ACLT:HP COND.SHLDS./TRXLPE



Sudden Death Test Plans

1/0 AWG 44 ACLT:HPCS/TRXLPE



F_F

Sudden Death Test Plans

Weibull Log Likelihood (LL) Comparison: Set Quantity = 2

Difference = Small ... Possible With Additional Data

73.27 % pff-Value Confidence

Set 2-5 Difference Significance

(86.88 % p-Value With Standard mle Test Bias)

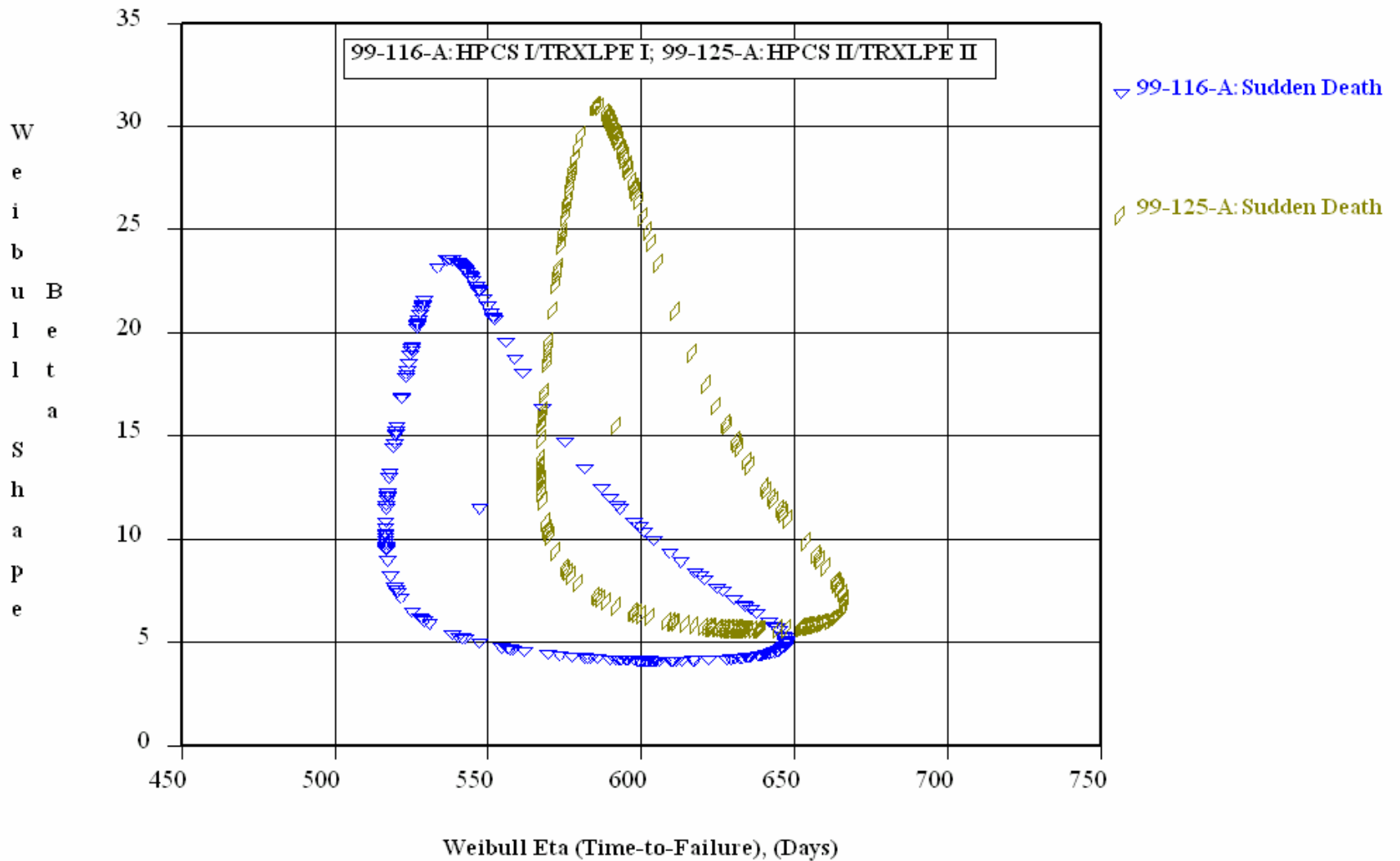
(LL2 Set Quantity 2 = -48.46416)

(LL1 All 1 Set = -50.4952)

(LL2-LL1 = 4.062069 / 2)

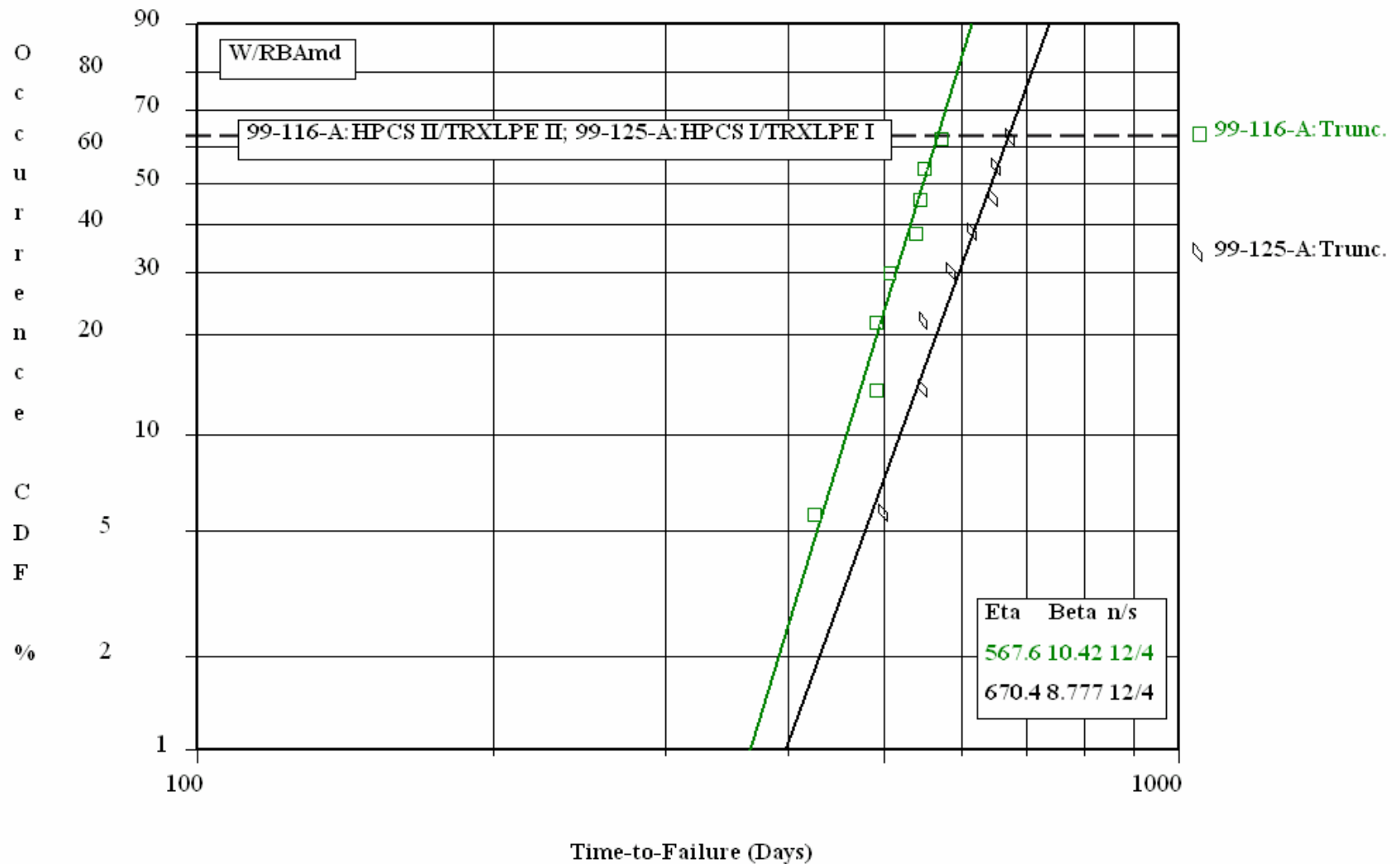
Sudden Death Test Plans

44 ACLT:HP COND.SHLDS./TRXLPE



Truncation Test Plans

1/0 AWG 44 ACLT:HPCS/TRXLPE



Truncation Test Plans

Weibull Log Likelihood (LL) Comparison: Set Quantity = 2

Difference = Extreme

96.17 % pff-Value Confidence

Set 3-6 Difference Significance

(98.2 % p-Value With Standard mle Test Bias)

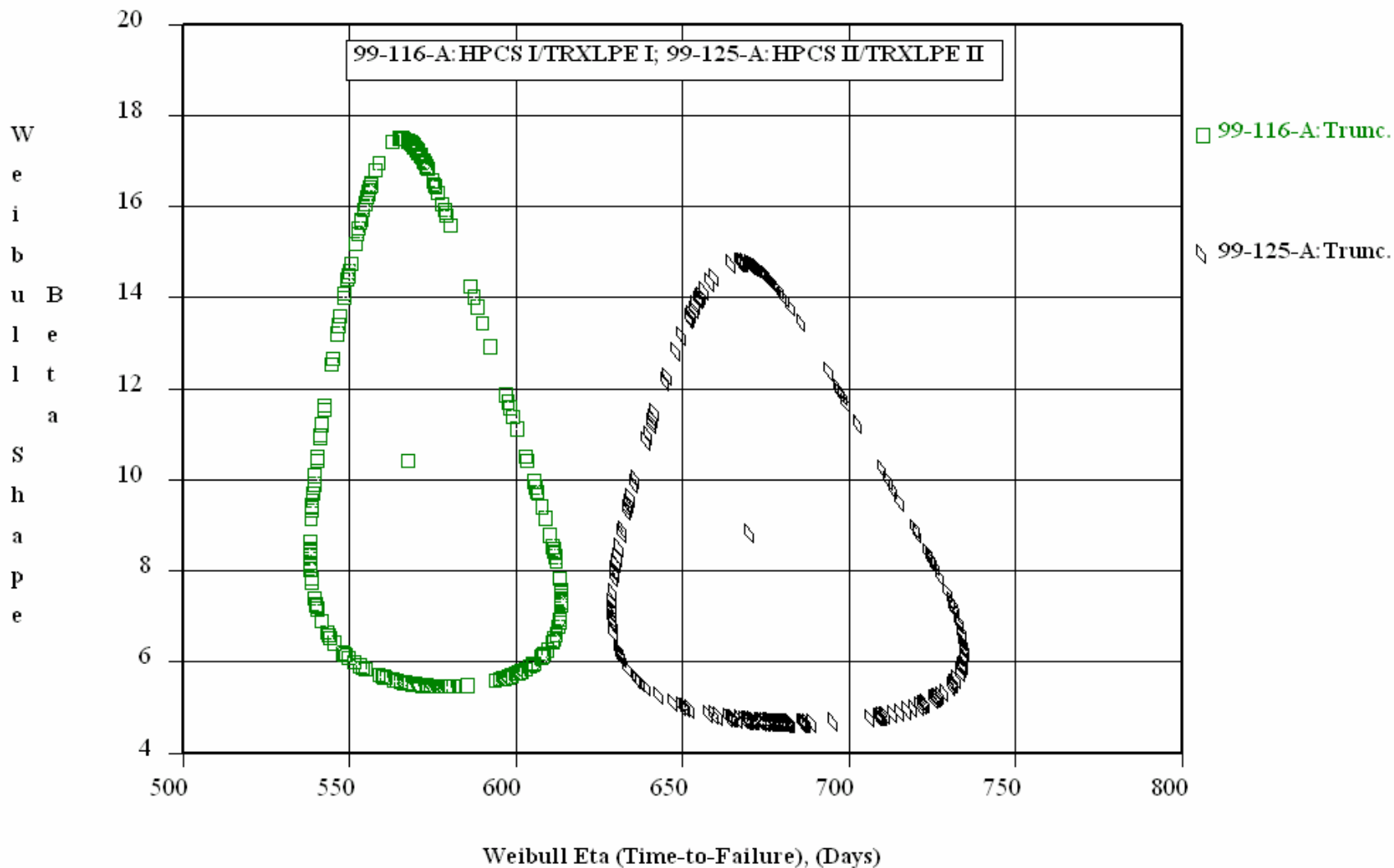
(LL2 Set Quantity 2 = -97.79275)

(LL1 All 1 Set = -101.8082)

(LL2-LL1 = 8.030821 / 2)

Truncation Test Plans

44 ACLT:HP COND.SHLDS./TRXLPE



Sudden Death and Truncation Test Plans Time Savings

#1/0 AWG 44 ACLT HPCS/TRXLPE: FAILED CABLE SAMPLES							
99-116-A	Timer Days			99-125-A	Timer Days		
Sample ID	Full Popn.	Sudden Death	Trunc.	Sample ID	Full Popn.	Sudden Death	Trunc.
P12*4108	425.4	425.4	425.4	U05*4205	501.2	501.2	501.2
P04*4110	492.2	492.2	492.2	U01*4201	549.6	549.6	549.6
P05*4111	492.2	492.2	492.2	U10*4210	551.0	551.0	551.0
P07*4110	507.2	507.2	507.2	U09*4209	588.4	588.4	588.4
P01*4107	539.2	539.2	539.2	U02*4202	618.3	618.3	618.3
P06*4112	544.1	544.1	544.1	U03*4203	649.5	649.5	649.5
P10*4112	550.2	550.2	550.2	U08*4208	653.7	653.7	653.7
P03*4109	572.0	572.0	572.0	U11*4211	676.0	676.0	676.0
P08*4111	597.2	597.2	597.2	U12*4212	734.2	734.2	734.2
P11*4109	599.9	599.9	599.9	U04*4204	784.9	784.9	784.9
P02*4108	652.2	652.2	652.2	U06*4206	946.0	946.0	946.0
P09*4107	-641.5			U07*4207	975.5	975.5	975.5
Months Req'd	21.7	18.0	19.1		32.5	19.6	22.5
Time Saved,%		17	12			40	31

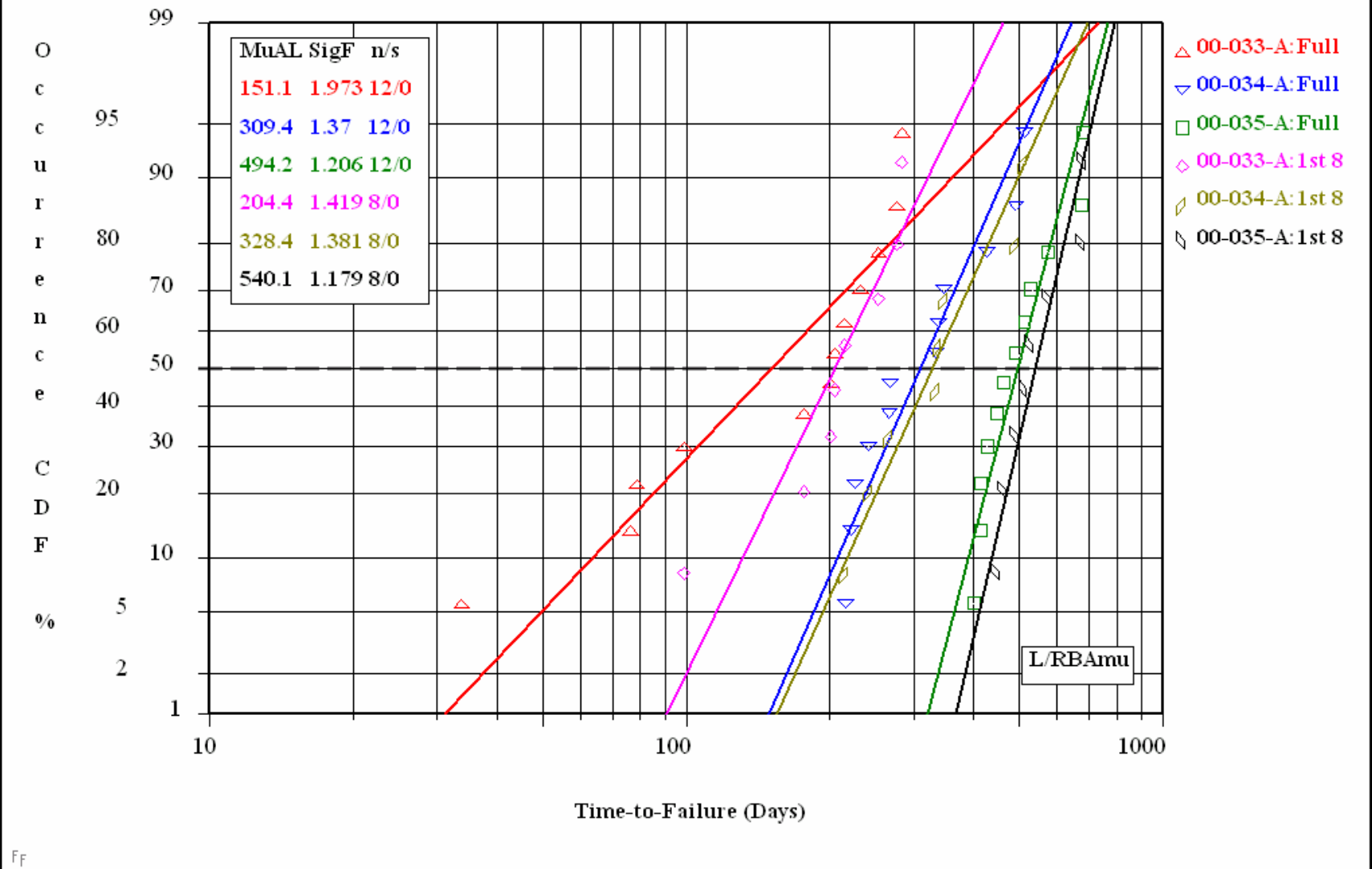
Smaller (Reduced) Sample Size Test Plans

#2 AWG 44 ACLT HPCS/XLPE: FAILED CABLE SAMPLES								
00-033-A Sample ID	Timer Days		00-034-A Sample ID	Timer Days		00-035-A Sample ID	Timer Days	
	Full Popn.	1st 8 Samples		Full Popn.	1st 8 Samples		Full Popn.	1st 8 Samples
A12*4604	33.7	98.7	B08*4608	215.2	215.2	C12*4602	400.5	448.0
A10*4504	76.2	176.5	B12*4508	221.2	241.2	C10*4604	413.8	463.7
A11*4602	78.6	200.9	B11*4604	225.8	266.2	C11*4605	413.9	490.8
A02*4502	98.7	204.5	B04*4508	241.2	334.0	C09*4603	427.3	512.1
A04*4504	176.5	214.7	B05*4605	266.2	337.5	C02*4510	448.0	527.9
A06*4602	200.9	252.9	B09*4608	267.0	346.9	C03*4511	463.7	573.3
A08*4604	204.5	276.5	B07*4607	334.0	490.6	C07*4611	490.8	673.5
A03*4503	214.7	283.0	B06*4606	337.5	510.7	C05*4609	512.1	680.7
A09*4502	231.4		B01*4505	346.9		C01*4509	527.9	
A07*4603	252.9		B10*4601	426.1		C06*4610	573.3	
A01*4501	276.5		B03*4507	490.6		C04*4609	673.5	
A05*4601	283.0		B02*4506	510.7		C08*4612	680.7	

Red Values = Outliers. Green Values + 33.7 Red Value Represent Values that Constitutes a Mixture. Blue Values Represent Additional Specimens Entered to Achieve Population Size of 12.

Smaller (Reduced) Sample Size Test Plans

#2 AWG 44 ACLT:HPCS/XLPE



Smaller (Reduced) Sample Size Test Plans

Outlier Test: Extreme Point P-Value (%)

Note: For All Occurrence Only

Set 1: .4955445 (Lower <1.35!) ... 13.66282 (Upper Okay)

Set 2: 73.70638 (Lower Okay) ... 69.24988 (Upper Okay)

Set 3: 75.23777 (Lower Okay) ... 79.91711 (Upper Okay)

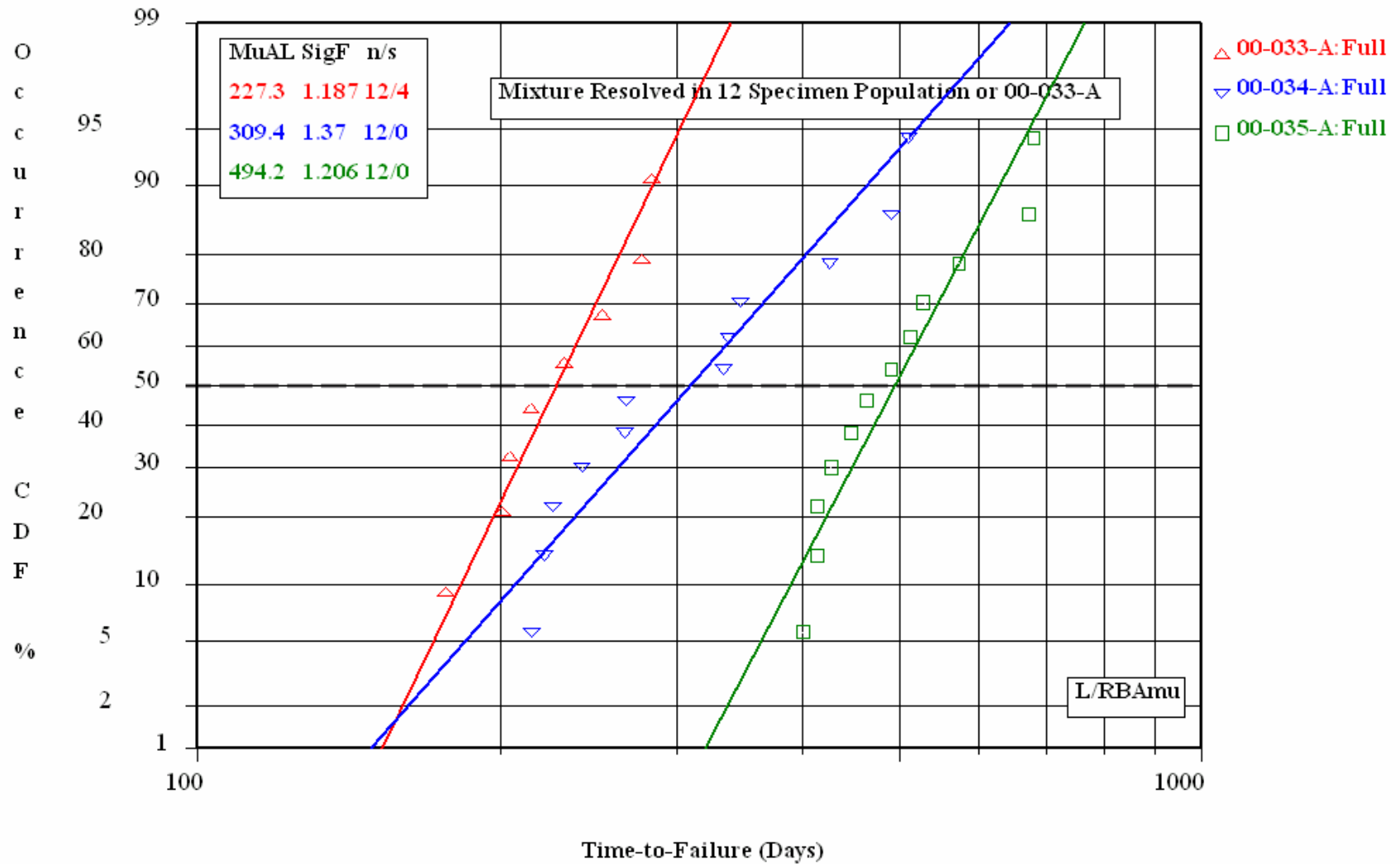
Set 4: 7.533779E-03 (Lower <1.35!) ... 30.12946 (Upper Okay)

Set 5: 36.73849 (Lower Okay) ... 68.52568 (Upper Okay)

Set 6: 54.71707 (Lower Okay) ... 72.70357 (Upper Okay)

Smaller (Reduced) Sample Size Test Plans

#2 AWG 44 ACLT:HPCS/XLPE



Smaller (Reduced) Sample Size Test Plans

LogNorm Log Likelihood (LL) Comparison: Set Quantity = 3

Difference = Extreme

>99.9999 % pff-Value Confidence

Set 1-2-3 Difference Significance

(>99.9999 % p-Value With Standard mle Test Bias)

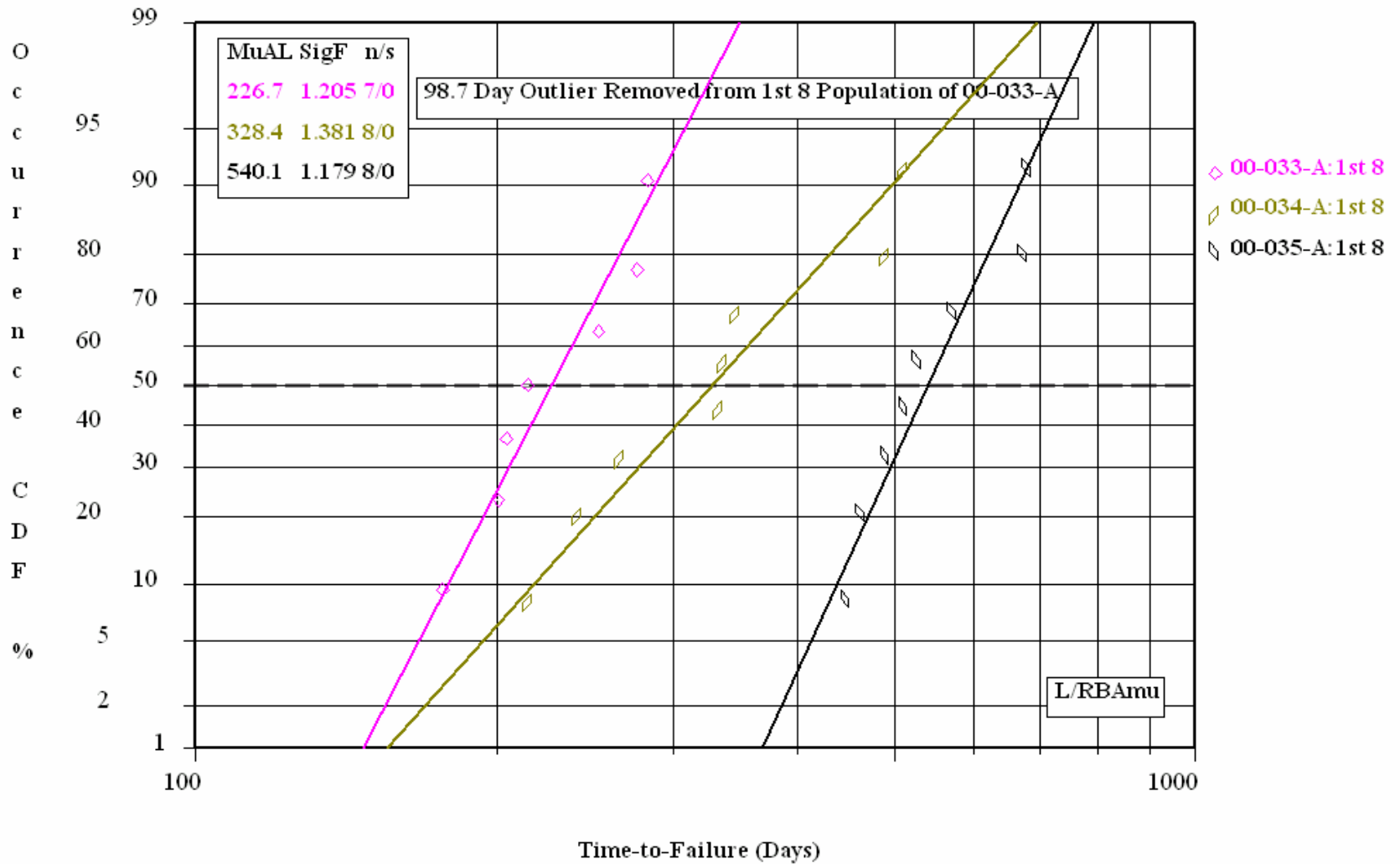
(LL3 Set Quantity 3 = -181.5787)

(LL1 All 1 Set = -201.3236)

(LL3-LL1 = 39.48984 / 2)

Smaller (Reduced) Sample Size Test Plans

#2 AWG 44 ACLT:HPCS/XLPE



F_F

Smaller (Reduced) Sample Size Test Plans

LogNorm Log Likelihood (LL) Comparison: Set Quantity = 3

Difference = Extreme

>99.9999 % pff-Value Confidence

Set 4-5-6 Difference Significance

(>99.9999 % p-Value With Standard mle Test Bias)

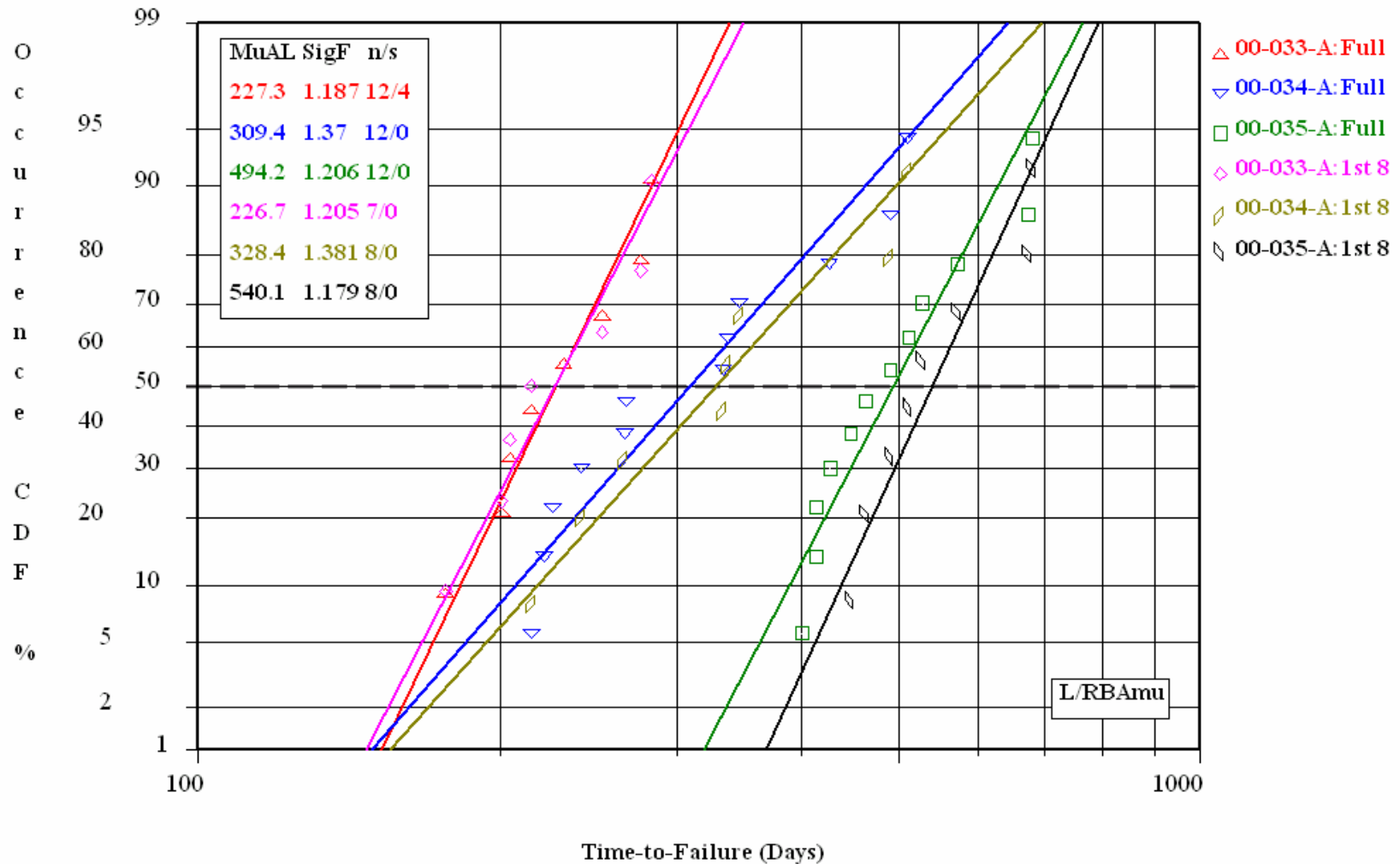
(LL3 Set Quantity 3 = -129.5682)

(LL1 All 1 Set = -146.8947)

(LL3-LL1 = 34.65297 / 2)

Smaller (Reduced) Sample Size Test Plans

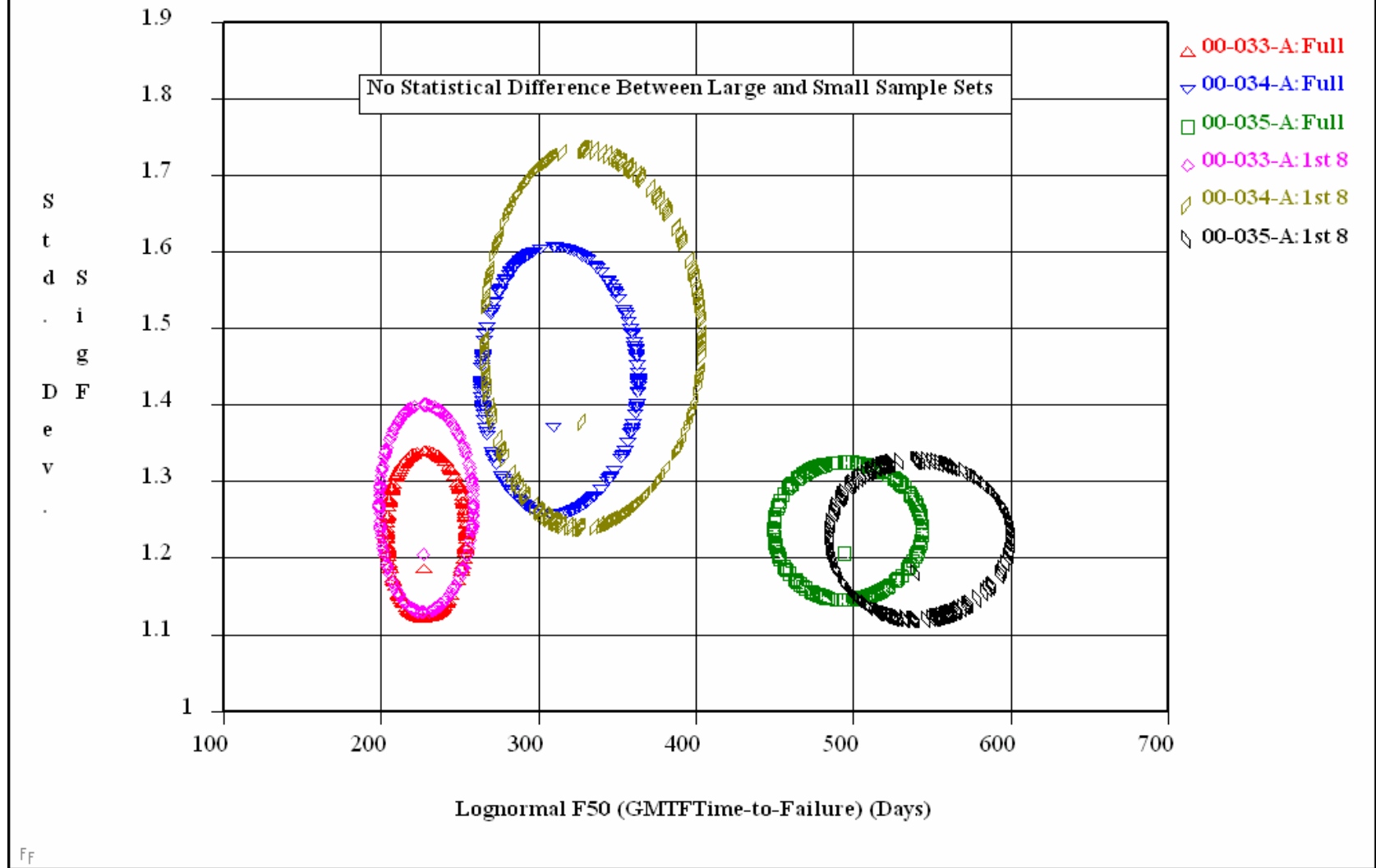
#2 AWG 44 ACLT:HPCS/XLPE



Repaired Populations; Parallel Plots Indicate Agreement Between 1st 8 and Full Sets

Smaller (Reduced) Sample Size Test Plans

#2 AWG 44 ACLT:HPCS/XLPE



Obviously Reliable Engineering Decisions Are Possible from Smaller Sample Sets

Smaller (Reduced) Sample Size Test Time Savings

#2 AWG 44 ACLT HPCS/XLPE: FAILED CABLE SAMPLES								
00-033-A	Timer Days		00-034-A	Timer Days		00-035-A	Timer Days	
Sample ID	Full Popn.	1st 8 Samples	Sample ID	Full Popn.	1st 8 Samples	Sample ID	Full Popn.	1st 8 Samples
A12*4604	33.7	98.7	B08*4608	215.2	215.2	C12*4602	400.5	448.0
A10*4504	76.2	176.5	B12*4508	221.2	241.2	C10*4604	413.8	463.7
A11*4602	78.6	200.9	B11*4604	225.8	266.2	C11*4605	413.9	490.8
A02*4502	98.7	204.5	B04*4508	241.2	334.0	C09*4603	427.3	512.1
A04*4504	176.5	214.7	B05*4605	266.2	337.5	C02*4510	448.0	527.9
A06*4602	200.9	252.9	B09*4608	267.0	346.9	C03*4511	463.7	573.3
08*4604	204.5	276.5	B07*4607	334.0	490.6	C07*4611	490.8	673.5
A03*4503	214.7	283.0	B06*4606	337.5	510.7	C05*4609	512.1	680.7
A09*4502	231.4		B01*4505	346.9		C01*4509	527.9	
A07*4603	252.9		B10*4601	426.1		C06*4610	573.3	
A01*4501	276.5		B03*4507	490.6		C04*4609	673.5	
A05*4601	283.0		B02*4506	510.7		C08*4612	680.7	
Months Req'd	11.5	9.6		22.2	17.8		23.6	23.5
Time Saved, %		17			20			0.4

Conclusions from Statistical Analysis of Sudden Death, Truncation and Small Sample Analysis Techniques in ACLT Evaluations

- **Sudden Death, Truncation and Smaller Sample Size Populations**
 - **Has Potential to provide test time and testing cost savings of up to 44%**
 - **Allows reliable engineering decisions to be made in shorter ACLT timeframes**
 - **Allows better utilization of ACLT facilities**
 - **Techniques are robust enough to handle data anomalies such as outliers and mixtures, and still provide data for meaningful and robust decisions**
 - **Weakness inherent in sudden death due to large number of suspensions can be overcome by continuing to test to a truncation level which reduces suspensions to optimize statistical differences**
 - **Both Weibull and Lognormal distributions are amenable to these techniques**