[redacted] Analysis of the Duration Data

1.0 Purpose

The following provides analysis and working notes for analysis of the Spurious Operation Duration for the PRA Expert Panel. The notes in Attachment are for information only, since they were used to look at various options for the analysis and results of the duration. Section 6 and Attachment 3 provide the recommended duration values.

2.0 Analysis of Duration Averages and Ratios

The Duration Analysis is based on the Duration data in the Excel file Durations "List format TS vs. TP 12-3-12.xlsx."

The following provides a summary of the duration results (average duration) for spurious operations, based on analysis of the data using Excel.

Table 2-1
Summary of Average Durations for various test configurations

			HGL			Plume			Flame	
	TS	**TS – Intra**	**TS-Inter**	**MSTG**	**TS – Intra**	**TS-Inter**	**MSTG**	**TS – Intra**	**TS-Inter**	**MSTG**
AC	**Grounded**	77.7	96.0	N/A	38.2	108.0	N/A	16.1	NA	N/A
AC	**Ungrounded**	88.5	No Data	N/A	48.9	No Data	N/A	23.2	No Data	N/A
DC	**Ungrounded**	73.1	No Data	67.0	18.3	No Data	33.8	31.6	No Data	42.4
	TP	**TP-Inter**	**TP-Intra**	**TP-MSTG**	**TP-Inter**	**TP-Intra**	**TP-MSTG**	**TP-Inter**	**TP-Intra**	**TP-MSTG**
AC	**Grounded**	132.6	549.0	N/A	82.9	240.0	N/A	3.9	No Data	N/A
AC	**Ungrounded**	14.6	No Data	N/A	No Data	No Data	N/A	11.5	No Data	N/A
DC	**Ungrounded**	58.0	No Data	No Data	136.7	No Data	No Data	63.8	No Data	170

Note: dark Blue data appears inconsistent with other data in the row. For example, DC Ungrounded Flame TS; should be shorter than Plume but is not.

Based on the data, a review of which data can or should be combined was performed. Here are the ratios for above results for areas that may be combined.

Table 2-2
General Ratios from Table 2-1

Cable	Ratio Description	Ratio	Comment
	TP(Ave.) to TS	2.4	Large Variation for various damage conditions and circuit type.
TS	Plume to Flame	1.8	
TS	HGL to Flame	2.5	AC Ungrounded TP

			shows a much smaller ratio.
TP	Plume to Flame	1.8	
TP	HGL to Flame	2.7	
	Intra to Inter	4.3	Not a lot of Intercable Data.
	MSTG to Inter	1.4	

Basic results of the ratios above; do not combine TS/TP, and Plume/Flame/HGL. However, MSTG (multiple shorts to ground) and Inter-cable can be combined. See below on discussion for Intra-cable and Inter-cable failures. Not shown above in the ratios is HGL to Plume, which from inspection in Table 1 above, can be combined in some cases.

3.0 Curve-Fit of Duration Results

I analyzed the major duration data separately, but cable type and location, and performed curve fit analysis using Weibull ++ (version 7.5.10) by ReliaSoft. Weibull++ includes a curve-fit analysis check of various curve-fit possibilities, including the following:

1. Exponential 1, and 2 parameter
2. Normal
3. Lognormal
4. Weibull, 2 and 3 parameter
5. Gamma – 2 and 3 parameter
6. Logistic
7. Loglogistic
8. Gumbel

The curves above were ranked by Weibull++, based on the data sets provided. Analysis of various data sets resulted in different curves being recommended. For example, for HGL, TS-Cable, and Grounded AC; the recommended curve type was Gamma, three parameter (called G-Gamma or generalized Gamma in the software) followed by the three parameter Weibull and Logistic. Other data included recommendations where 3-parameter Weibull was the recommended curve, with possibility of using exponential, etc. Based on the analysis of the various data sets, it is recommended to use the three-parameter gamma for the final data analysis. The three-parameter Weibull is also a good fit and could be used.

The Generalized (three-parameter) Gamma distribution is defined for the PDF as:

$$f(x;a,d,p) = \frac{(p/a^d)x^{d-1}e^{-(x/a)^p}}{\Gamma(d/p)},$$

The denominator above is the Gamma distribution (typical) formula, not provided here. However, the <u>2-point Weibull is recommended</u> for the following reasons:

1) When the 2-point Weibull is compared to either of the recommended curves, the lower times get similar results, while the longer times (e.g., 240 seconds and above) get more conservative results. For example, for the TS, Intra-cable, Grounded AC, the probability of exceeding 240 seconds on the G-Gamma and 3-point Weibull is around 0.04, versus 0.12 for the 2-point Weibull (see Attachment 1)

2) In reviewing the uncertainty bounds (see below), the above is well within the uncertainty bounds which is fairly large especially at the longer times.
3) The conservatism in the tail would help account for uncertainty concerns related to the number of tests performed and other variables.
4) The 2-point Weibull is more easily handled within the PRA modeling, using Excel, etc.

Two point Weibull is defined as:

4.0 Initial Recommendations for Duration Curves

The following are recommended for the duration results based on the above considerations.

A) Use a 2-point Weibull curve-fit for the data to estimate the duration curves.
B) Combine the data for inter and intra-cable failures into a single curve. For DC, combine with multiple shorts to ground.
    a. The combination will basically "convolute" the Intra and Inter-cable HS probabilities in the duration (e.g., the percentage of each short is accounted for in the data). In most cases, there is little or no inter-cable data or MSTG, so the results are not greatly impacted. Data analysis below will however provide a value to be used in the Inter-cable failure is the only mode applicable.
    b. The simplified modeling is easier to apply in the PRA.
    c. MSTG data for DC does not appear to be greatly different than the Intra-cable data, so combining should not greatly impact the results.
C) Keep HGL, Plume and Flame initially separate, but consider combining based on the analysis results.

Based on the above recommendations, the following are developed for the duration data (See Table 4-1). The plots of many of the curves are provided in Attachment 2.

Table 4-1 Summary Table DWH Durations						
Test	**Cable**	**Exposure**	**Mode**	**Beta (β)**	**Eta (η)**	**Comments (Case #s based on DWH Weibull ++ Worksheet)**
AC-Grounded	TS	HGL	Intra/Inter	0.662	77.9	Case 9
	TS	HGL	Intra Only	0.631	72.7	Just for information – Case 1
	TS	HGL	Inter Only	1.96	113.4	Only 2 points - Case 10
	TS	Plume	Intra/Inter	1.16	51.9	Case 2
	TS	Flame	Intra	1.38	18.0	No Inter data - Case 3
	TS	Combined (HGL, Plume, Flame)	All	1.14	37.7	Case 22: Based on combining all tests, not by "averaging"
	TS	HGL/Plume Combined	Intra/Inter	0.842	64.2	Case 32: Combine Case 2 and Case 9
	TP	HGL	Intra/Inter	0.784	166.9	Case 4
		Plume	Intra/Inter	1.30	124.7	Case 5
	TP	HGL/Plume Combined	Intra/Inter	0.968	148.0	Case 33: Case 4, 5 Combined
	TP	Flame	Intra/Inter	0.769	4.12	No Inter – Case 6
	TP	Combined	All	0.604	94.2	Case 23
AC-Grounded	TS/TP	Combined	All	0.82	67.0	Case 24 – Again, based on tests not averages
Ungrounded – AC	TS	HGL	Intra	2.99	99.5	No Inter – Case 7
	TS	Plume	Intra	3.61	54.2	No Inter – Case 12
	TS	Flame	Intra	2.48	26.7	No Inter – Case 13
	TS	Combined	All	1.94	73.4	Case 25
	TP	HGL	Intra	1	14.6	Need to combine with something – 1 point. Case 14
	TP	Plume	No Data	No Data	No Data	Average Plume and Flame?
	TP	Flame	Intra	0.500	8.78	No Inter Case 15
	TP	Combined	All	0.536	10.3	Case 26 Recommend this for TP since no data on Plume and one data point for HGL.
Ungrounded – AC	Both	Combined	All	0.67	47.5	Case 27 – Combining 25 and 26.
DC - Ungrounded	TS	HGL	Intra and MSTG	2.12	82.4	No Inter – Case 16
	TS	Plume	Intra and MSTG	1.19	29.9	No Inter – Case 17
	TS	Flame	Intra and MSTG	1.06	38.7	Case 8
	TS	Flame	MSTG Only	1.22	47.4	Similar to Combined. Case 11. Not plotted below.

Table 4-1 Summary Table DWH Durations						
Test	**Cable**	**Exposure**	**Mode**	**Beta (β)**	**Eta (η)**	**Comments (Case #s based on DWH Weibull ++ Worksheet)**
	TS	Combined	All	1.13	39.7	Case 28
	TP	HGL	Intra Only	1.02	73.6	May Want to Combine with Plume. 2 Points - Case 18
	TP	Plume	Intra Only	1.30	169.4	See above. 2 points –Case 19
	TP	HGL and Plume combined	Intra Only	1.23	113.4	Combined – Case 21
	TP	Flame	Intra and MSTG	1.06	92.7	3 MSTG – Case 20
	TP	Combined	All	1.17	97.5	Case 29
DC - Ungrounded	TP/TS	Combined	All	1.09	51.6	Case 30

5.0 Additional Notes

A review of the > 10 amp DC circuits was performed. The Hot Short Durations were much longer than lower amp circuits, average above 1000 seconds. A review of the ratio of duration from Hot Short to Duration was performed for the < 10 amp circuits was performed, with ratios of 5.30, 14.08 and 2.62 for HGL, Plume and Flame. Based on these ratios, the average HS duration for > 10 amp DC would be 448, 103 and 300 seconds for HGL, Plume and Flame (TP only); but is 73, 18 and 31 based on the < 10 amp cases. As a result of this review, a possible increase in a factor of 5 is recommended for HS durations for > 10 amps. However, this needs to be discussed further.

6.0 Recommendations

Table 6-1 provides a summary of the recommended values to be used for Fire PRA. It provides a limited set of cases from Table 4-1 above, based on combined groupings where similar attributes were obtained, or where limited data was available. The resulting curve fits, with uncertainty bounds, are provided in Attachment 3.

Table 6-1 Summary Table DWH Recommended Durations						
Test	**Cable**	**Exposure**	**Mode**	**Beta (β)**	**Eta (η) (5^{th}, 95^{th})**	**Comments (Case #s based on DWH Weibull ++ Worksheet)**
AC-Grounded	TS/TP	Flame	Intra/Inter	1.4	18 (12, 26)	Based on Case 3. Recommend using the TS data for both TS and TP. Both are short, and the 18 second Eta is bounding.
	TS	HGL/Plume Combined	Intra/Inter	0.84	64 (50, 100)	Based on Case 32. Since significantly different than Flame and TP data, did not recommend combining.
	TP	HGL/Plume Combined	Intra/Inter	0.97	150 (100, 240)	Based on Case 33. Since significantly different than Flame and TS data, did not recommend combining.
Ungrounded – AC	TS/TP	Combined	All	1.9	74 (55, 100)	Based on Case 25. Recommend this since there is limited TP data for Plume and HGL, and the flame data shows a low average time/duration.
DC - Ungrounded	TP/TS	Combined	All	1.1	60 (30, 80)	Based on rounding up Case 30. DC Cases range from 29 to 82 seconds (Eta), but with some limited data for intercable. Recommend a single value for all cable types, with an Eta = 60 seconds. May want to use One Ungrounded value for both AC and DC. If so, the bounding AC Value should be used from Case 25.

Additional Recommendations include:

R1: If the HS includes intercable only; use a factor of 4 increase for the above ETA values. A factor of 4 is used since the data already includes some intercable data, raising the average and ETA used (Table 2-2 shows 4.3 for the ratio).

R2: increase the DC Ungrounded values above by a factor of 5 for HS durations for > 10 amps. However, since there were no spurious operations observed, this should correspond to a lower spurious operation probability. If a separate probability is not developed for > 10 amps, the general ungrounded DC duration value above should be used.

R3: Uncertainty bounds for the above are shown in Attachment 3. A range is given for Eta, based on the LB and UB values at the same probability of Eta. LB/UB values for DC are adjusted since the table value above is adjusted from the case 30 value.

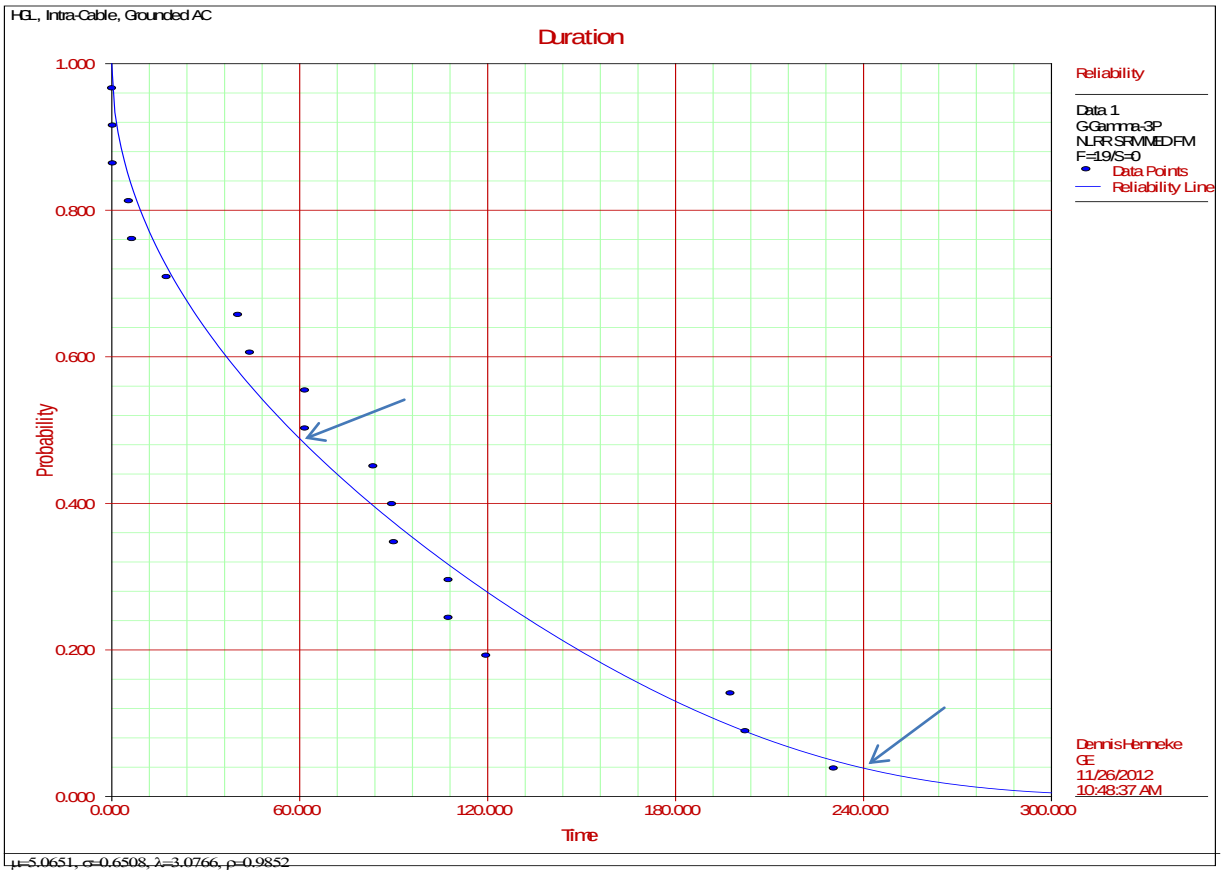
Attachment 1

Background and DWH Notes

Initial analysis of the data using Weibull++ (version 7) indicated that a three-parameter Gamma Distribution is recommended. An initial analysis was performed using this three-point gamma, and compared with the 2-point Weibull recommended above. A three-point Weibull was also recommended (see plot below). In general, the two-point Weibull was found to be conservative for longer duration times. Based on the three parameter gamma distribution, the following table is developed for the data (provided for background):

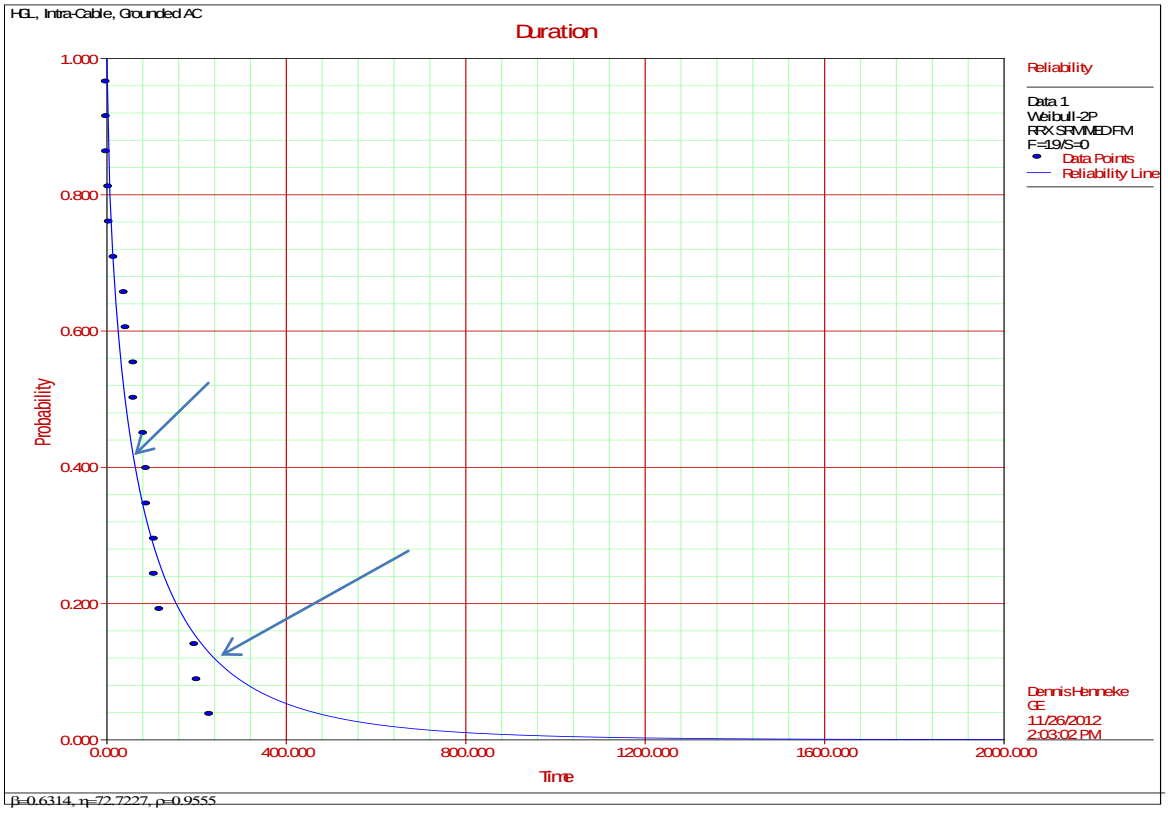
Test	Cable	Exposure	Mode	Mu (a)	Sigma (d)	Lambda (p)	Comments
AC-Grounded	TS	HGL	Intra	5.1	0.65	3.1	
		Plume		3.8	1.0	0.54	
		Flame		3.6	0.071	17	
	TP	HGL		3.7	1.6	-0.61	
		Plume		4.3	0.53	1.1	
		Flame		1.98	0.65	2.7	
Ungrounded – AC	TS	HGL	Intra	4.7	0.18	2.2	
		Plume					Not completed
		Flame					Not completed
	TP	HGL					Not completed
		Plume					Not completed
		Flame					Not completed
DC	TS	HGL	Intra	3.8	0.92	1.8	
		Plume					Not completed
		Flame		3.8	0.92	1.8	

Example plots are provided below for Grounded AC, Intra-cable, and HGL as well as ungrounded AC.

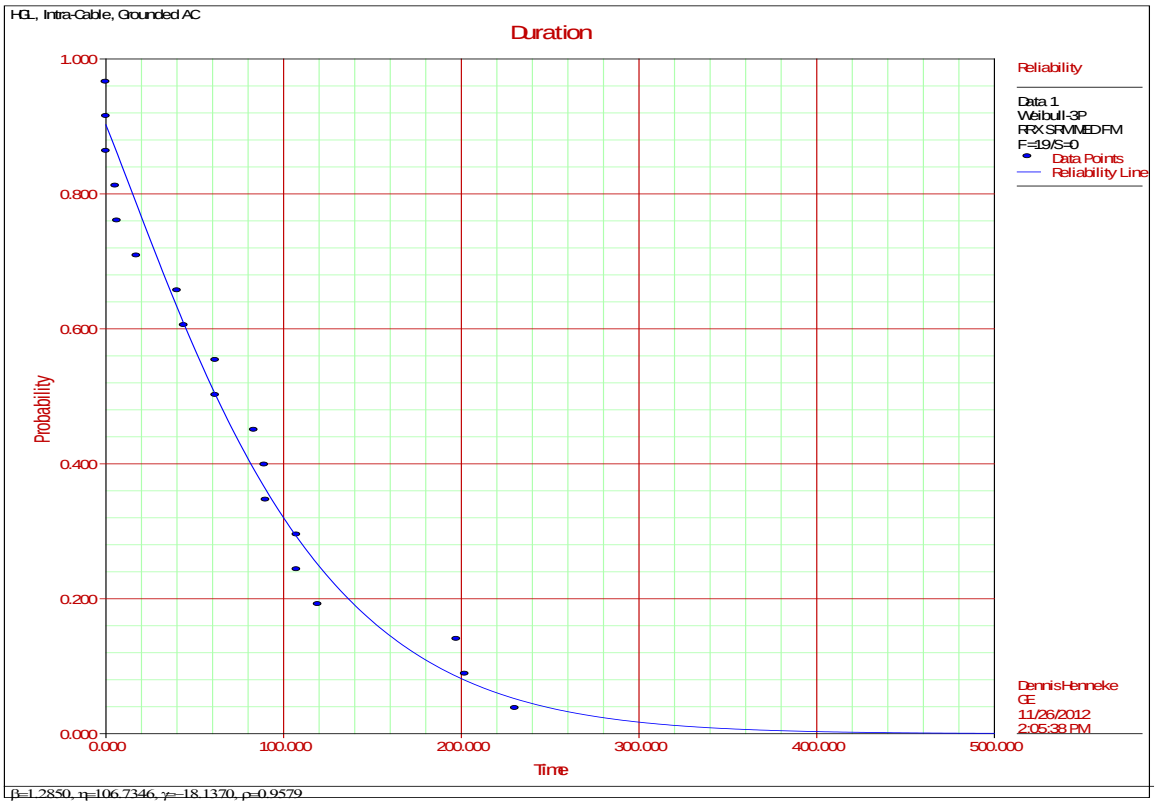


Note: at 60 seconds; .48, at 240 seconds; 0.04. Below with a 2-point Weibull: 60 seconds 0.42, 240 seconds; .12 (slightly conservative)

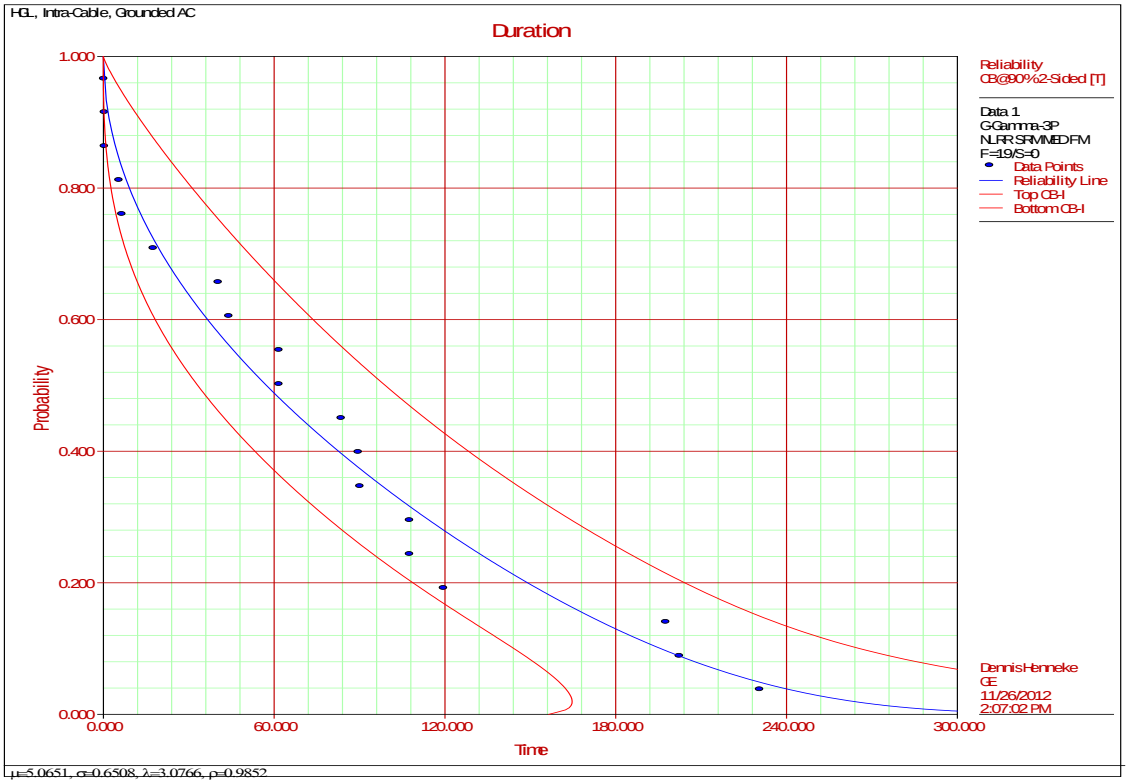
2-Point Weibull – same as above



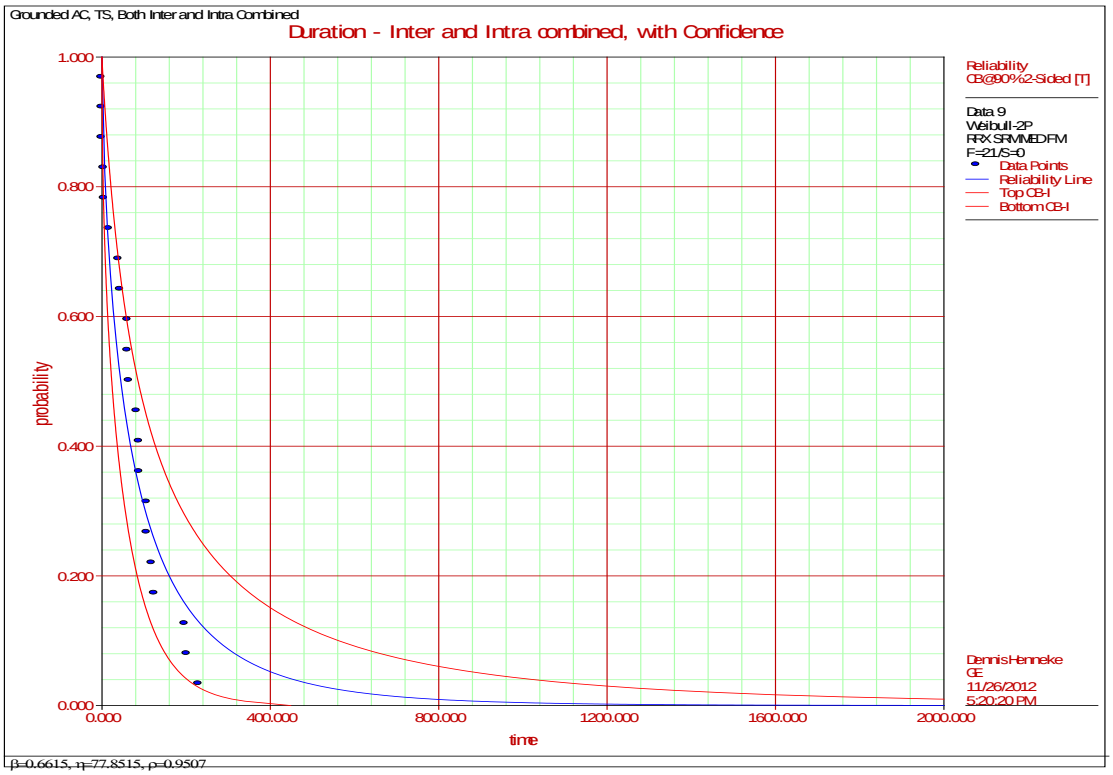
3-point Weibull:



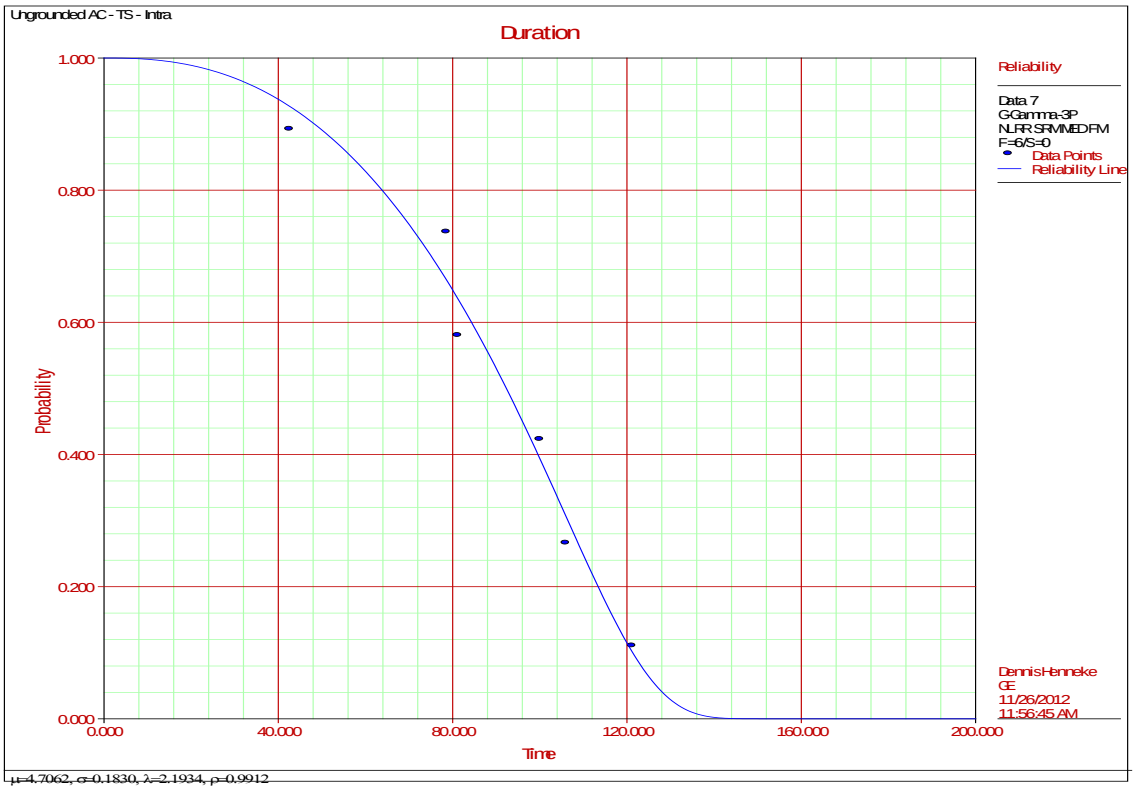
G-Gamma with 90% confidence bounds:

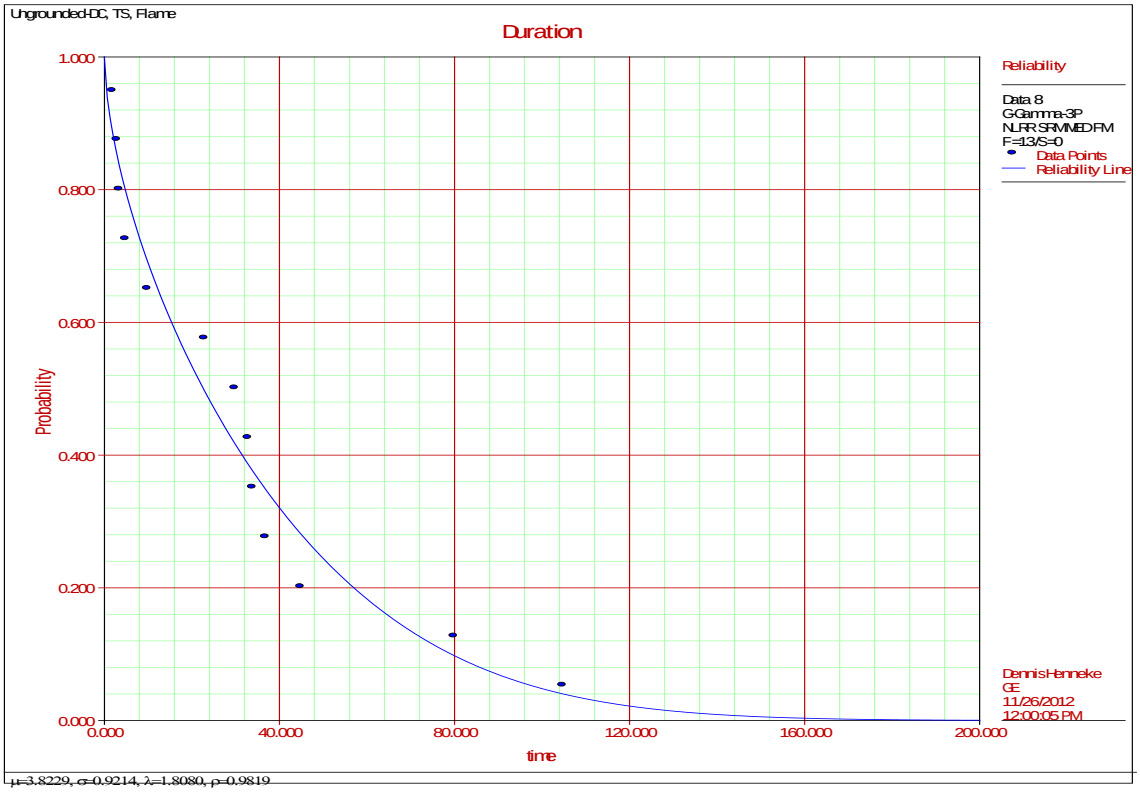


Inter and Intra Combined:



Other curves for example….


Ungrounded AC - TS - Intra
Duration
Reliability
Data 7
G-Gamma-3P
N-RR SRM MED FM
F=6/S=0
Data Points
Reliability Line
Probability
1.000
0.800
0.600
0.400
0.200
0.000
0.000
40.000
80.000
120.000
160.000
200.000
Time
Dennis Henneke
GE
11/26/2012
11:56:45 AM
μ=4.7062, σ=0.1830, λ=2.1934, ρ=0.9912

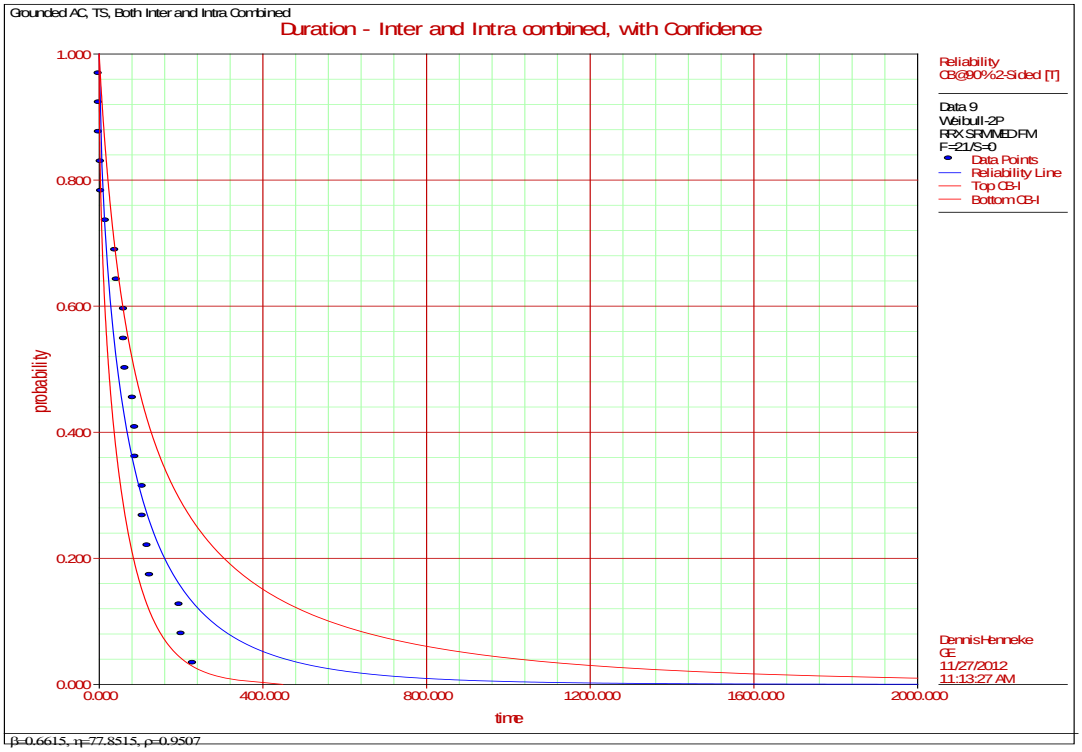

Ungrounded-DC, TS, Flame
Duration
Reliability
Data 8
G-Gamma-3P
N-RR SRM MED FM
F=13/S=0
Data Points
Reliability Line
Probability
1.000
0.800
0.600
0.400
0.200
0.000
0.000
40.000
80.000
120.000
160.000
200.000
time
Dennis Henneke
GE
11/26/2012
12:00:05 PM
μ=3.8229, σ=0.9214, λ=1.8080, ρ=0.9819

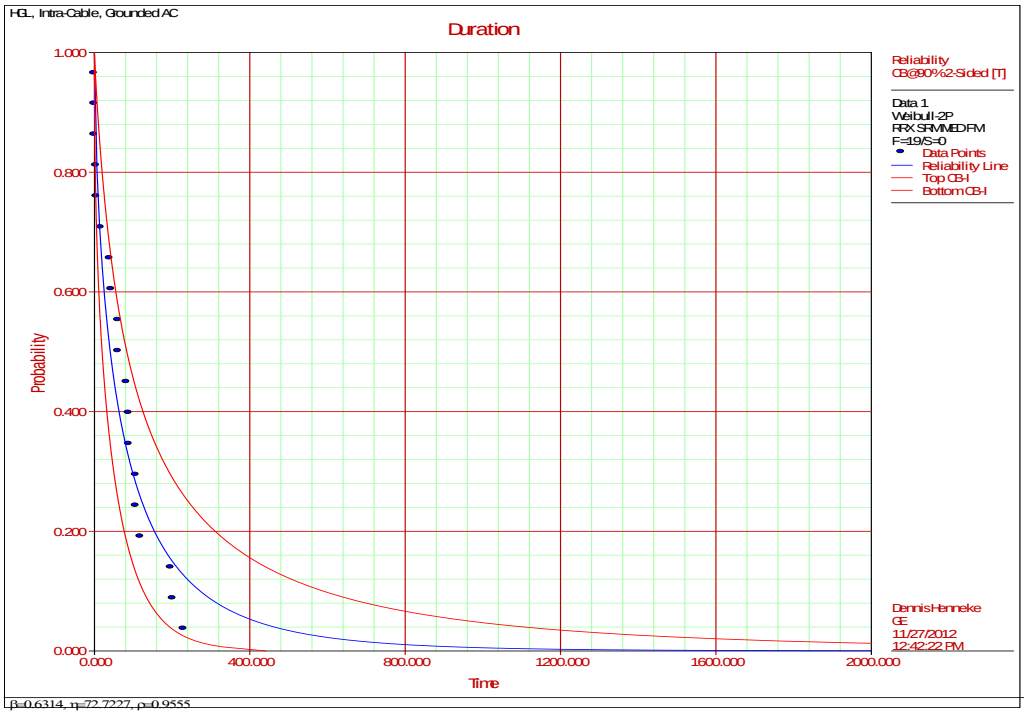
Attachment 2

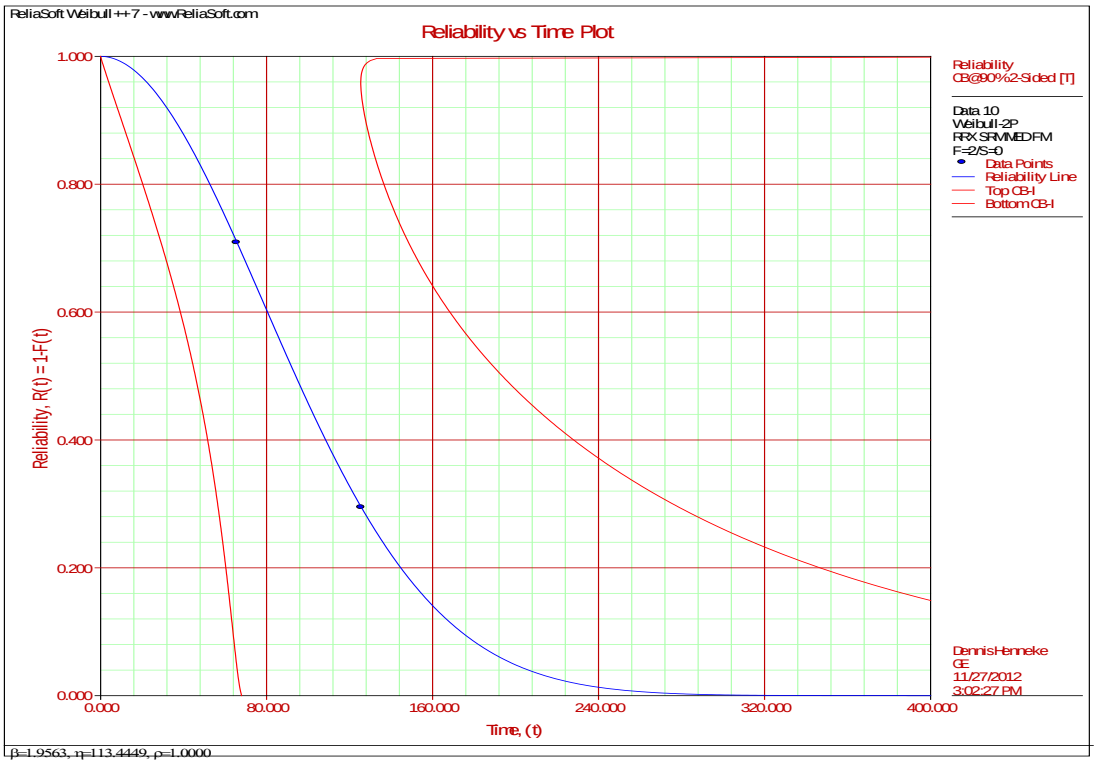
Graphs for HS Durations

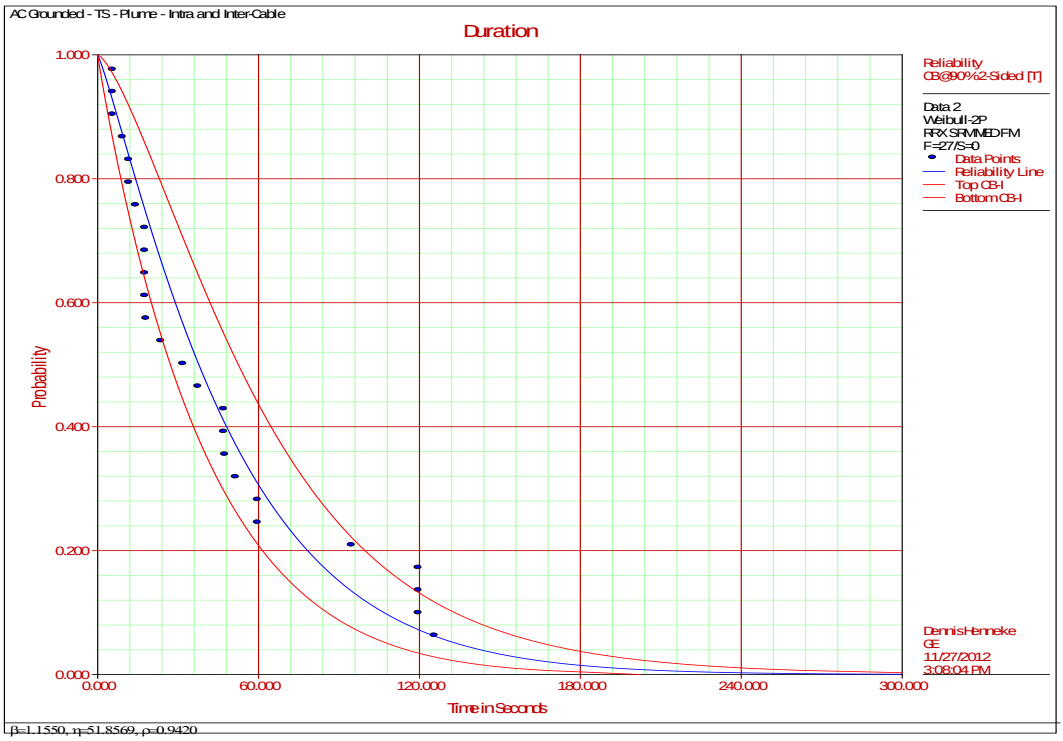
2-point Weibull, with Uncertainties

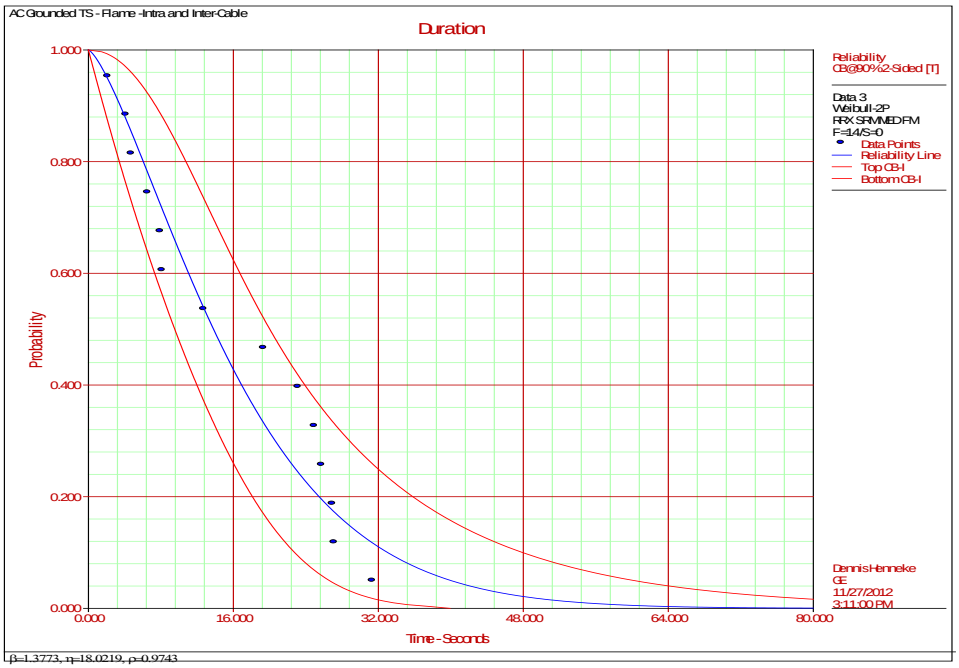
Grounded AC TS Cable

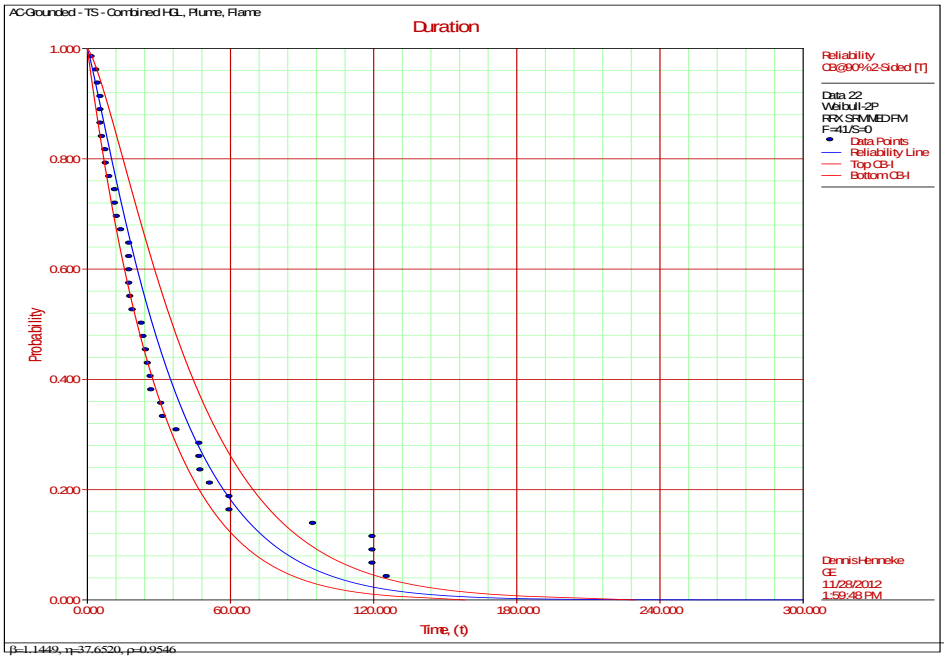




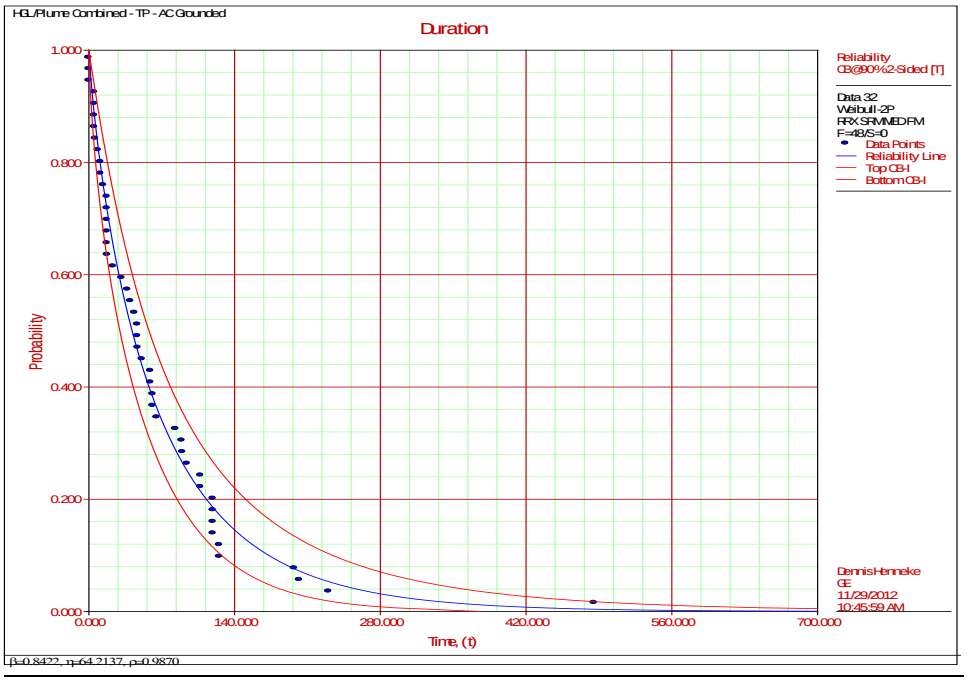

ReliaSoft Weibull ++ 7 - www.ReliaSoft.com
Reliability vs Time Plot
Reliability, R(t) = 1-F(t)
1.000
0.800
0.600
0.400
0.200
0.000
0.000
80.000
160.000
240.000
320.000
400.000
Time, (t)
Reliability
CB@90%2-Sided [T]
Data 10
Weibull-2P
RRX SRM MED FM
F=2/S=0
Data Points
Reliability Line
Top CB-I
Bottom CB-I
Dennis-Henneke
GE
11/27/2012
3:02:27 PM
β=1.9563, η=113.4449, ρ=1.0000


AC Grounded - TS - Plume - Intra and Inter-Cable
Duration
Probability
1.000
0.800
0.600
0.400
0.200
0.000
0.000
60.000
120.000
180.000
240.000
300.000
Time in Seconds
Reliability
CB@90%2-Sided [T]
Data 2
Weibull-2P
RRX SRM MED FM
F=27/S=0
Data Points
Reliability Line
Top CB-I
Bottom CB-I
Dennis-Henneke
GE
11/27/2012
3:08:04 PM
β=1.1550, η=51.8569, ρ=0.9420

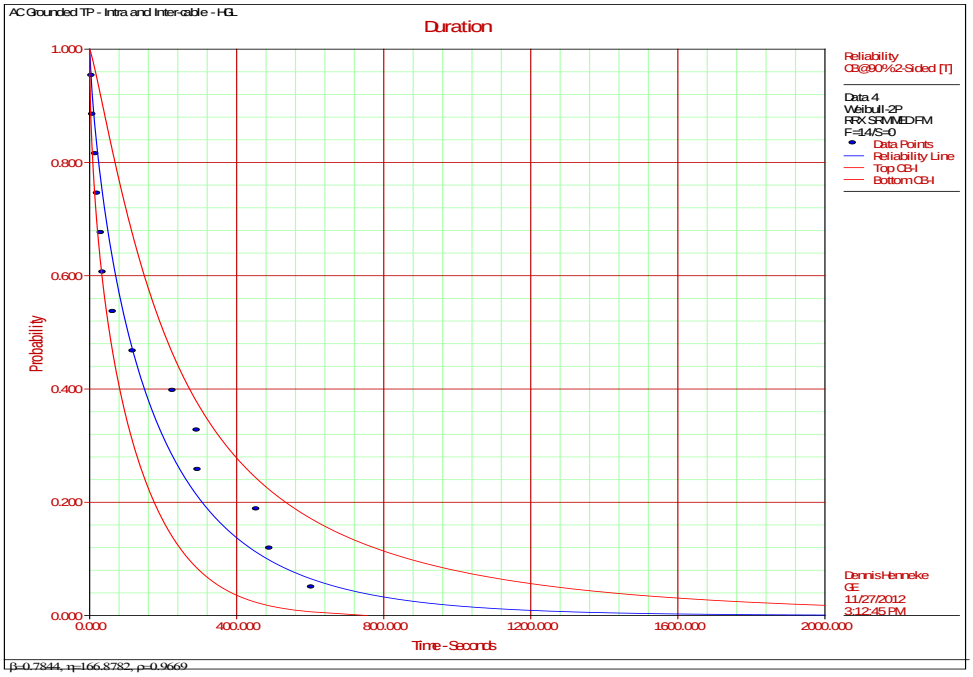


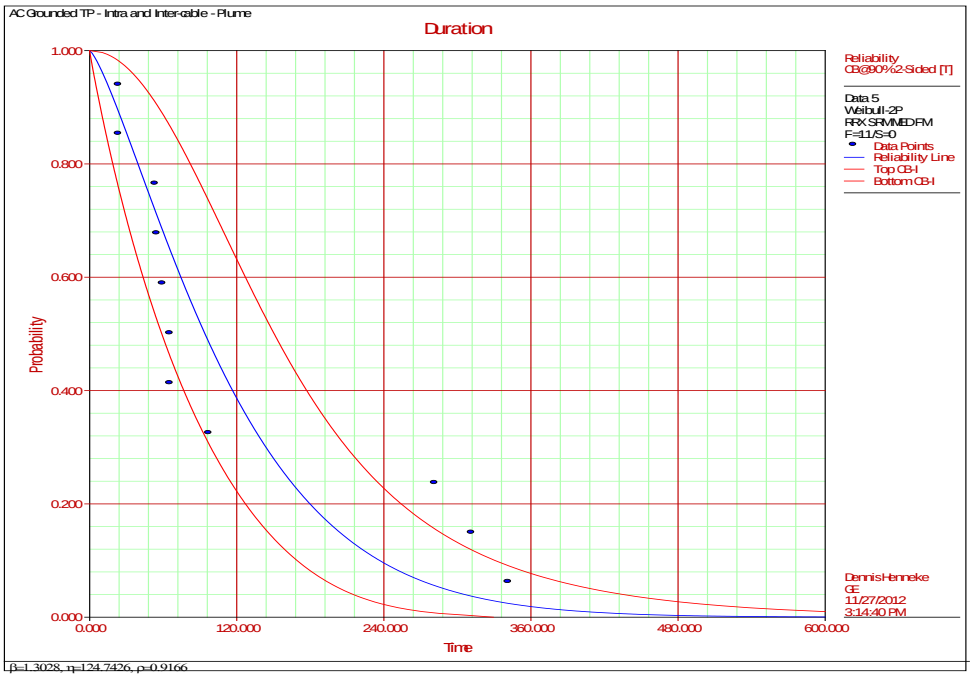


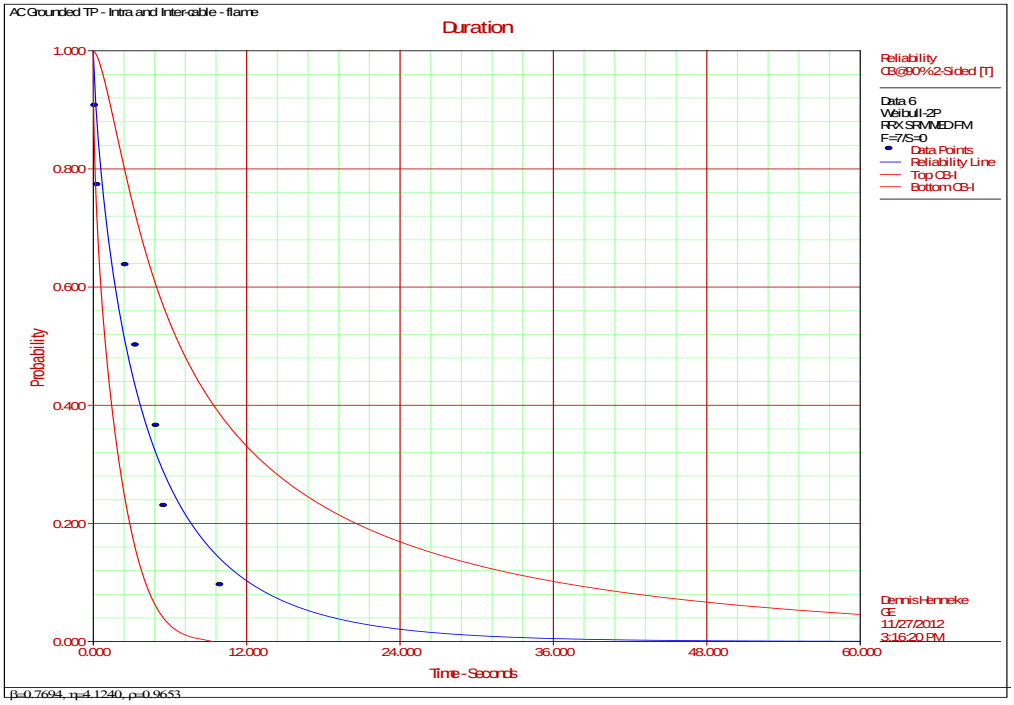
This is the recommended Curve for TS-Grounded AC:

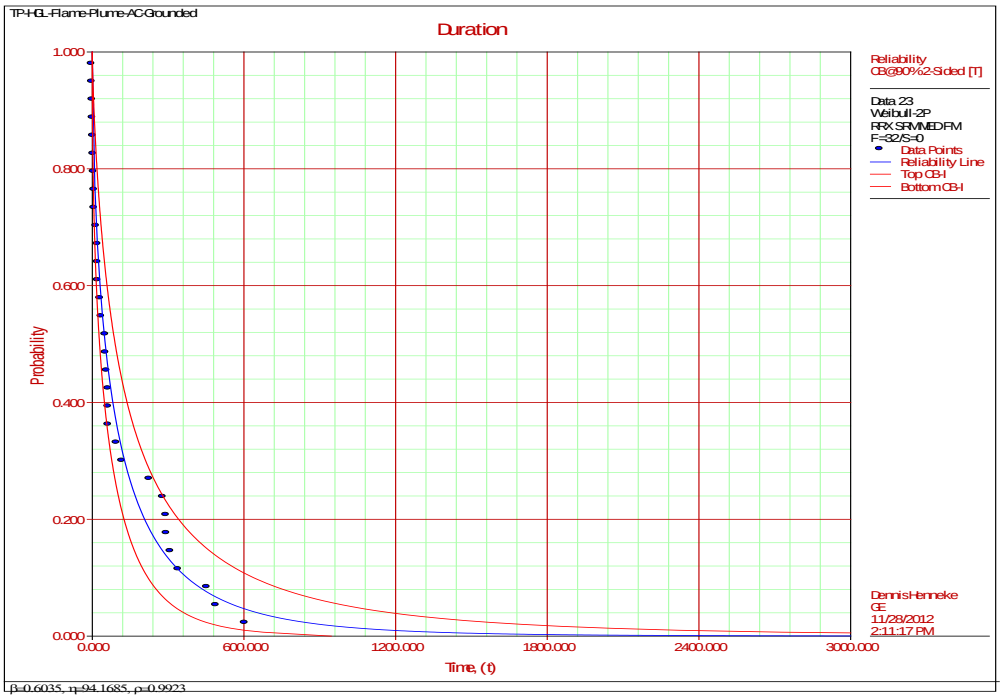


Grounded AC – TP Cable

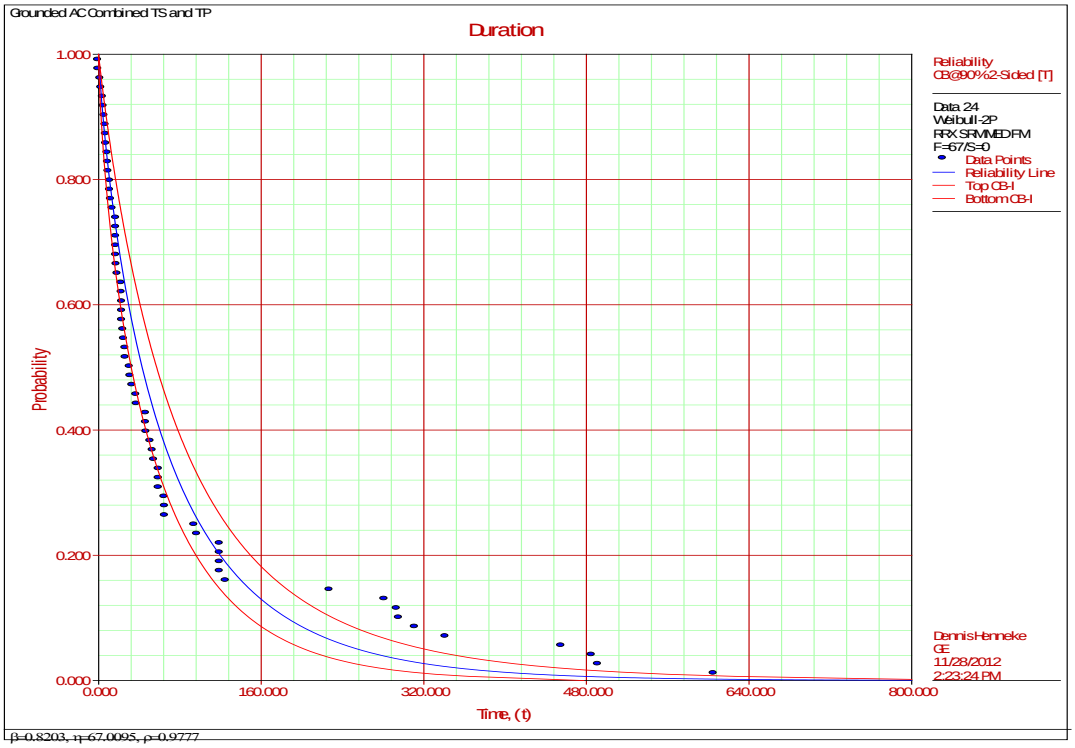



AC Grounded TP - Intra and Inter-cable - Plume
Duration
Probability
Time
1.000
0.800
0.600
0.400
0.200
0.000
0.000
120.000
240.000
360.000
480.000
600.000
Reliability
CB@90%2-Sided [T]
Data 5
Weibull-2P
RRX SRM MED FM
F=11/S=0
Data Points
Reliability Line
Top CB-I
Bottom CB-I
Dennis Henneke
GE
11/27/2012
3:14:40 PM
β=1.3028, η=124.7426, ρ=0.9166

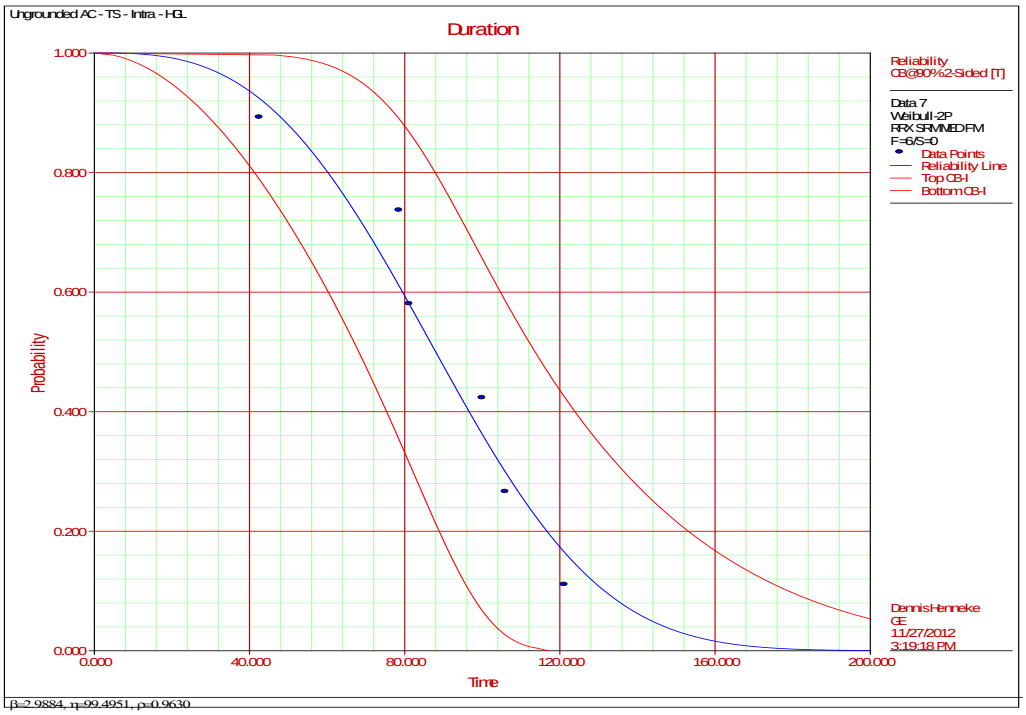

AC Grounded TP - Intra and Inter-cable - flame
Duration
Probability
Time - Seconds
1.000
0.800
0.600
0.400
0.200
0.000
0.000
12.000
24.000
36.000
48.000
60.000
Reliability
CB@90%2-Sided [T]
Data 6
Weibull-2P
RRX SRM MED FM
F=7/S=0
Data Points
Reliability Line
Top CB-I
Bottom CB-I
Dennis Henneke
GE
11/27/2012
3:16:20 PM
β=0.7694, η=4.1240, ρ=0.9653

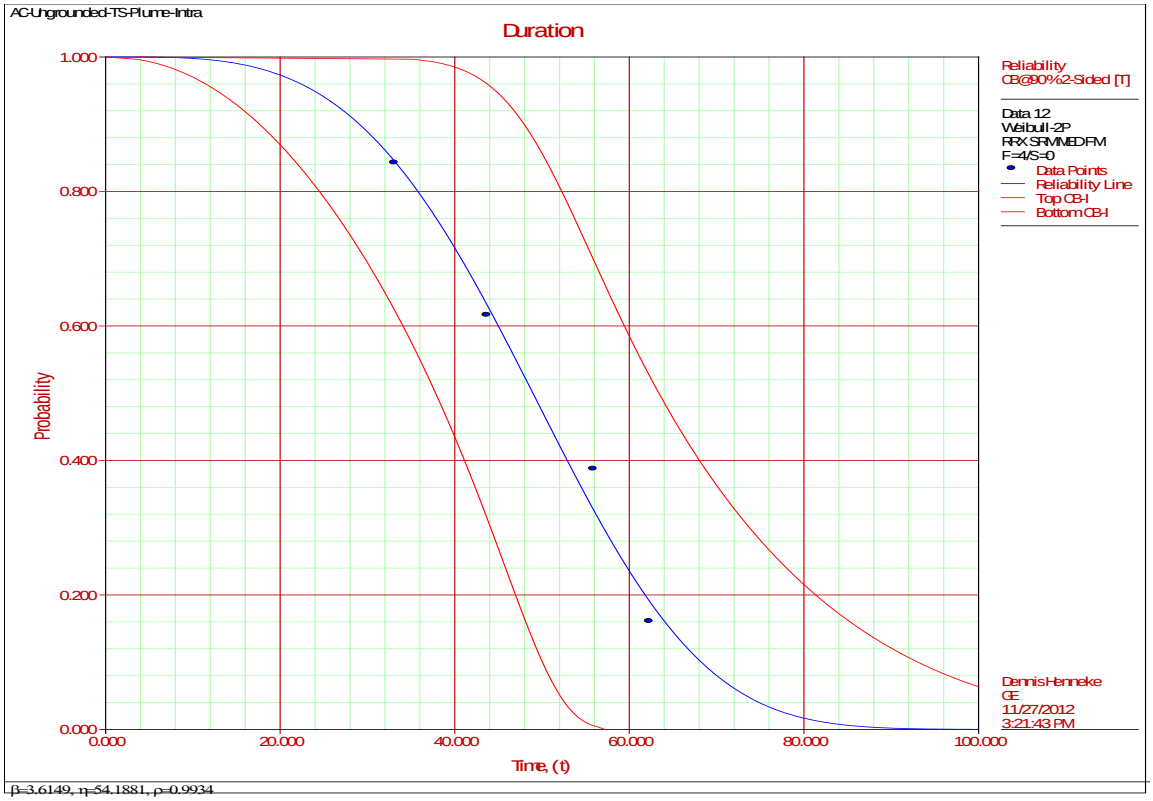


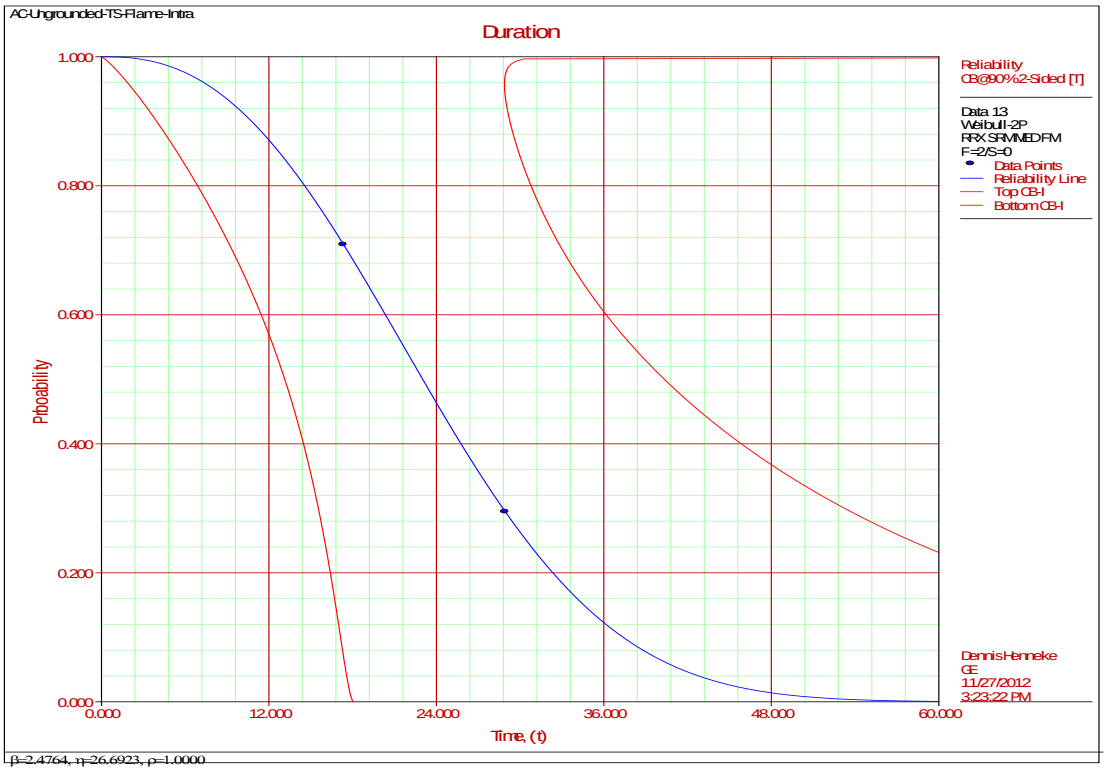
Grounded AC Combined TS and TP: Curve 24



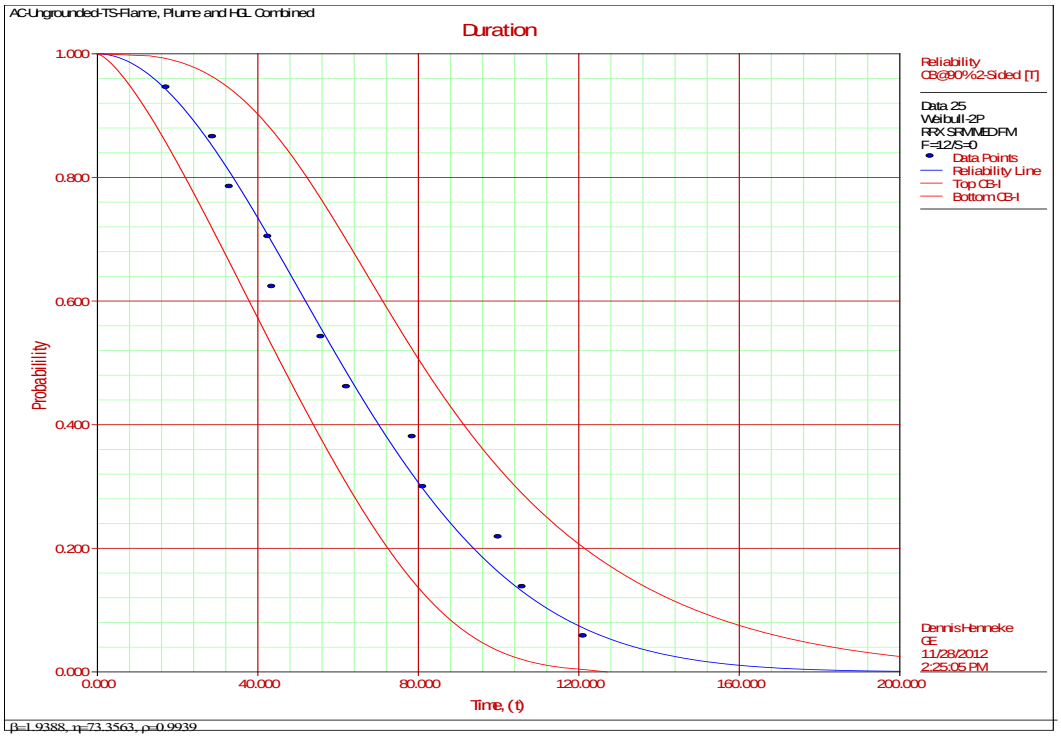
<u>Ungrounded AC TS Cable:</u>


Ungrounded AC - TS - Intra - HGL
Duration
Probability
Time
1.000
0.800
0.600
0.400
0.200
0.000
0.000
40.000
80.000
120.000
160.000
200.000
Reliability
CB@90%2-Sided [T]
Data 7
Weibull-2P
RRX SRMMEDFM
F=6/S=0
Data Points
Reliability Line
Top CB-I
Bottom CB-I
Dennis Henneke
GE
11/27/2012
3:19:18 PM
β=2.9884, η=99.4951, ρ=0.9630


AC-Ungrounded-TS-Plume-Intra
Duration
Probability
Time, (t)
1.000
0.800
0.600
0.400
0.200
0.000
0.000
20.000
40.000
60.000
80.000
100.000
Reliability
CB@90%2-Sided [T]
Data 12
Weibull-2P
RRX SRMMEDFM
F=4/S=0
Data Points
Reliability Line
Top CB-I
Bottom CB-I
Dennis Henneke
GE
11/27/2012
3:21:43 PM
β=3.6149, η=54.1881, ρ=0.9934



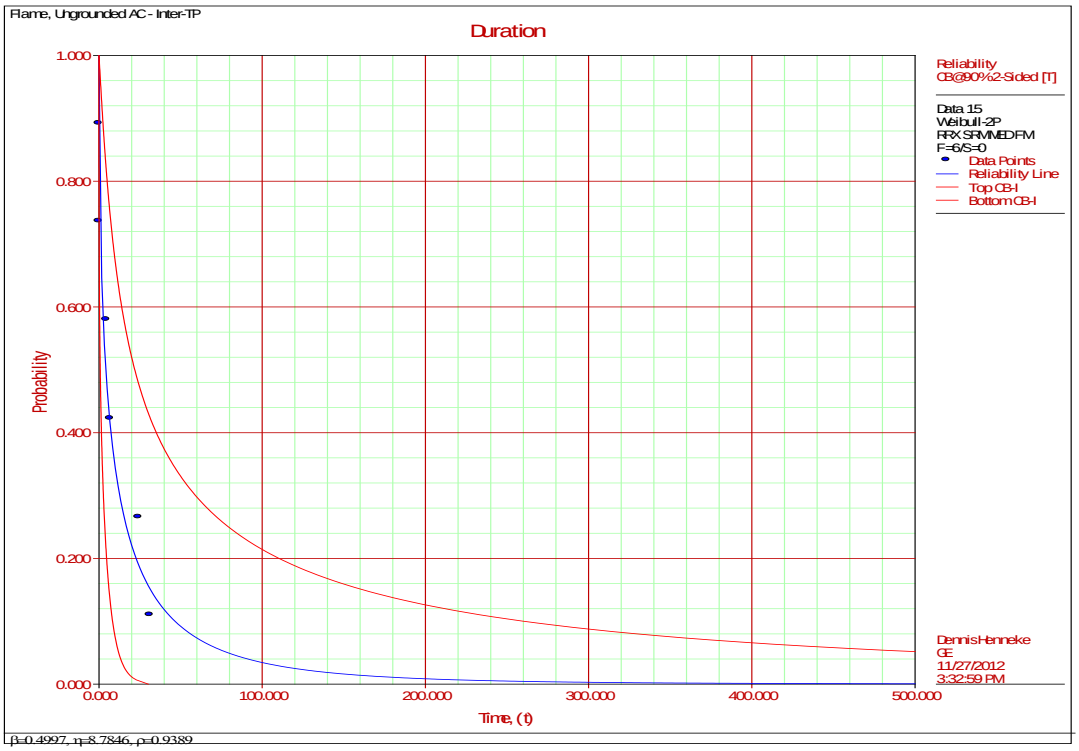
Case 25 – AC Ungrounded TS-Flame, Plume and HGL Combined



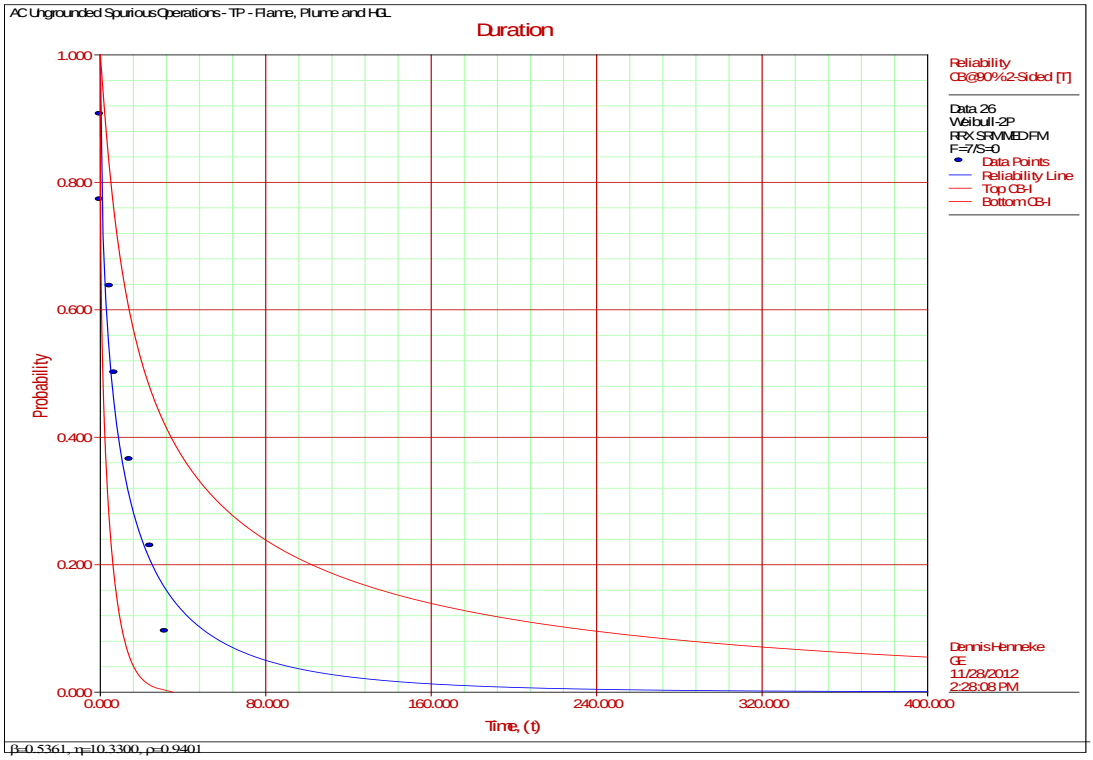
No Plot for Ungrounded AC - Inter-TP – HGL - only one data point….

No data for Plume Ungrounded AC - Inter-TP

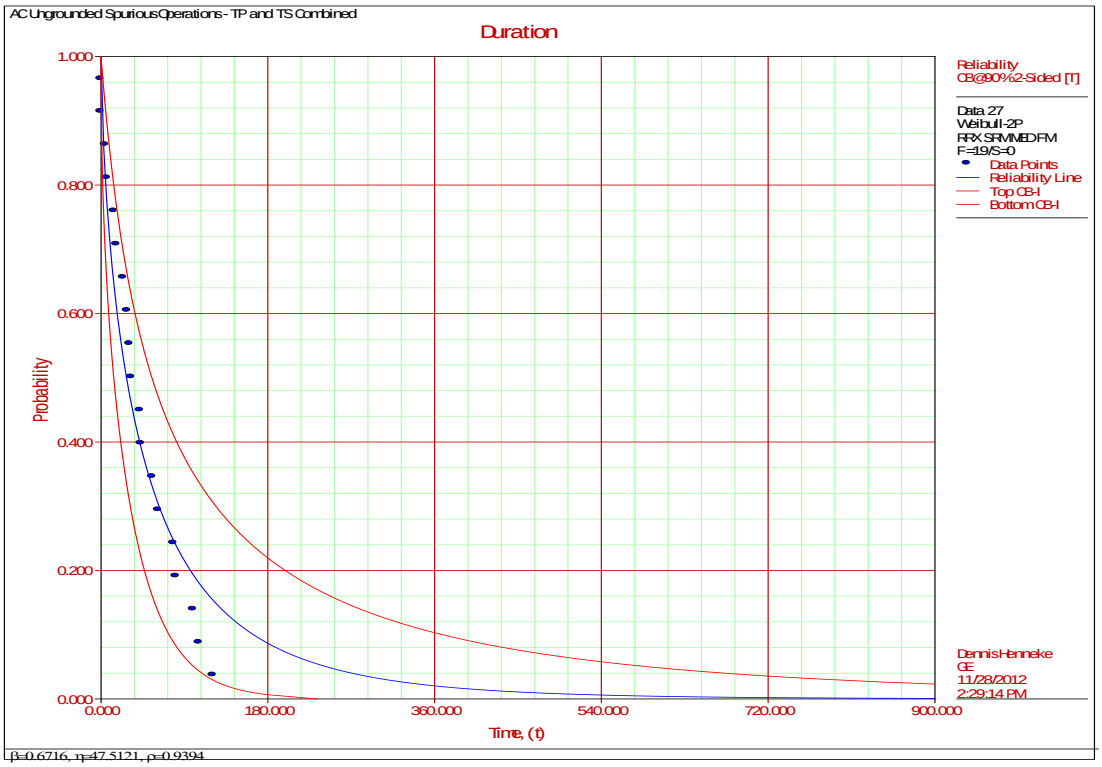
The following is for Flame, Ungrounded AC - Inter-TP:



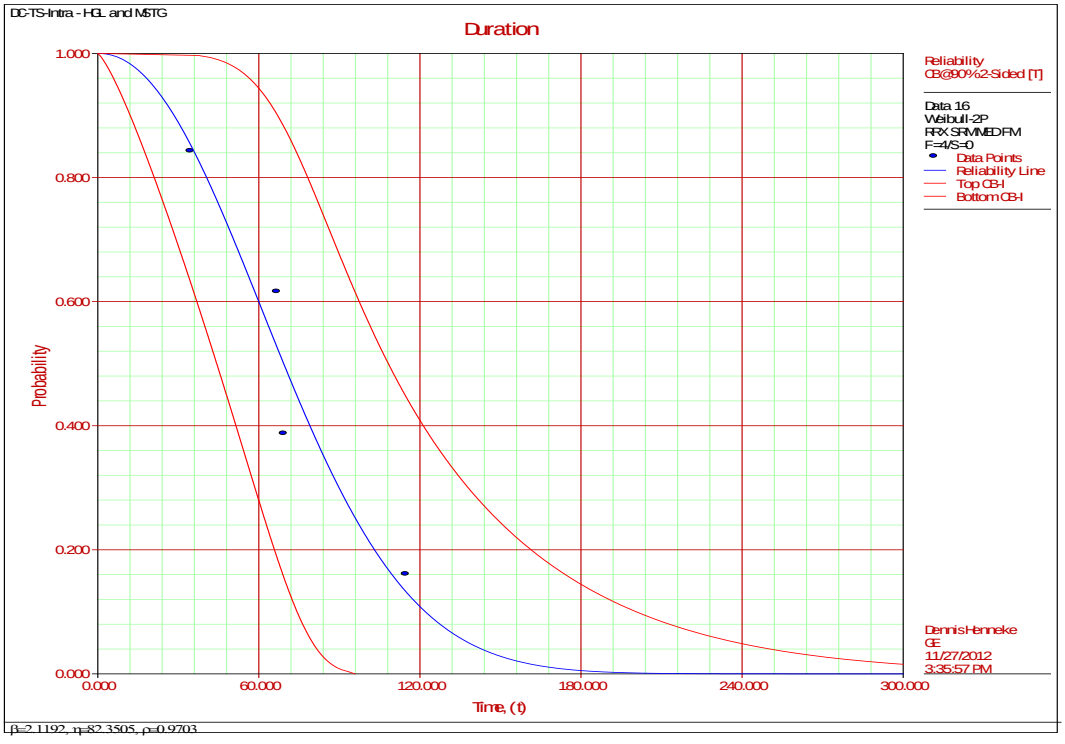
Combined TP - 26

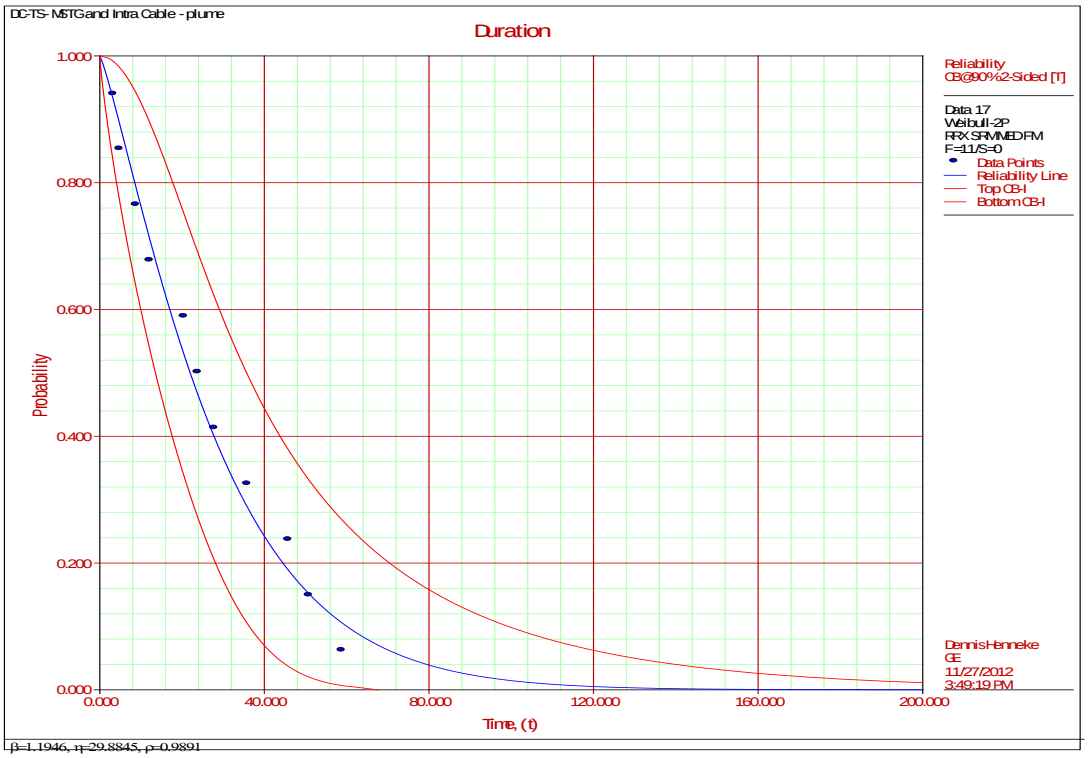


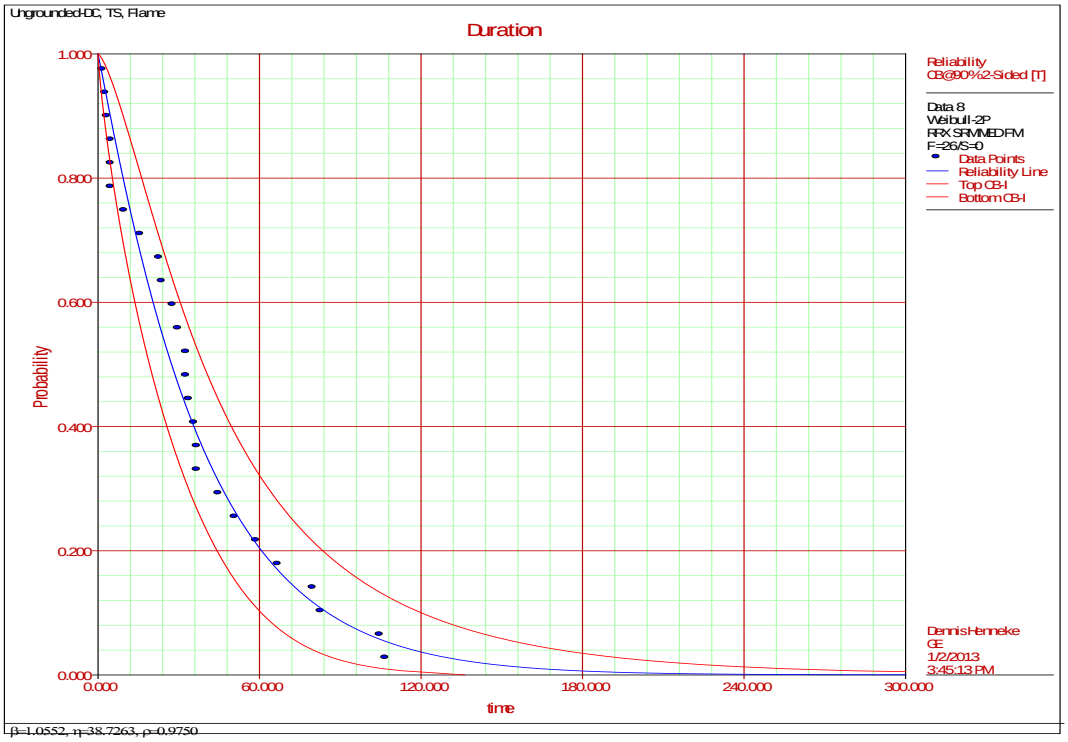
Combined TS and TP for Ungrounded AC



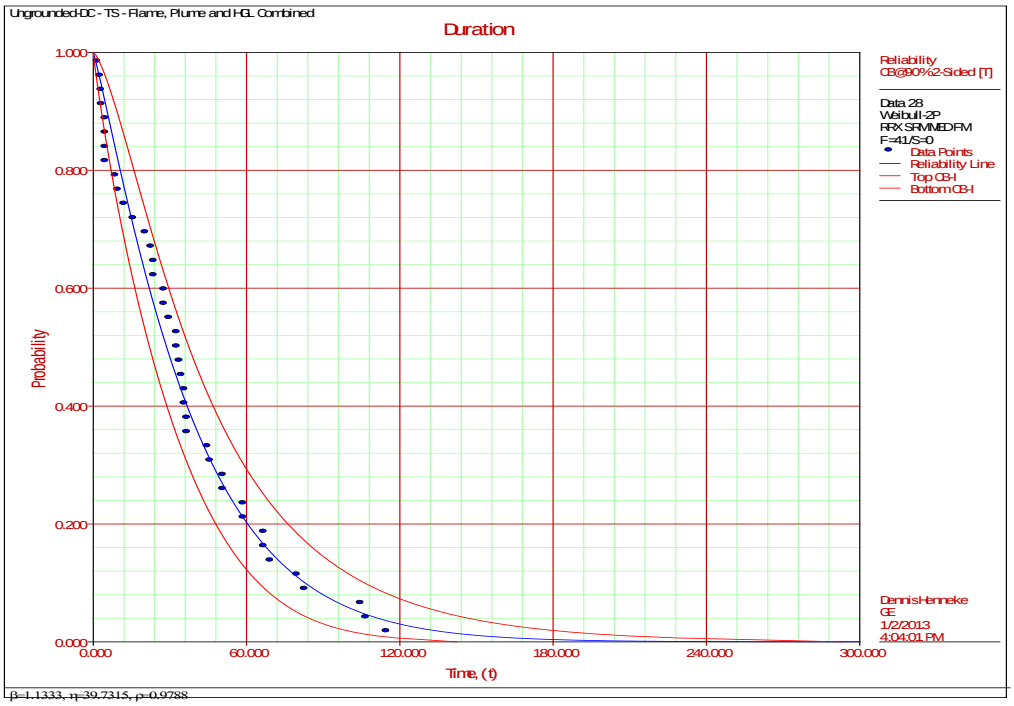
DC TS Results:





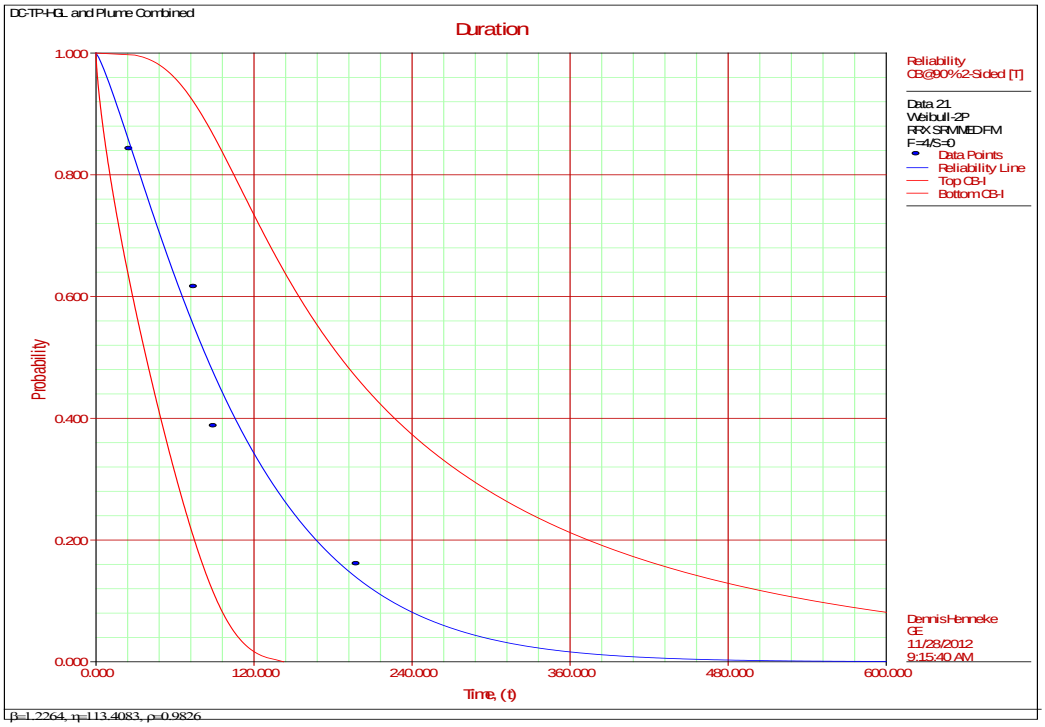


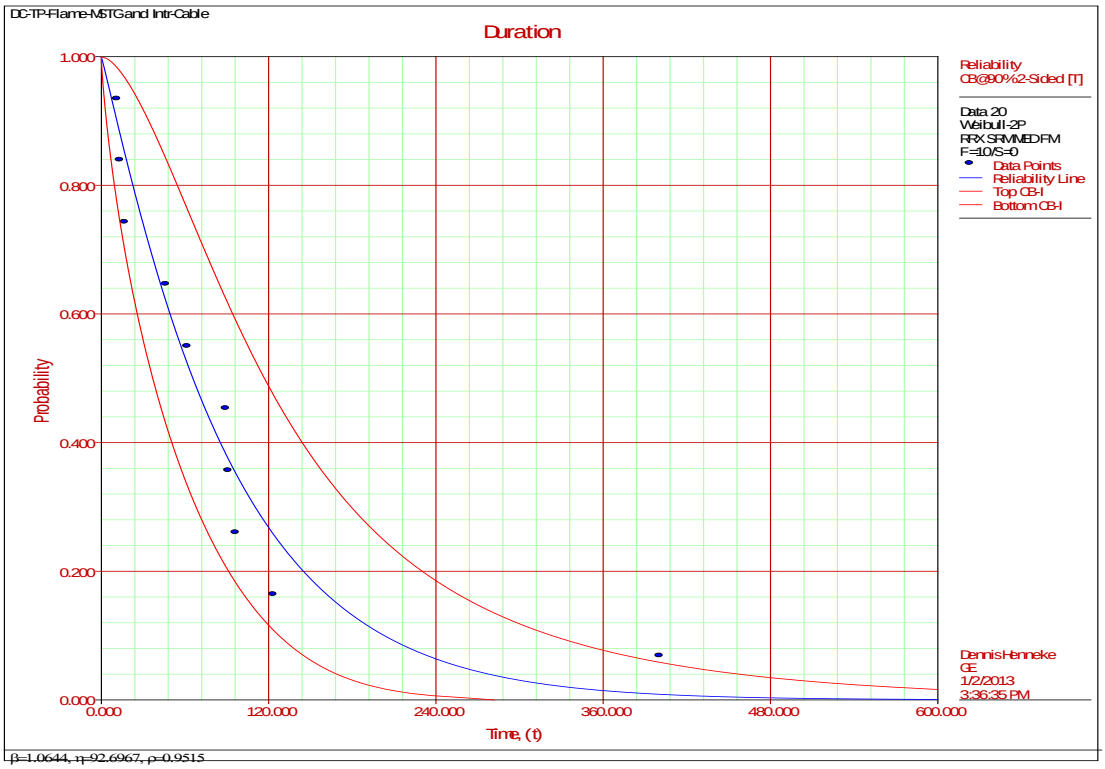
TS-Combined HGL, Plume, Flame:

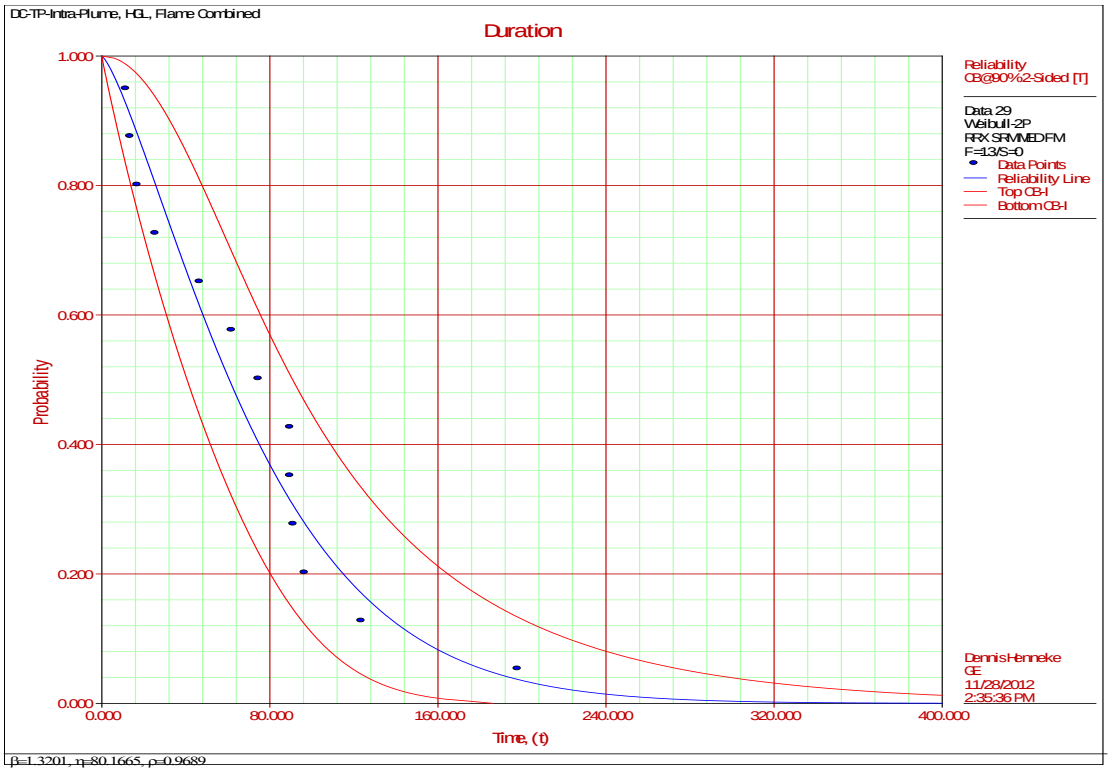


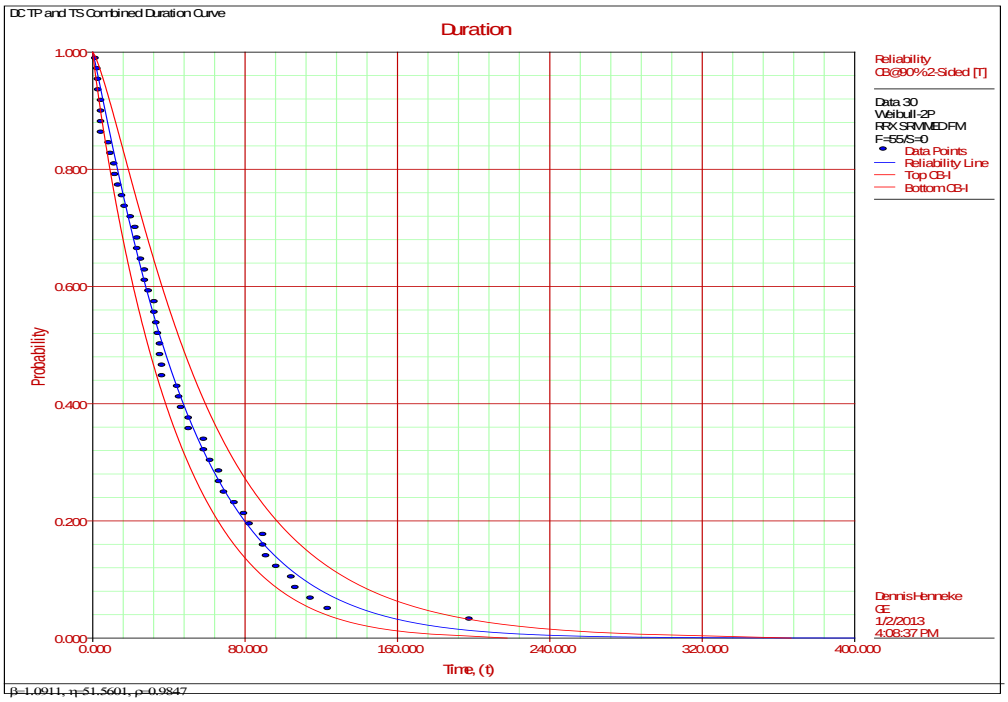
DC TP Results:


DC-TP-Intra-Plume
Duration
Probability
1.000
0.800
0.600
0.400
0.200
0.000
0.000
160.000
320.000
480.000
640.000
800.000
Time, (t)
Reliability
CB@90%2-Sided [T]
Data 19
Weibull-2P
RRX SRM MED FM
F=2/S=0
Data Points
Reliability Line
Top CB-I
Bottom CB-I
Dennis Henneke
GE
11/27/2012
3:55:29 PM
β=1.3006, η=169.3902, ρ=1.0000

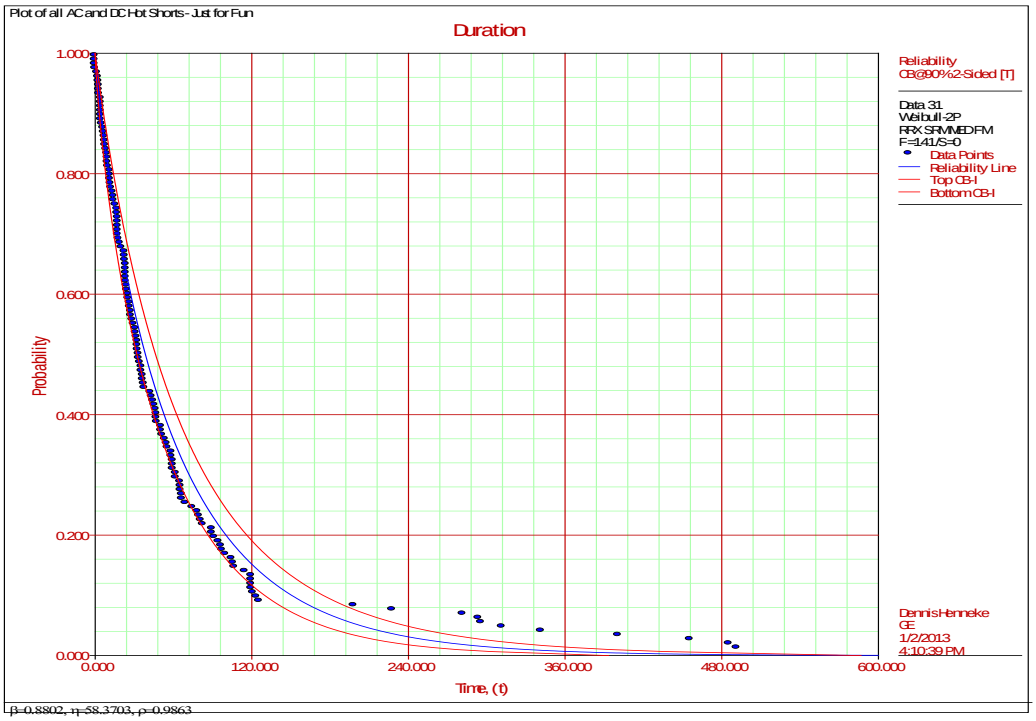

DC-TP-HGL and Plume Combined
Duration
Probability
1.000
0.800
0.600
0.400
0.200
0.000
0.000
120.000
240.000
360.000
480.000
600.000
Time, (t)
Reliability
CB@90%2-Sided [T]
Data 21
Weibull-2P
RRX SRM MED FM
F=4/S=0
Data Points
Reliability Line
Top CB-I
Bottom CB-I
Dennis Henneke
GE
11/28/2012
9:15:40 AM
β=1.2264, η=113.4083, ρ=0.9826


DC-TP-Flame-MSTGand Intr-Cable
Duration
Probability
Time, (t)
1.000
0.800
0.600
0.400
0.200
0.000
0.000
120.000
240.000
360.000
480.000
600.000
Reliability
CB@90%2-Sided [T]
Data 20
Weibull-2P
RRX SRMMED FM
F=10/S=0
Data Points
Reliability Line
Top CB-I
Bottom CB-I
Dennis Henneke
GE
1/2/2013
3:36:35 PM
β=1.0644, η=92.6967, ρ=0.9515


DC-TP-Intra-Plume, HGL, Flame Combined
Duration
Probability
Time, (t)
1.000
0.800
0.600
0.400
0.200
0.000
0.000
80.000
160.000
240.000
320.000
400.000
Reliability
CB@90%2-Sided [T]
Data 29
Weibull-2P
RRX SRMMED FM
F=13/S=0
Data Points
Reliability Line
Top CB-I
Bottom CB-I
Dennis Henneke
GE
11/28/2012
2:35:36 PM
β=1.3201, η=80.1665, ρ=0.9689



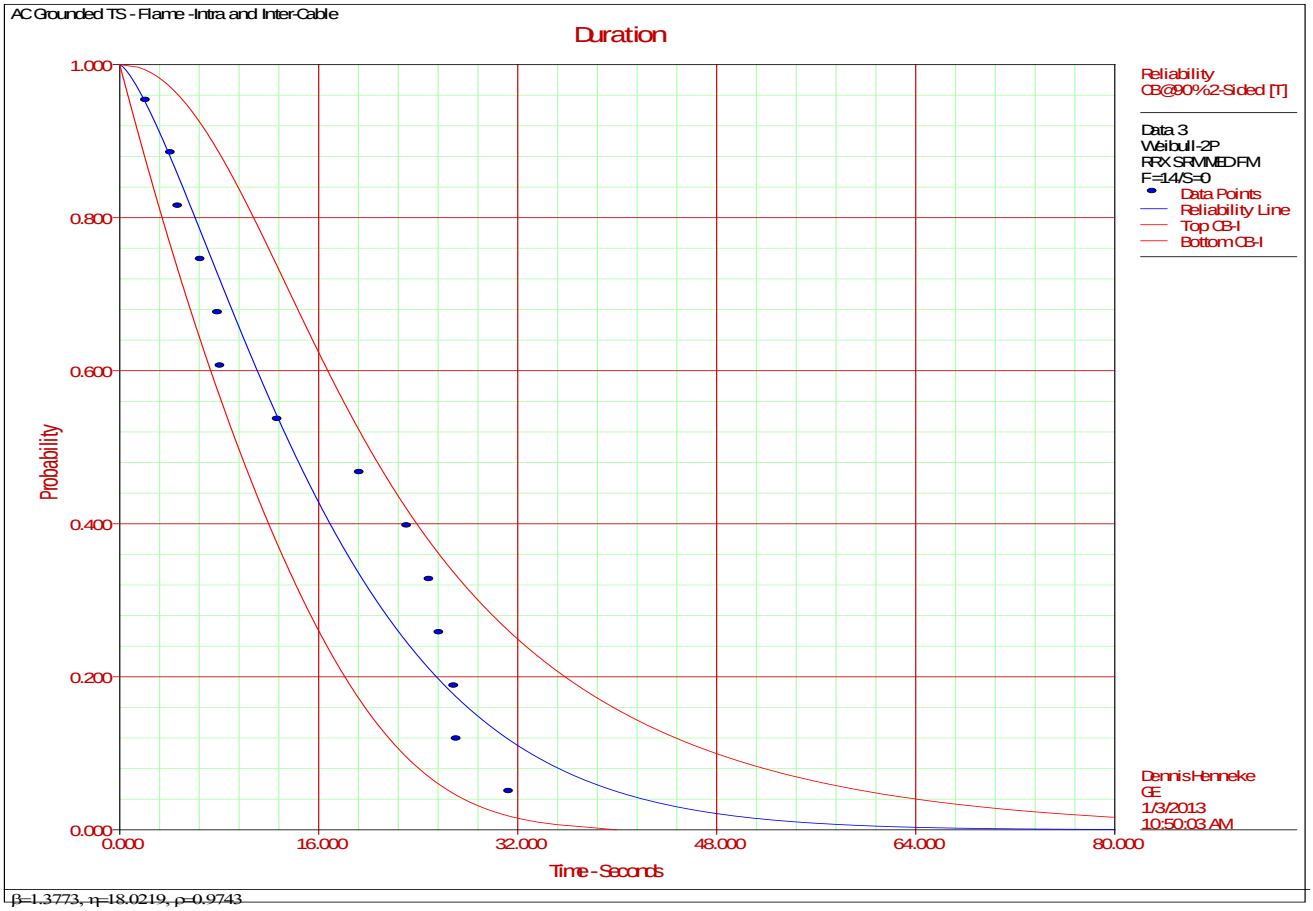
Plot of all AC and DC durations Combined:



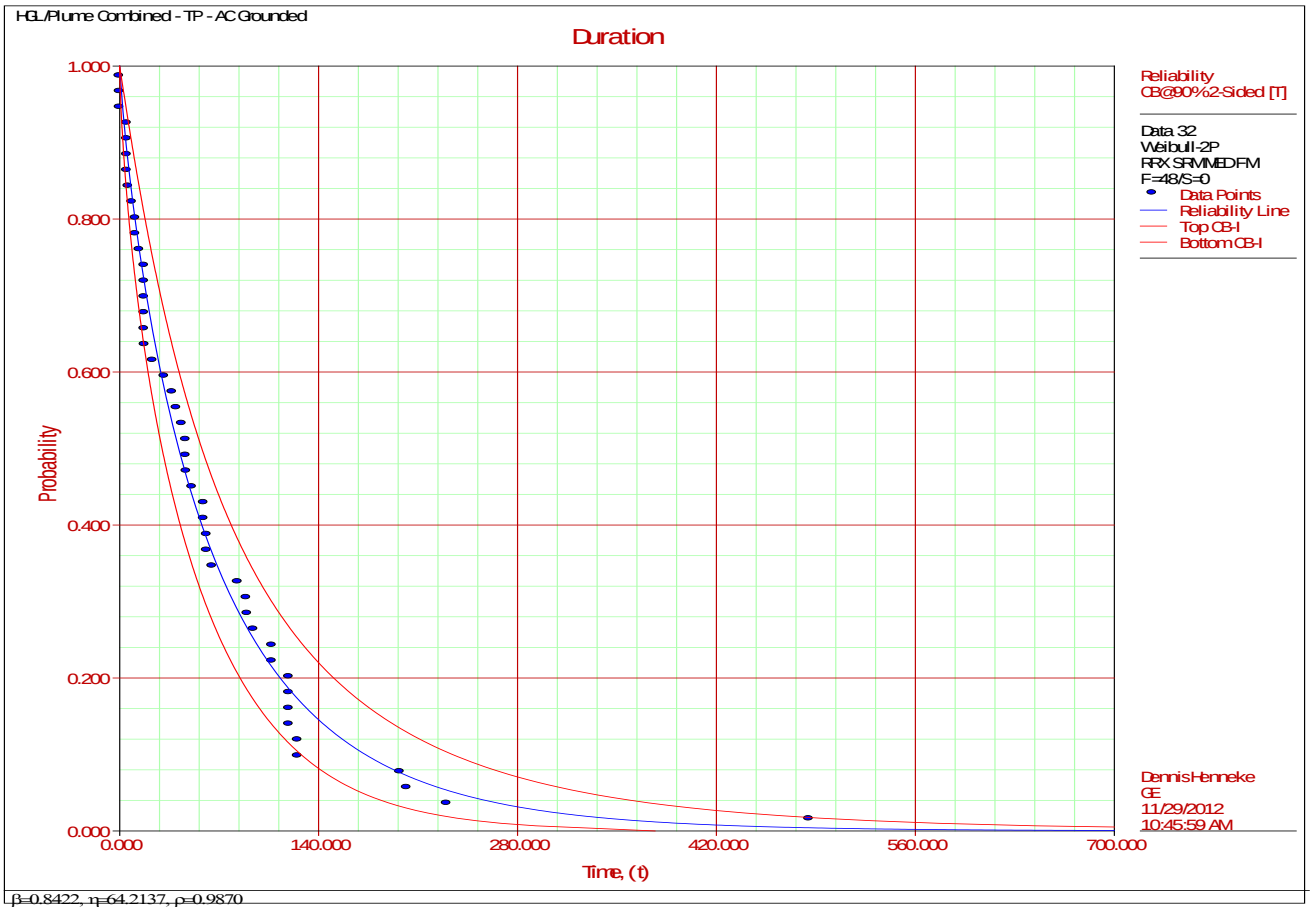
Attachment 3

Final Recommend Curves for HS Duration from Table 6-1

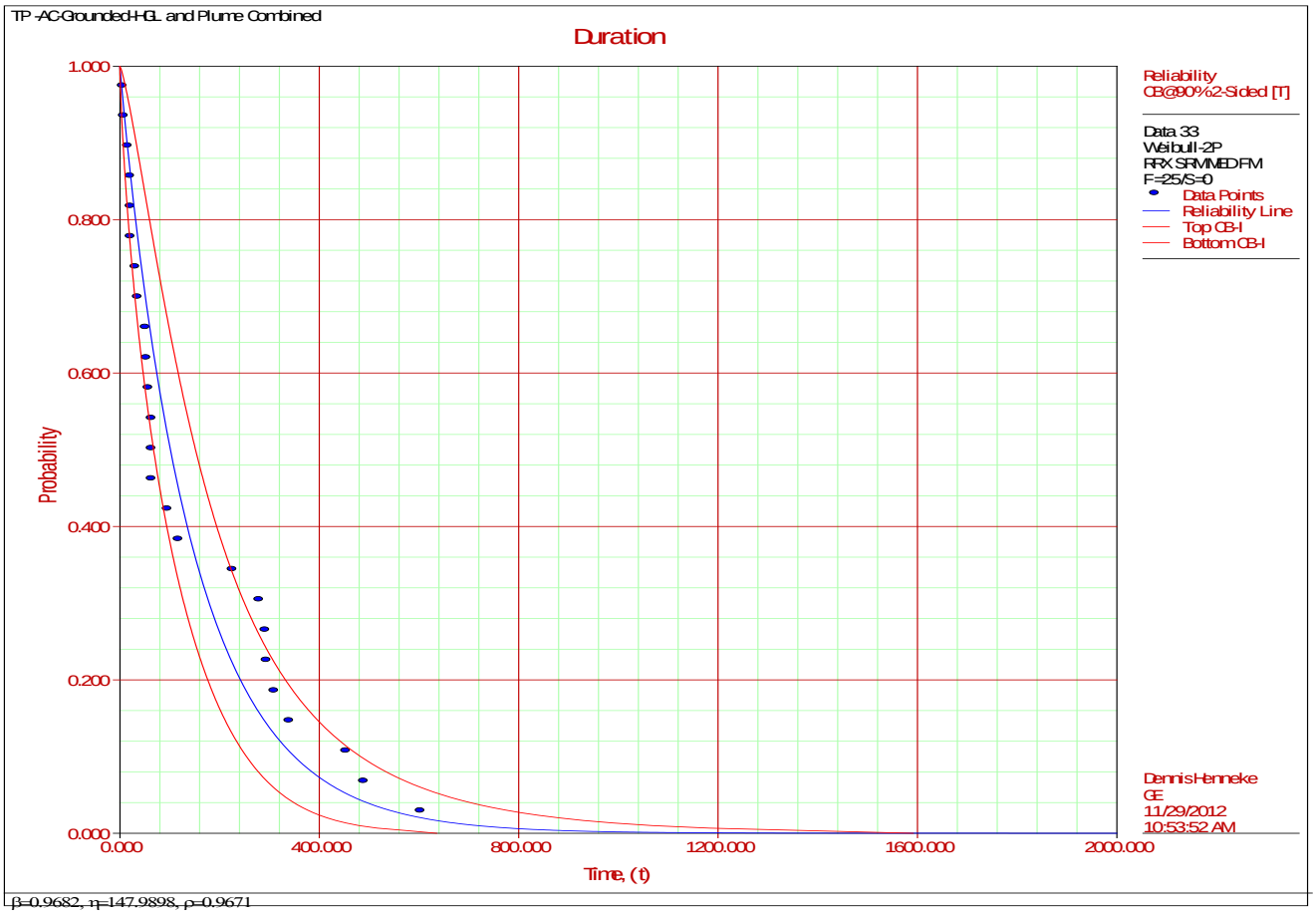
Case 3:



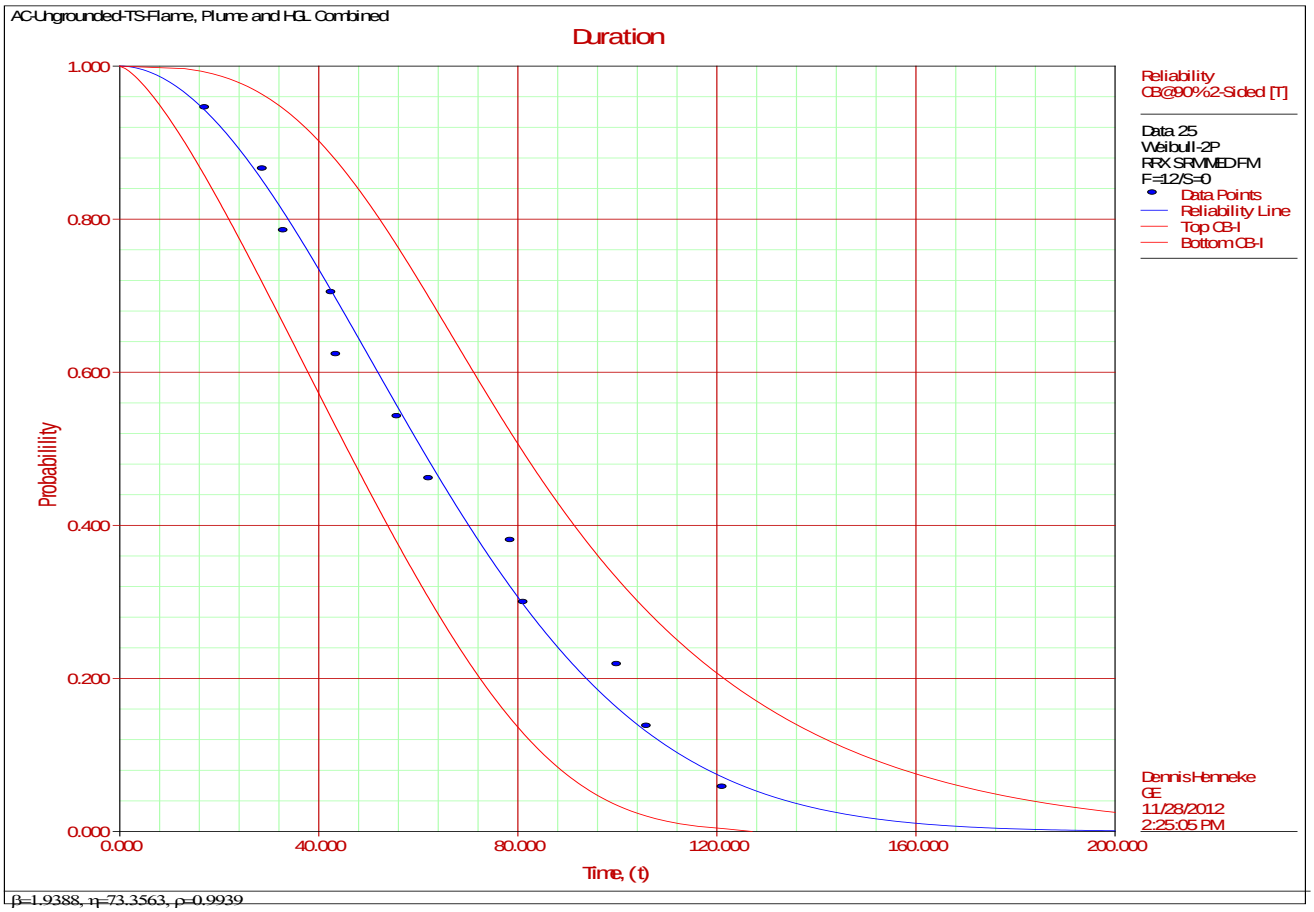
Case 32:


HGL/Plume Combined - TP - AC Grounded
Duration
Probability
1.000
0.800
0.600
0.400
0.200
0.000
0.000
140.000
280.000
420.000
560.000
700.000
Time, (t)
Reliability
CB@90%2-Sided [T]
Data 32
Weibull-2P
RRX SRM MED FM
F=48/S=0
Data Points
Reliability Line
Top CB-I
Bottom CB-I
Dennis Henneke
GE
11/29/2012
10:45:59 AM
β=0.8422, η=64.2137, ρ=0.9870

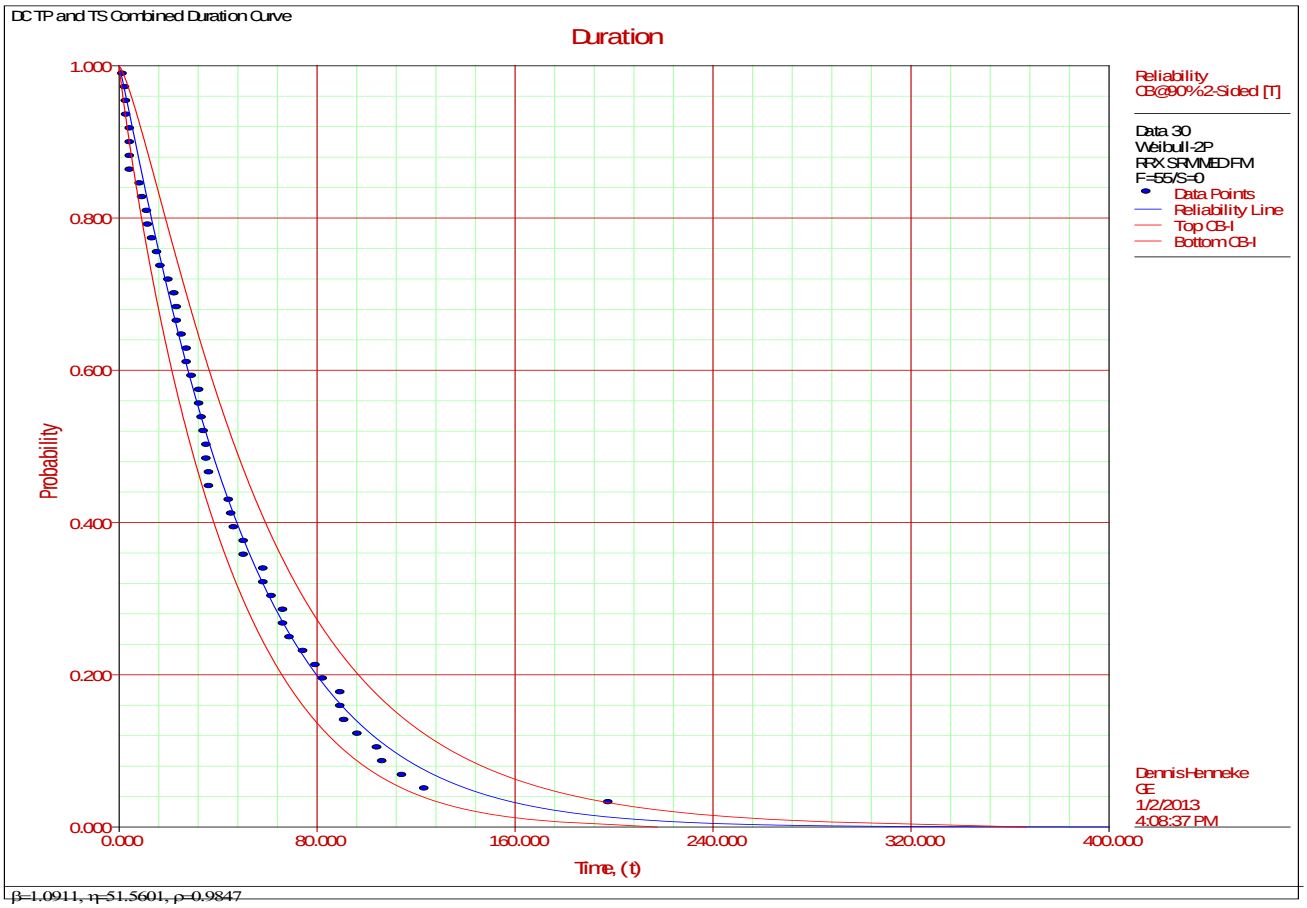
Case 33:


TP -AC Grounded-HGL and Plume Combined
Duration
Reliability
CB@90%2-Sided [T]
Data 33
Weibull-2P
RRX SRMMED FM
F=25/S=0
Data Points
Reliability Line
Top CB-I
Bottom CB-I
Probability
1.000
0.800
0.600
0.400
0.200
0.000
0.000
400.000
800.000
1200.000
1600.000
2000.000
Time, (t)
Dennis Henneke
GE
11/29/2012
10:53:52 AM
β=0.9682, η=147.9898, ρ=0.9671

Case 25:


AC Ungrounded-TS-Flame, Plume and HGL Combined
Duration
1.000
0.800
0.600
0.400
0.200
0.000
Probability
0.000
40.000
80.000
120.000
160.000
200.000
Time, (t)
Reliability
CB@90%2-Sided [T]
Data 25
Weibull-2P
RRX SRM MED FM
F=12/S=0
Data Points
Reliability Line
Top CB-I
Bottom CB-I
Dennis Henneke
GE
11/28/2012
2:25:05 PM
β=1.9388, η=73.3563, ρ=0.9939

Case 30:


DC TP and TS Combined Duration Curve
Duration
Probability
1.000
0.800
0.600
0.400
0.200
0.000
0.000
80.000
160.000
240.000
320.000
400.000
Time, (t)
Reliability
CB@90%2-Sided [T]
Data 30
Weibull-2P
RRX SRM MED FM
F=55/S=0
Data Points
Reliability Line
Top CB-I
Bottom CB-I
Dennis Henneke
GE
1/2/2013
4:08:37 PM
β=1.0911, η=51.5601, ρ=0.9847