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Date: **May 27, 2005**

Location: **Multek Asia - AMD Lab**

Title: **IST Correlation Study Between Multek Asia, PWB Interconnect Solutions, and Multek Germany**

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Tracking #: **1614**

1. Objective

To conduct an interlaboratory Interconnect Stress Test (IST) comparison between PWB Interconnect Solutions Inc. (PWB), Multek Germany (BBN), and Multek Asia (ASIA).

2. Introduction

An increasing number of customers are requiring IST testing as part of their qualification process. Certain customers require submissions of IST data, which they may be used to compare against competing PCB suppliers' on the same qualification part. The performance requirements consider different accept/reject criteria from customer to customer. For example, customers specify "greater than 300 cycles", or "at least 75 cycles, at a 1% failure rate extrapolated from a Weibull distribution". This situation may result that one suppliers' IST data shows fewer cycles to failure than others, with the consequences of delaying qualification, or in worse case being dropped from the qualification process.

The objective of this study was designed to answer the following question: Can it be demonstrated that multiple IST systems inside and outside of Multek correlate well with one another?

This study addresses this question by testing a sample set on three different IST testers with and without IST preconditioning, and also a sample set preconditioned by convection reflow oven.

If the IST systems are primarily used as a tool for PCB manufactures to regularly monitor their process, then the answer to the above question is of no relevant importance

3. Executive Summary

One hundred and eighty IST coupons from three panels were randomized and tested on three different IST testers, located in Multek Asia, Multek Germany and PWB Interconnect Solutions Inc. The three panels represented the following conditions:

Panel "A" – Tested As Received "AR"
Panel "B" – Tested after 6 cycles of IST Preconditioning to 230C peak "6XIST".
Panel "C" – Tested after 6 passes through Convection Reflow with 230C peak "Reflow".

Coupons from Panel B (6XIST) were preconditioned on each site's IST tester, coupons from Panel C (Reflow) were preconditioned using an Convection reflow oven at Multek Asia. Each panel contained a total of 63 IST coupons, which allowed each site to test approximately 21 samples from each panel.

The cycles to failure results were statistically compared using Lognormal base e distribution with a 95% confidence interval. The analysis is tabulated below:

Lognormal base e Shape (σ) and Median Life (T_{50}) parameters.

Test Site	ASIA		PWB		GERMANY	
Condition	σ	T_{50}	σ	T_{50}	σ	T_{50}
AR	0.28±0.04	618±38	0.41±0.07	603±55	0.40±0.07	480±43
6XIST	0.38±0.06	230±21	0.30±0.05	250±18	0.27±0.04	195±12
REFLOW	0.36±0.06	391±31	0.36±0.06	533±42	0.42±0.08	354±38

The T_{50} 95% confidence intervals are the following:

Test Site	ASIA		PWB		GERMANY	
Condition	T_{50}		T_{50}		T_{50}	
AR	618	(548 , 696)	603	(505 , 720)	480	(403 , 571)
6XIST	230	(193 , 274)	250	(218 , 286)	195	(172 , 221)
REFLOW	391	(335 , 456)	533	(456 , 622)	354	(287 , 436)

All three testers' T_{50} 95% confidence intervals overlap for the as received sample sets, and all three testers' T_{50} 95% confidence intervals overlap for the 6X IST preconditioning sample sets. Therefore, it can be accepted that all three testers are equal for both the as received and 6X IST preconditioning conditions at a 95% confidence interval. However, it is suspected that given a larger sample size the Germany IST would prove to have a lower T_{50} than BBN and ASIA at a 95% CI.

Interestingly, each site's results for 6X reflow preconditioning demonstrated differences, although all of the samples were preconditioned at Multek Asia. The T_{50} 95% confidence intervals do not overlap for the 6X reflow between PWB and Germany, and between PWB and ASIA, although ASIA and Germany do overlap.

In summary:
- As received: H_o T_{50} Asia = T_{50} PWB = T_{50} BBN is accepted.
- 6X IST preconditioning: H_o T_{50} Asia = T_{50} PWB = T_{50} BBN is accepted.
- 6X Reflow: H_o T_{50} Asia = T_{50} PWB = T_{50} BBN is rejected.

Variations between ASIA and PWB IST systems versus the Germany system are somewhat explainable due to fundamental differences in the hardware and software configuration (see section 6). Recent agreements have been reached to replace the DOS based system in Germany with a new Window based system, this will ensure consistency between all locations. A second (smaller) study will be completed to determine the ability to correlate the 3 sites, specifically with Windows based systems.

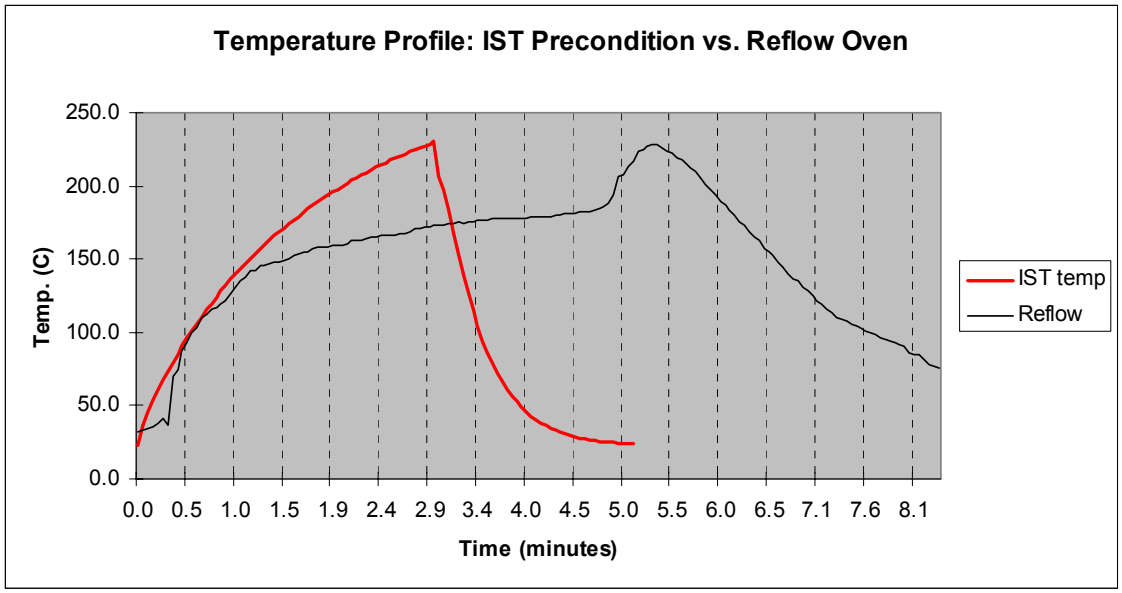
All coupons eventually failed for wear-out/fatigue of the electrolytic copper plated through holes, microsection analysis confirmed barrel cracking generally occurred in the central zone of the barrel, adjacent to internal interconnects. Copper cracking was also found in the knee/corners of the PTH barrels, specifically in the preconditioned coupons.

The variation in cycles to failure are strongly influenced by the natural affects of crack propagation, as determined by the coalescing of micro-cracks into semi-cylindrical cracks, ultimately leading to circumferential cracks. The IST data confirms that all coupons demonstrated consistent crack initiations (see Appendix B), this illustrates that all coupons were being stressed equally.

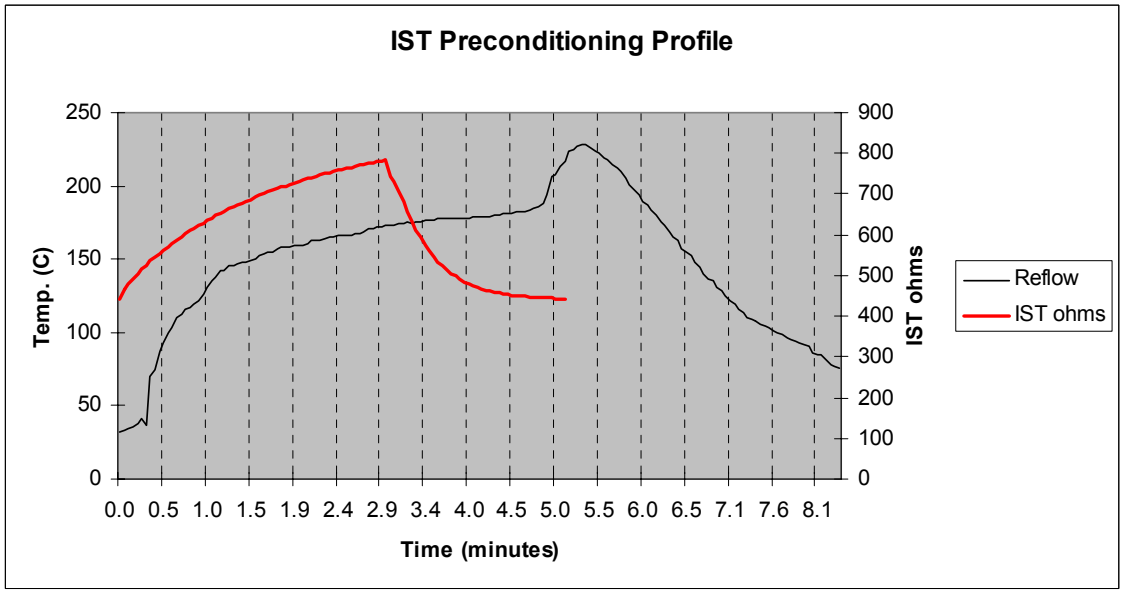
There were no indications of internal interconnect degradation during any sites testing, even after 6 cycles of IST or convection oven preconditioning. This is a positive indication that no false failures were identified. Subsequent microsections confirmed that no interconnect separation was visible, although hole to pad breakout was clearly evident.

This study demonstrated that preconditioning by IST was more severe than by the traditional reflow oven. It is understood that the time to temperature of IST preconditioning is more severe than traditional convection reflow (3 minutes versus 5 minutes), this situation is contributing to the damage accumulation effects. Secondly, the logic of the IST preconditioning profile also considers the faster temperature rise experienced during the component rework process. Lastly, the IST internally heats the test vehicles to a preset temperature, whereas a reflow oven profile represents the surface temperature of the samples as they pass through the reflow oven. It would stand to reason that internal bulk heating by IST preconditioning should create more stress on PTH interconnects than external heating by convection reflow when both techniques are referencing the same peak temperature (230C in this case).

For comparison sake the chart on the following page overlays the temperature profiles of the IST preconditioning and reflow oven. It can be seen that the IST curve from room to peak temperature is as steep as the preheat section of the reflow oven profile. The IST preconditioning cooling phase is even steeper than that of after reflow cooling. The IST preconditioning profile reaches peak temperature at 3 minutes, whereas the reflow profile reaches peak temperature around 5.25 minutes where the difference can be attributed to the reflow profile having a lengthy soak zone before reaching peak temperature.



It should be noted that the IST profile shown above was extrapolated from the resistance data found in the IST preconditioning file. A two point least squares regression was calculated from the lowest resistance value which represented room temperature and the highest resistance value which represented peak temperature. The plot below shows the actual resistance (mOhms) vs. time IST measurements.



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4. Test Vehicle Description

Design:	GT40800B	Coupon Origin:	Multek China (B5)
No. of Layers:	18	Date Code:	Oct 2004
Thickness:	102 +/-10mil	Coupon Size:	6” X 0.5”
Material:	Isola FR406 T_g=170C	Grid:	0.04”
Surface Finish:	OSP	Solder Mask:	PSR4000MP
Drill Diameter:	13.5mil (P1/S1)	Panel:	18”x24”
Hole Wall Thick:	0.0013”	Pad size:	0.026”

Process Parameters:

- Horizontal Oxide Replacement
- Vertical Double Desmear

Plating:		
Type	Panel	Pattern
Current Density (ASF):	18	16
Plating Time (min.):	70	65
DC or Pulse:	Pulse	Pulse
Machine Type:	Vertical	Vertical

Drilling:	P1/S1
Drill bit size (mil):	13.5
Infeed Rate (IPM):	95.7
Retract Rate (IPM):	500
Spindle Speed (KRPM):	110
Stack Height:	1
Max Hits:	1000

5. Coupon Preconditioning

IST:

Number of Cycles	**6 cycles**
Peak Test Temperature	**230°C**
Maximum Temperature	240°C
% Reject Sense	10%
Precycle Time Window	+/- 5 seconds

Convection Reflow Oven:

Number of Passes	**6 cycles**
Average Ramp-up Rate	<3C / second
>100C	360 to 600 seconds
>150C	At least 180 seconds
>183C	60 to 90 seconds
Peak Temp Range	**230C +5/ 0C**
Cool Down Rate (peak to 50C)	<6C / second
Total Profile Time from 30C to 230C	No greater than 360 seconds

Panel "C" coupons received six passes through a Convection Reflow Oven, with a peak temperature of 230C +5/-0C. The panel was routed into arrays of 3 coupons; resulting in 21 arrays. One array of three coupons from a sacrificial panel "S" was used to create the thermal profile by placing five thermocouples in the corners and center of the array, to ensure that all coupons heated evenly in the reflow oven.

The temperature profile was verified with a temperature profiler. The 21 arrays were allowed to completely cool to room temperature between each pass through the oven. See appendix (E) for actual profile.

IST Test Set-up Conditions:

Maximum # of Cycles	**1000 cycles**
Test Temperature	**150°C**
% Reject Sense	**10%**
% Reject Power	**10%**
Data Every Cycles	25
Precycle Time Window	5 seconds
Compensation	VB-Calculated / DOS-Yes
Cooling Time	VB-Automatic / DOS-0.66

ASIA and PWB IST system runs on VB (Visual Basic) software. BBN is DOS based.

6. IST System Configuration

Test Site	ASIA	PWB	Germany
Serial Number / ID	4802	Service 9-Contempra	1798
Model	IST VBP	IST VBP	IST 70
Date of Manufacture	Aug 2002	Nov 2003	Oct 1998
Power Supply	Kepco	Kepco	Farnell
Resistance Meter	Keithley 2750	Keithley 2750	Keithley 580/197
Operating System	Win2000	Win2000	Win 95 / DOS
Software Version	3.3.20*	1.3.23*	IST 70-02

*The software version used by PWB (1.3.23) is part of PWBs internal database software; effectively it's the same software used by Multek Asia (3.3.20).

7. Overview of Results, Failure Analysis, Chemical/Material Analysis, Test Conditions

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IST Cycles to Failure Results	A
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Thermal Analysis (TMA)	F
Reflow Oven Profile	G
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Lognormal base e Distribution Analysis Data	I

8. Discussion

IST coupons from three panels were randomized and tested on three different IST systems located in Multek Asia, Multek Germany and PWB Interconnect Solutions. The three panels represented the following conditions:

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All samples failed within 1000 cycles on the sense (PTH) circuit with the exception five samples (two at BBN and three at PWB). Six samples tested at GERMANY were rejected from the analysis for the following reasons: 1) coupons loaded backwards, 2) changes made to the testing system during the actual test, 3) defective coupon.

9. Acknowledgements

The author would like to extend special thanks to Bill Birch for his participation and support with making this correlation study possible.

10. Key Words

IST, Correlation

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Appendix A

IST Cycles to Failure Results

Multek Asia:

ASIA			Failure	
IST SET	HEAD	Coupon ID	# Cycles	Failure Type
1	1	A-7	386	PTH
	2	C-62	352	PTH
	3	A-37	725	PTH
	4	C-7	292	PTH
	5	B-7	235	PTH
	6	B-13	287	PTH
2	1	A-10	737	PTH
	2	C-4	454	PTH
	3	A-1	673	PTH
	4	C-50	256	PTH
	5	B-56	331	PTH
	6	C-28	278	PTH
3	1	B-37	135	PTH
	2	C-16	684	PTH
	3	B-62	317	PTH
	4	A-47	345	PTH
	5	A-22	745	PTH
	6	A-44	411	PTH
4	1	B-16	349	PTH
	2	A-31	603	PTH
	3	C-25	348	PTH
	4	A-4	937	PTH
	5	A-62	697	PTH
	6	A-56	558	PTH
5	1	A-28	687	PTH
	2	C-31	352	PTH
	3	B-10	302	PTH
	4	C-37	323	PTH
	5	C-53	676	PTH
	6	C-34	465	PTH
6	1	B-53	198	PTH
	2	B-31	216	PTH
	3	A-59	534	PTH
	4	B-34	179	PTH
	5	A-13	696	PTH
	6	C-19	578	PTH
7	1	C-44	665	PTH
	2	A-16	944	PTH
	3	A-50	592	PTH
	4	B-25	441	PTH
	5	A-53	638	PTH
	6	B-28	137	PTH
8	1	C-10	388	PTH
	2	B-50	115	PTH
	3	C-59	290	PTH
	4	B-19	225	PTH
	5	C-13	183	PTH
	6	A-25	521	PTH
9	1	B-4	166	PTH
	2	A-19	423	PTH
	3	B-47	181	PTH
	4	C-40	329	PTH
	5	C-22	472	PTH
	6	C-1	319	PTH
10	1	C-56	330	PTH
	2	C-47	740	PTH
	3	B-22	418	PTH
	4	A-40	638	PTH
	5	A-34	980	PTH
	6	B-59	208	PTH

Multek Boeblingen:

Multek BBN			Failure	
IST SET	HEAD	Coupon ID	# Cycles	Failure Type
1	1	C-26	265	PTH
	2	C-42	254	PTH
	3	C-60	416	PTH
	4	A-45	332	PTH
	5	B-32	239	PTH
	6	B-5	145	PTH
2	1	B-35	240	PTH
	2	C-48	424	PTH
	3	A-29	351	PTH
	4	B-17	344	PTH
	5	A-8	574	PTH
	6	C-29	248	PTH
3	1	A-32	382	PTH
	2	A-26	453	PTH
	3	B-26	247	PTH
	4	A-51	401	PTH
	5	C-54	294	PTH
	6	B-57	149	PTH
4	1	B-8	163	PTH
	2	A-38	191	PTH
	3	A-5	683	PTH
	4	B-51	202	PTH
	5	A-11	647	PTH
	6	C-2	604	PTH
5	1	B-63	210	PTH
	2	B-20	144	PTH
	3	A-63	629	PTH
	4	A-23	502	PTH
	5	B-29	208	PTH
	6	A-35	1000	No Failure
6	1	A-2	357	PTH
	2	B-54	167	PTH
	3	C-14	Discard	Note A
	4	A-17	399	PTH
	5	C-8	551	PTH
	6	A-48	483	PTH
7	1	C-57	393	PTH
	2	A-20	Discard	Note A
	3	C-11	1000	No Failure
	4	B-11	183	PTH
	5	A-60	582	PTH
	6	C-35	246	PTH
8	1	B-14	145	PTH
	2	C-32	270	PTH
	3	A-54	522	PTH
	4	B-23	124	PTH
	5	A-42	722	PTH
	6	C-5	292	PTH
9	1	B-60	229	PTH
	2	C-51	Discard	Note B
	3	B-38	296	PTH
	4	C-17	Discard	Note B
	5	B-48	204	PTH
	6	C-63	Discard	Note B
10	1	C-23	Discard	Note C
	2	A-57	269	PTH
	3	A-14	716	PTH
	4	C-45	221	PTH
	5	C-38	268	PTH
	6	C-20	402	PTH

Notes
A: Coupon loaded backwards. i.e. Pwr and Sns circuits reversed.
B: Activated carbon filter installed on IST tester at cycle 300 which changed thermal conditions. Therefore, all coupons for that run with failures above 300 cycles were discarded.
C: High resistance short observed between Pwr and Sns circuits.

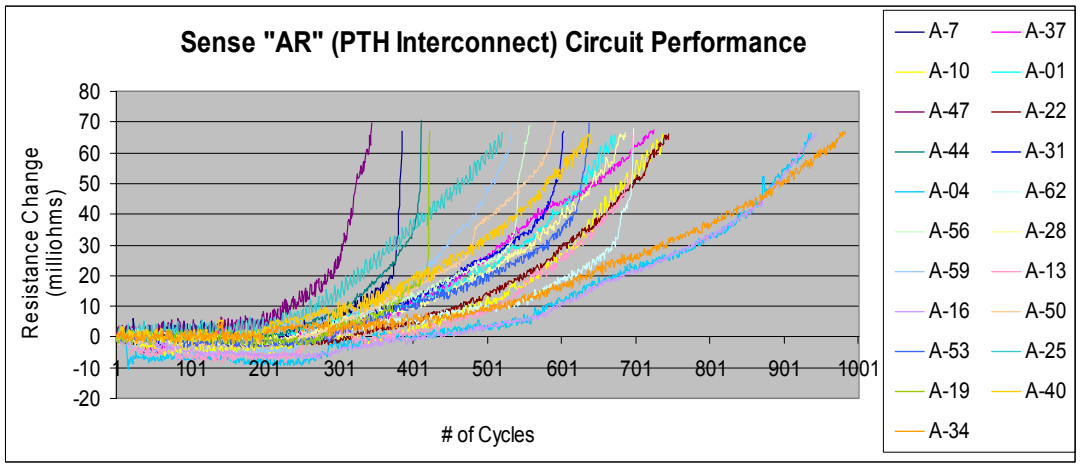
PWB Interconnect Solutions:

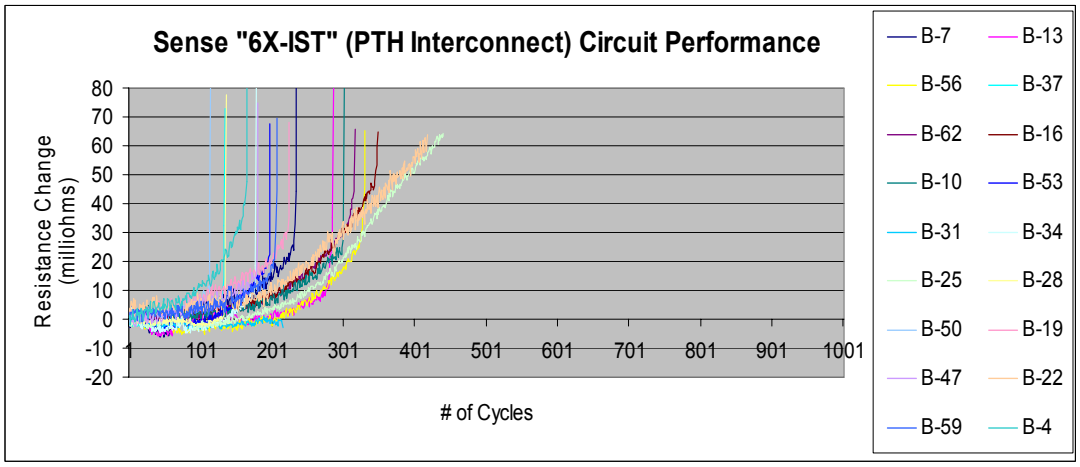
PWB			Failure	
IST SET	HEAD	Coupon ID	# Cycles	Failure Type
1	1	B-52	264	PTH
	2	C-21	361	PTH
	3	B-15	270	PTH
	4	C-12	267	PTH
	5	A-55	549	PTH
	6	C-27	389	PTH
2	1	B-61	147	PTH
	2	B-30	220	PTH
	3	B-6	401	PTH
	4	B-36	243	PTH
	5	C-15	477	PTH
	6	C-33	853	PTH
3	1	A-58	548	PTH
	2	B-55	318	PTH
	3	A-33	408	PTH
	4	C-61	442	PTH
	5	A-12	556	PTH
	6	A-49	321	PTH
4	1	A-6	477	PTH
	2	C-58	672	PTH
	3	C-30	446	PTH
	4	C-41	537	PTH
	5	A-3	581	PTH
	6	B-9	196	PTH
5	1	B-39	142	PTH
	2	C-24	340	PTH
	3	C-36	407	PTH
	4	C-43	513	PTH
	5	A-30	912	PTH
	6	C-49	796	PTH
6	1	A-18	836	PTH
	2	C-39	732	PTH
	3	A-36	266	PTH
	4	A-52	540	PTH
	5	C-3	1000	No Failure
	6	B-12	211	PTH
7	1	B-27	254	PTH
	2	C-46	963	PTH
	3	C-52	395	PTH
	4	A-46	660	PTH
	5	A-24	811	PTH
	6	A-41	1000	No Failure
8	1	B-58	310	PTH
	2	A-21	1000	No Failure
	3	A-43	807	PTH
	4	C-18	568	PTH
	5	A-15	861	PTH
	6	C-6	617	PTH
9	1	B-21	279	PTH
	2	B-46	485	PTH
	3	C-55	453	PTH
	4	B-24	295	PTH
	5	A-61	584	PTH
	6	C-9	579	PTH
10	1	A-9	458	PTH
	2	B-33	218	PTH
	3	B-18	198	PTH
	4	A-39	313	PTH
	5	B-49	248	PTH
	6	A-27	789	PTH

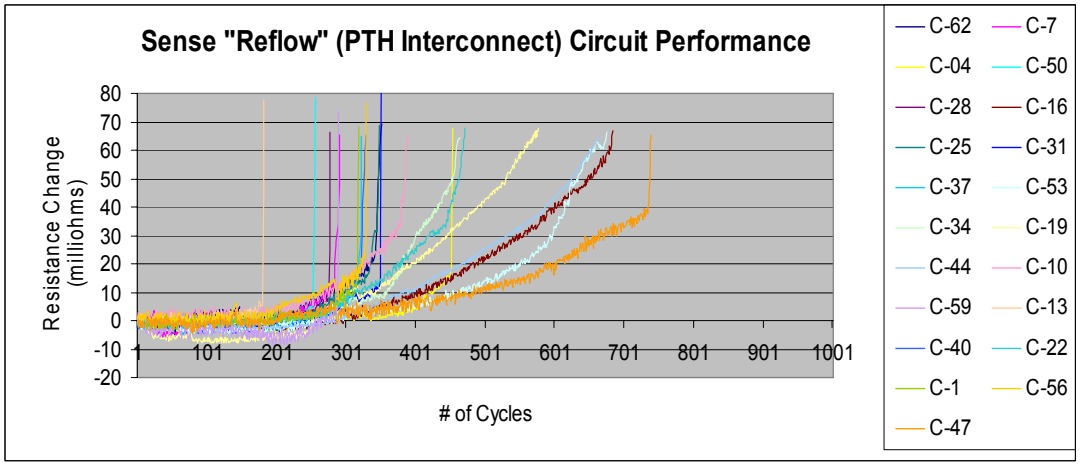
Appendix B

Resistance Change vs. Cycles Graphs

Multek ASIA







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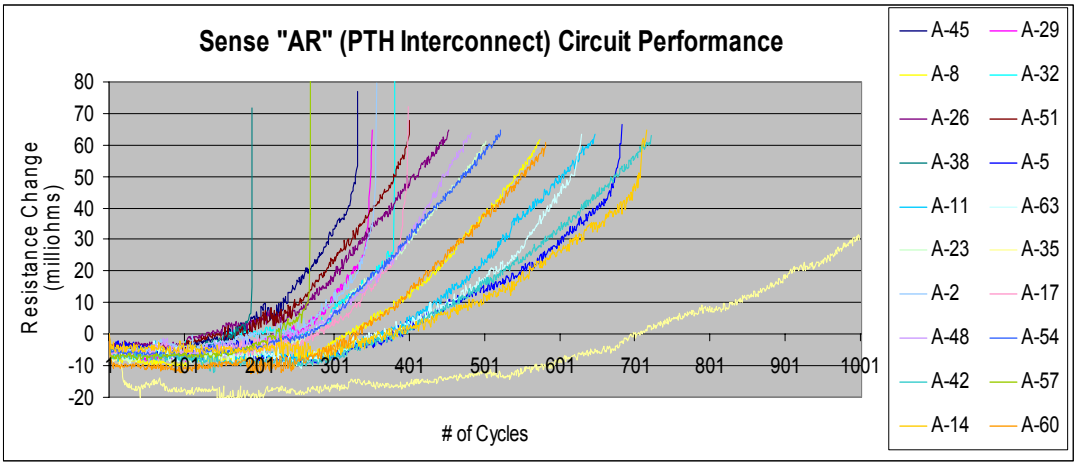
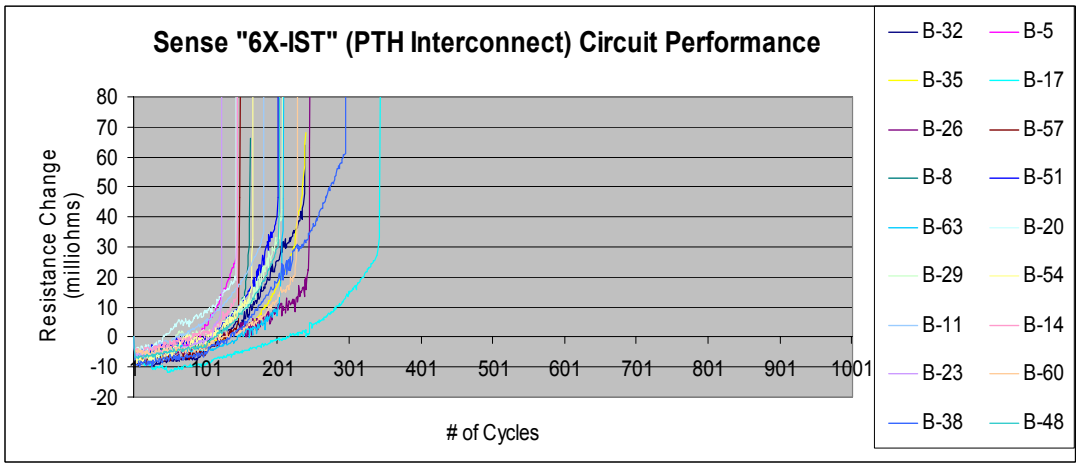
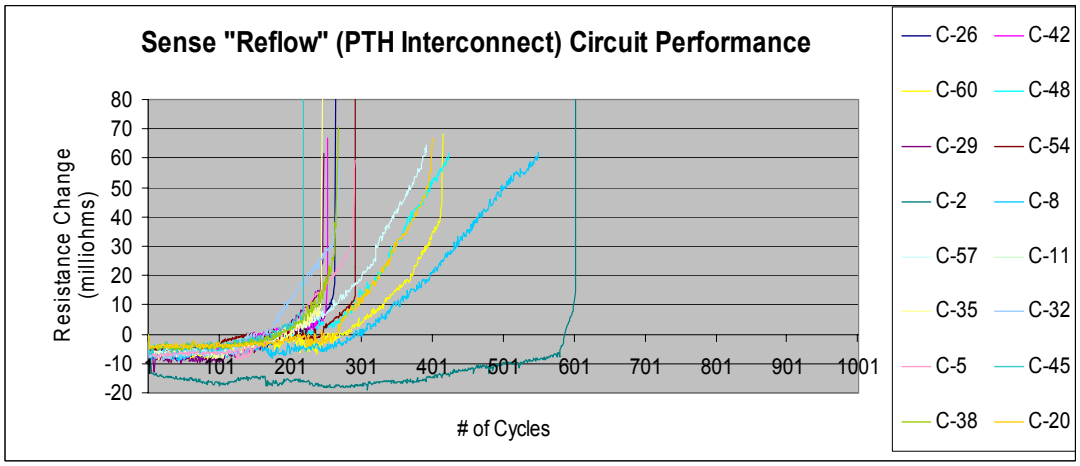
Multek Boeblingen







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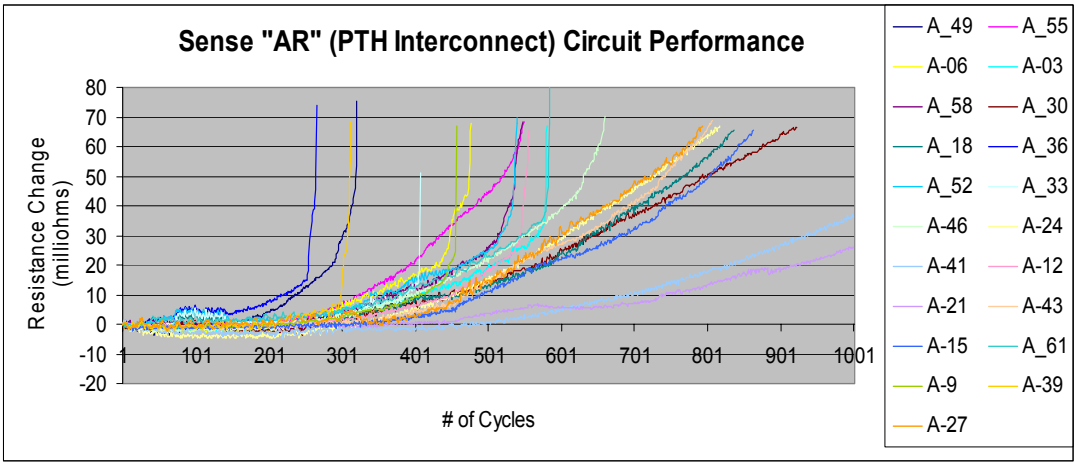
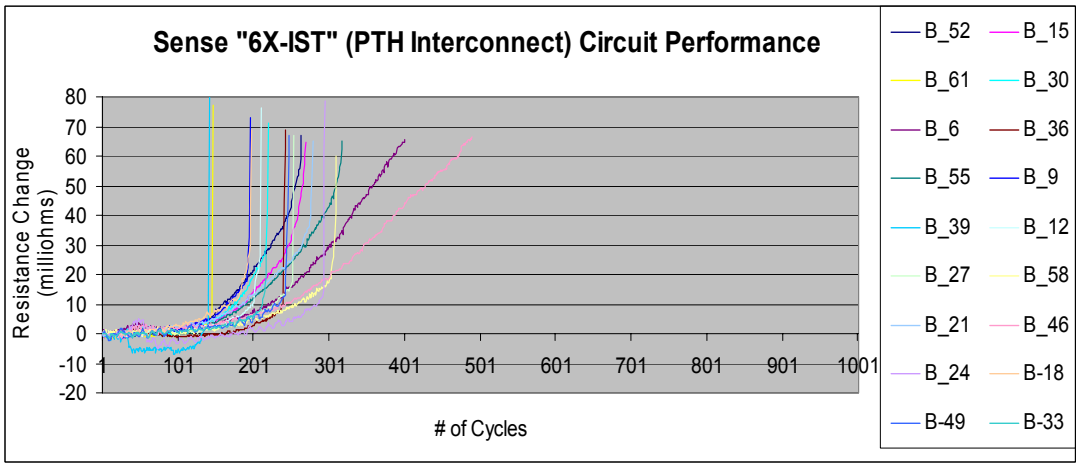
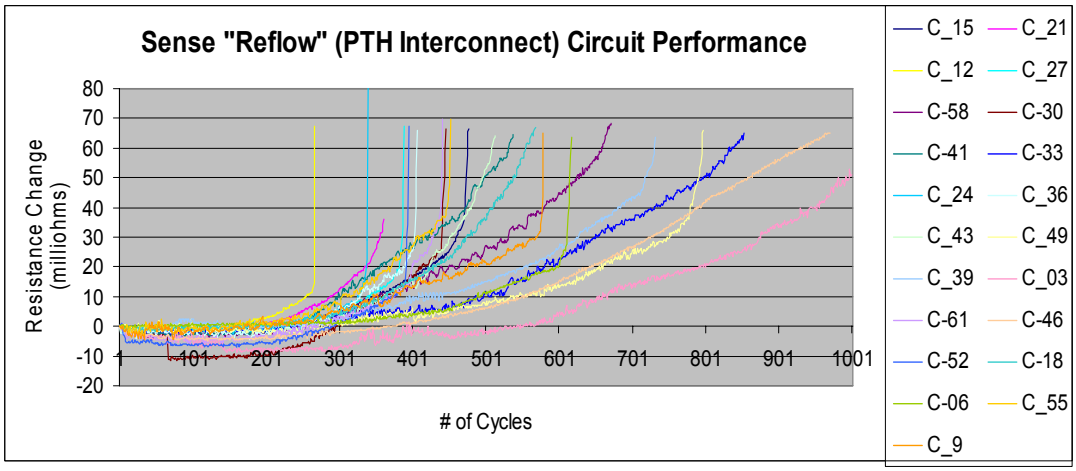
PWB Interconnect Solutions







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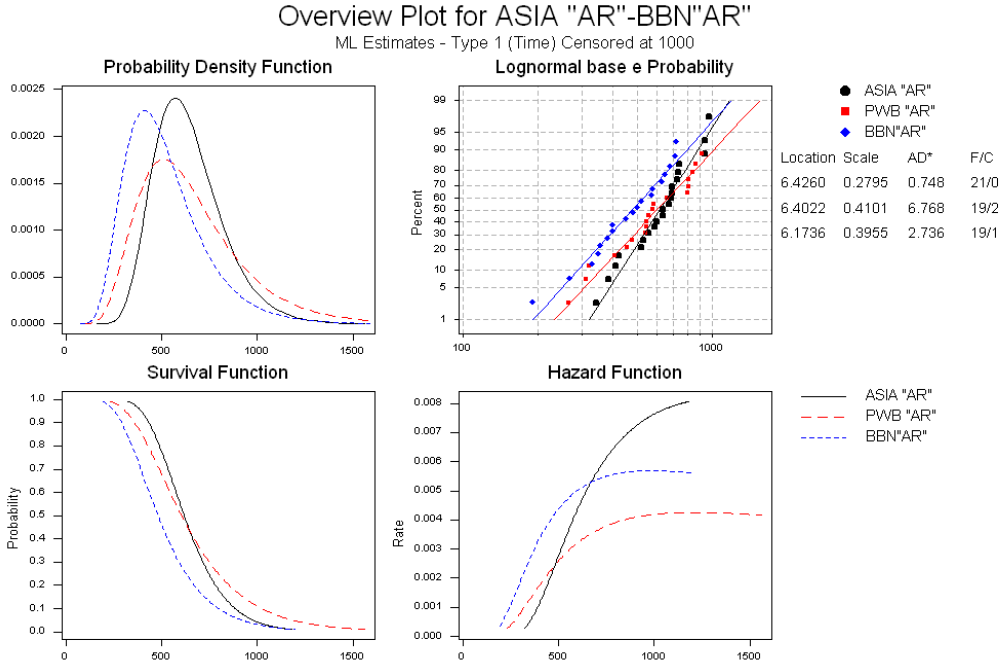
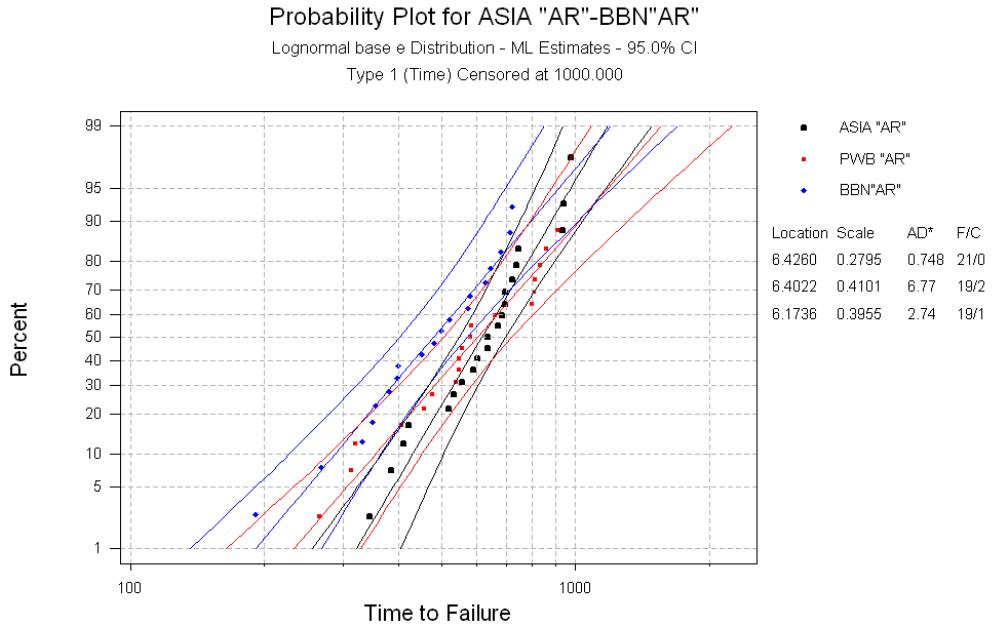
Appendix C

Statistical Analysis

"As Received" for ASIA (Black), PWB (Red), and BBN (Blue).

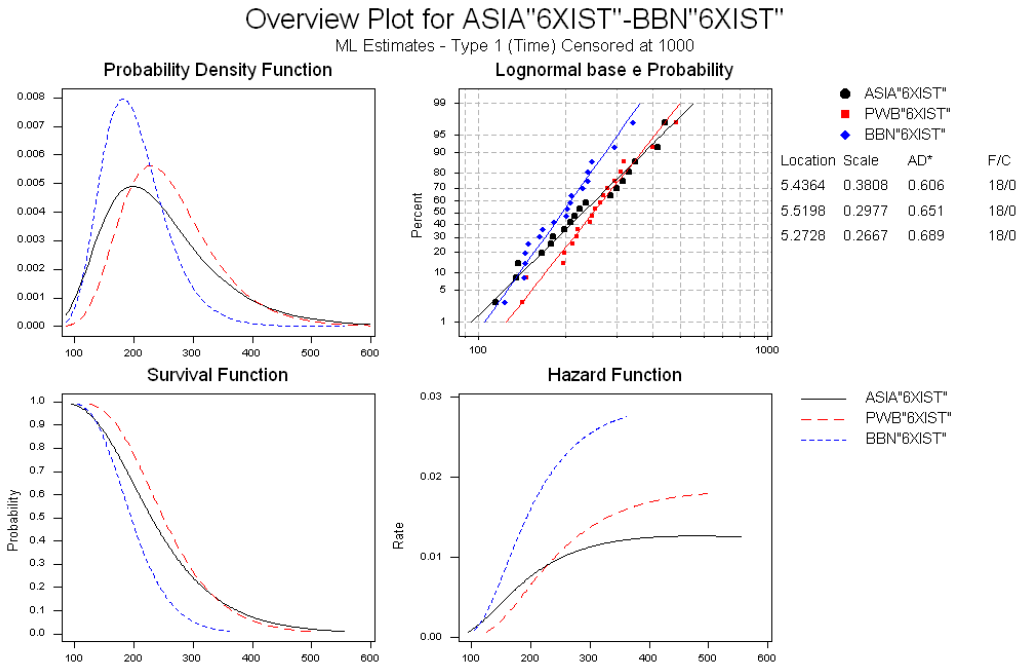


"As Received" for ASIA (Black), PWB (Red), and BBN (Blue).

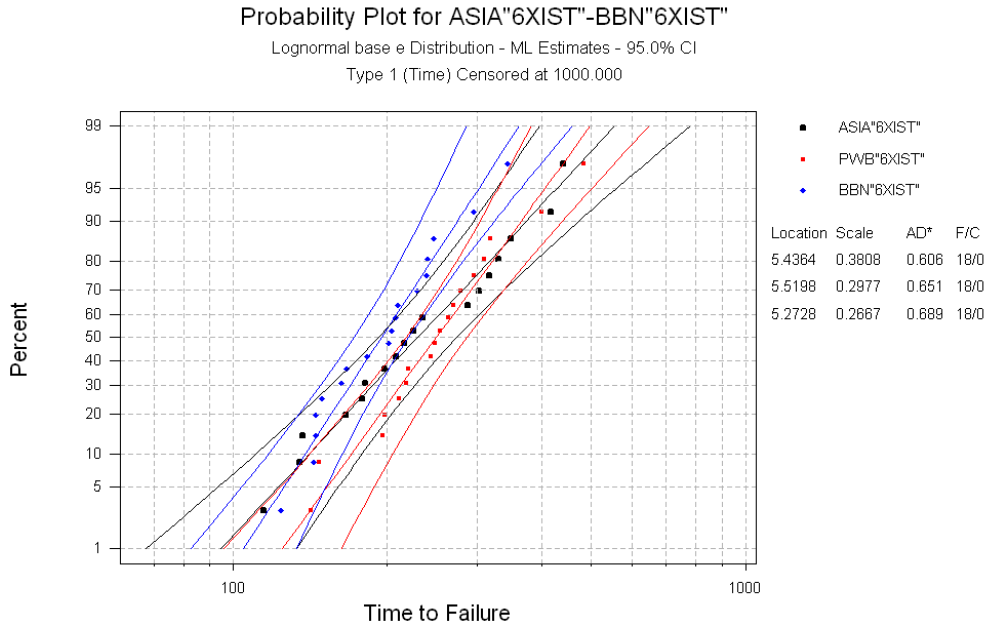


Appendix C

"6X IST" for ASIA (Black), PWB (Red), and BBN (Blue).

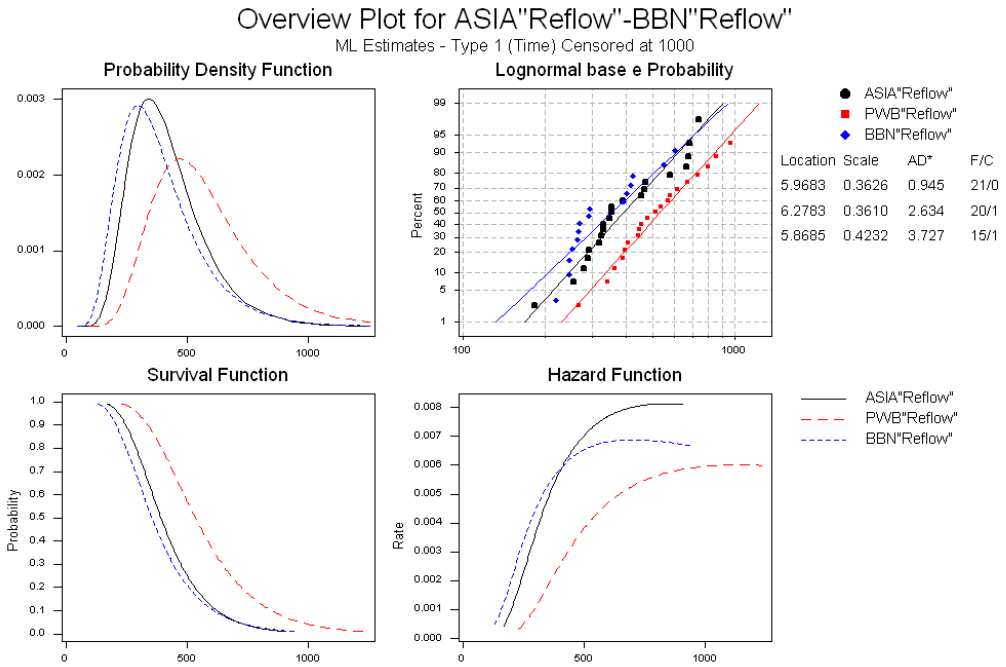


"6X IST" for ASIA (Black), PWB (Red), and BBN (Blue).

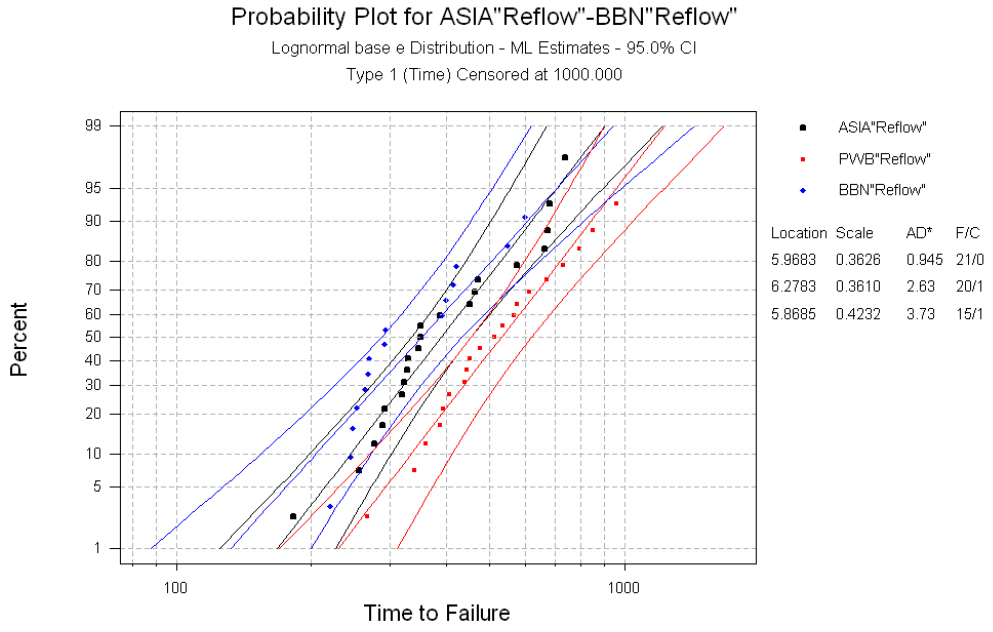


Appendix C

"REFLOW" for ASIA (Black), PWB (Red), and BBN (Blue).



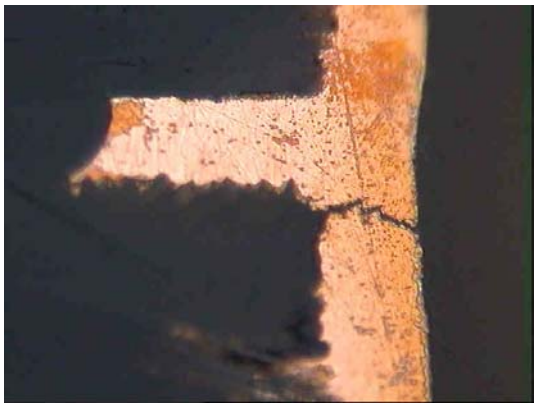
"REFLOW" for ASIA (Black), PWB (Red), and BBN (Blue).



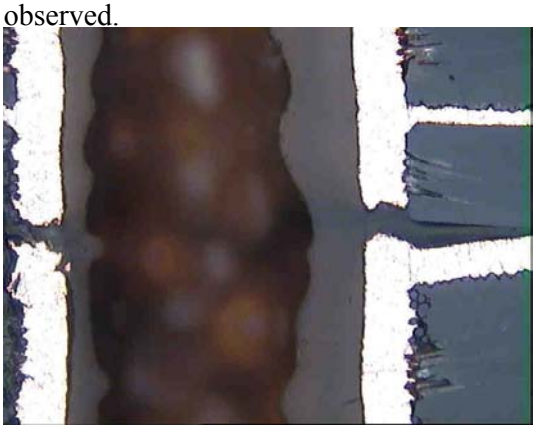
Appendix D

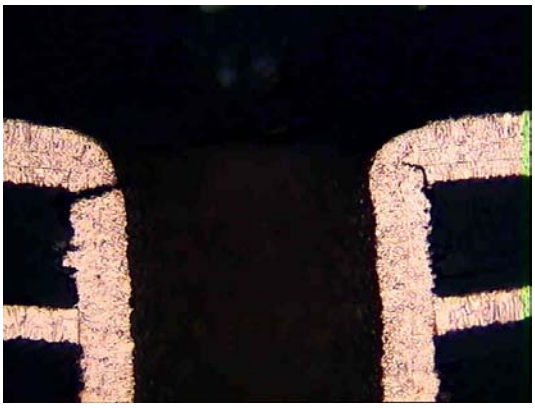
Failure Analysis

Multek BBN
Sample A-45 failed at 332 cycles due to sense circuit barrel cracking.

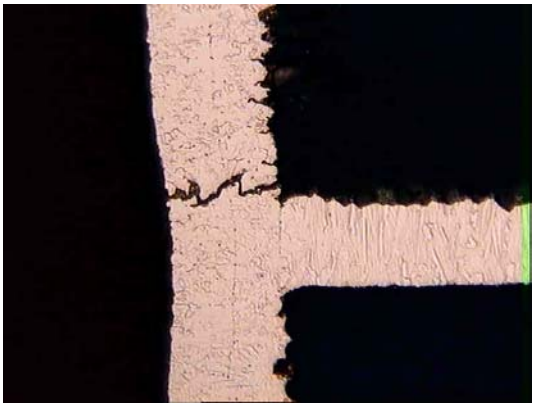


Sample B-17 failed at 344 cycles due to sense circuit barrel cracking. Corner cracking also observed.





Sample C-54 failed at 294 cycles due to sense circuit barrel cracking.



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Appendix E

PTH Cu Thickness and Hole Wall Roughness

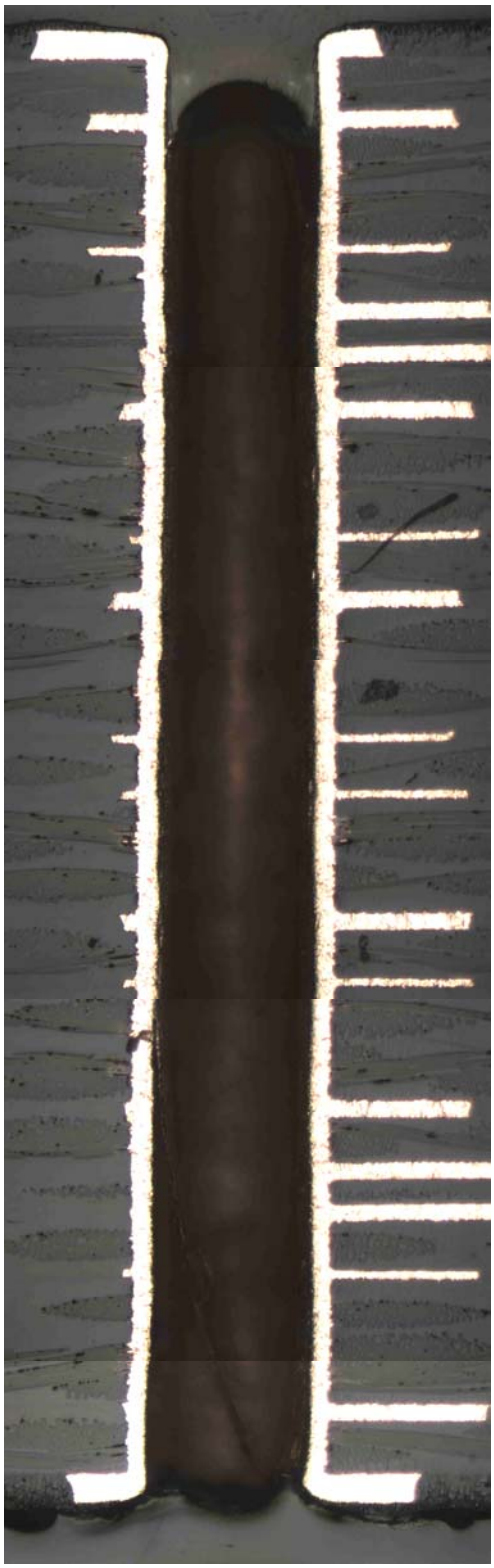
Sample: S-43

Hole wall Cu thickness: (µm)

A	B	C	D	E	F	Avg.
34	35	34	34	34	35	34

Hole wall Roughness: (µm)

1	2	3	4	5	Avg.
15	17	15	16	13	15



Cu Tensile Strength & % Elongation

IPC TM-650-2.4.18.1

Panel plating: 42.8Kpsi ±0.8Kpsi
31% ±3%

Pattern plating: 45.0Kpsi ±1.1Kpsi
31% ±3%

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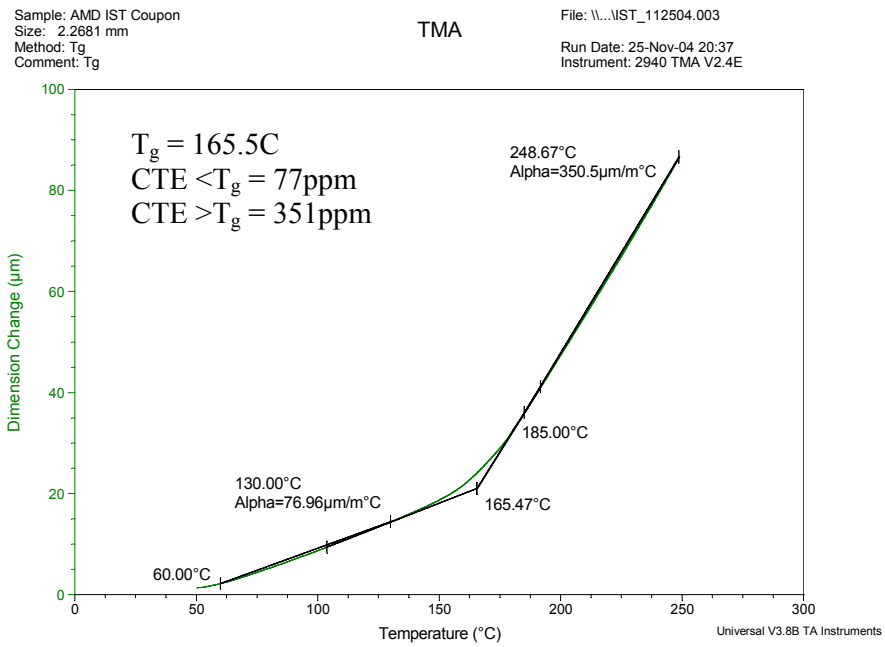
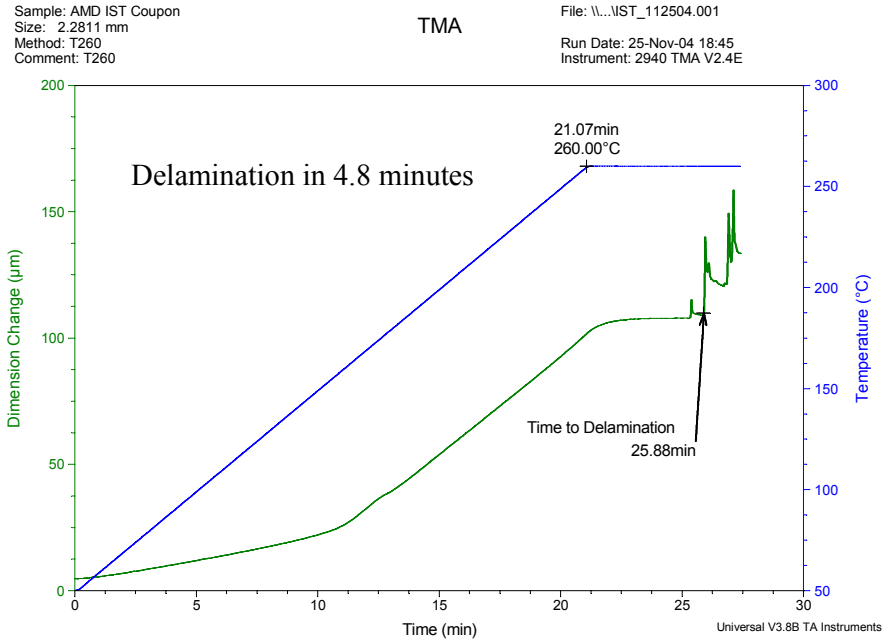
Appendix F

Thermal Analysis (TMA)

Tg and CTE Plot (IPC TM-650-2.4.24 Rev C):



T-260 Time to Delamination Plot (IPC TM-650-2.4.24.1):



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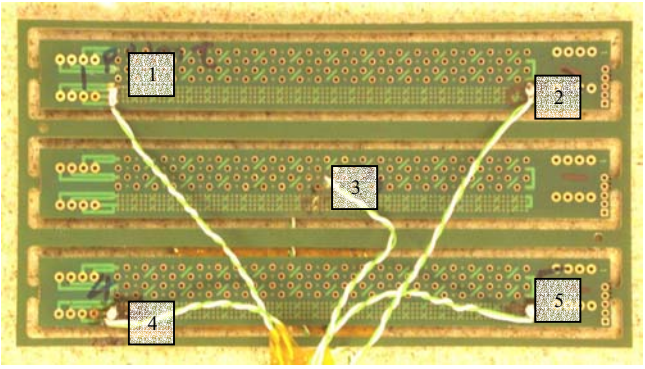
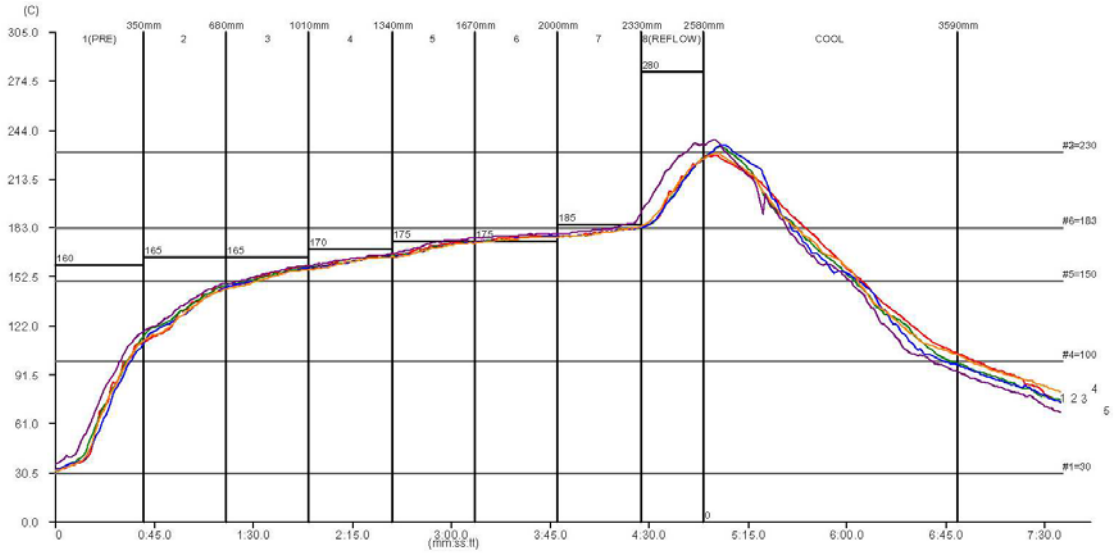
Appendix G

Reflow Oven Profile

Condition	Requirement	Actual
Average ramp-up rate	<3C / second	0.67C/ second
>100C	360 to 600 seconds	375 seconds
>150C	At least 180 seconds	275 seconds
>183C	60 to 90 seconds	73 seconds
Peak Temp range	230C +5/ 0C	233C
Cool down (peak to 50C)	<6C / second	1C / second
Total profile time from 30C to 230C	No greater than 360 seconds	299 seconds





Probe	Max (C)	t>100	t=150	t>150	t=183	t>183	Max+ C/Sec	Max- C/Sec
Channel 1	228.5	6:25.0	1:57.0	4:37.0	4:52.0	1:17.0	4.4@0:21	-1.5@5:29
Channel 2	233.9	6:14.0	1:57.0	4:34.0	4:51.0	1:14.0	3.3@0:19	-2.3@5:22
Channel 3	234.8	6:08.0	1:59.0	4:34.0	4:53.0	1:09.0	3.4@0:22	-3.1@5:26
Channel 4	229.8	6:21.0	2:00.0	4:33.0	4:51.0	1:14.0	3.7@0:19	-2.0@6:07
Channel 5	238.2	6:08.0	1:52.0	4:37.0	4:43.0	1:17.0	3.2@0:19	-2.9@5:17

Appendix H

Test Panel Coupon Layout and Stack-up:

Material	FR-406
Layers	18
Drill	13.5mil
Grid	40mil
Thick:	100mil
Finish:	Entek

Asia	63 coupons
BBN	63 coupons
PWB	63 coupons
Missing	
p = precondition (sacrificial)	

Panel 1:
As Received

A-21	A-22	A-63
A-20	A-23	A-62
A-19	A-24	A-61
A-18	A-25	A-60
A-17	A-26	A-59
A-16	A-27	A-58
A-15	A-28	A-57
A-14	A-29	A-56
A-13	A-30	A-55
A-12	A-31	A-54
A-11	A-32	A-53
A-10	A-33	A-52
A-9	A-34	A-51
A-8	A-35	A-50
A-7	A-36	A-49
A-6	A-37	A-48
A-5	A-38	A-47
A-4	A-39	A-46
A-3	A-40	A-45
A-2	A-41	A-44
A-1	A-42	A-43

Panel 2:
IST 6X @230C

B-21	B-22	B-63
B-20	B-23	B-62
B-19	B-24	B-61
B-18	B-25	B-60
B-17	B-26	B-59
B-16	B-27	B-58
B-15	B-28	B-57
B-14	B-29	B-56
B-13	B-30	B-55
B-12	B-31	B-54
B-11	B-32	B-53
B-10	B-33	B-52
B-9	B-34	B-51
B-8	B-35	B-50
B-7	B-36	B-49
B-6	B-37	B-48
B-5	B-38	B-47
B-4	B-39	B-46
B-3p	B-40p	B-45p
B-2p	B-41p	B-44p
B-1p	B-42p	B-43p

Panel 7:
6X Reflow 230C +5/-0

C-21	C-22	C-63
C-20	C-23	C-62
C-19	C-24	C-61
C-18	C-25	C-60
C-17	C-26	C-59
C-16	C-27	C-58
C-15	C-28	C-57
C-14	C-29	C-56
C-13	C-30	C-55
C-12	C-31	C-54
C-11	C-32	C-53
C-10	C-33	C-52
C-9	C-34	C-51
C-8	C-35	C-50
C-7	C-36	C-49
C-6	C-37	C-48
C-5	C-38	C-47
C-4	C-39	C-46
C-3	C-40	C-45
C-2	C-41	C-44
C-1	C-42	C-43

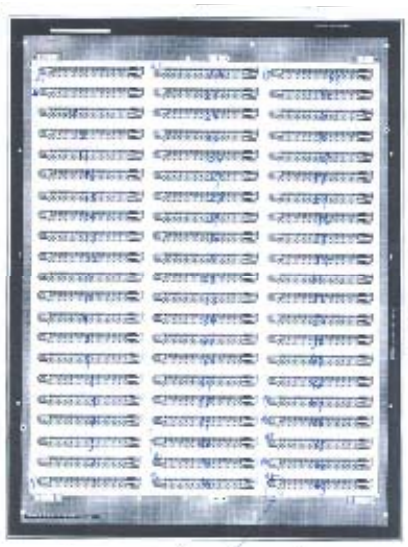
Panel 4:
Sacrificial / Setting Up Coupons

S-21	S-22	S-63
S-20	S-23	S-62
S-19	S-24	S-61
S-18	S-25	S-60
S-17	S-26	S-59
S-16	S-27	S-58
S-15	S-28	S-57
S-14	S-29	S-56
S-13	S-30	S-55
S-12	S-31	S-54
S-11	S-32	S-53
S-10	S-33	S-52
S-9	S-34	S-51
S-8	S-35	S-50
S-7	S-36	S-49
S-6	S-37	S-48
S-5	S-38	S-47
S-4	S-39	S-46
S-3	S-40	S-45
S-2	S-41	S-44
S-1	S-42	S-43

Total coupons tested:					TOTAL
	21		18	21	60
	21		18	21	60
	21		18	21	60

Notes:
1. Multek Asia will manufacture the samples, and they will be serialized according to panel and location on panel.
2. Multek Asia will perform reflow on panel 7, before coupons are singulated.
3. Multek Asia will prescreen (take initial resistance measurements) all coupons to verify they are OK.
4. Multek Asia will solder connectors to all coupons.
5. P1/S1 will be tested.
6. Multek Boeblingen will receive an additional 12 "S" series coupons for setting up their IST.
7. Coupon S-43 used for TMA Tg / T260 and hole wall thickness and roughness.

Panel with IST coupons.



Stack-Up:

H
2116*1
8mil 1/H 2116*2
2116*1
2.0mil 1/1 106*1
2116*1
8mil 1/H 2116*2
2116*1
8mil 1/H 2116*2
2116*1
8mil H/1 2116*2
2116*1
8mil H/1 2116*2
2116*1
2.0mil 1/1 106*1
2116*1
8mil H/1 2116*2
2116*1
H

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Appendix I

Distribution Analysis: ASIA "AR"

Variable: ASIA "AR"

Censoring Information	Count
Uncensored value	21

Type 1 (Time) Censored at 1000.000

Estimation Method: Maximum Likelihood
Distribution: Lognormal base e

Parameter Estimates

Parameter	Estimate	Standard Error	95.0% Normal CI Lower	Upper
Location	6.42603	0.06099	6.30649	6.54558
Scale	0.27951	0.04313	0.20656	0.37821

Log-Likelihood = -137.975

Goodness-of-Fit
Anderson-Darling (adjusted) = 0.7484

Characteristics of Distribution

	Estimate	Standard Error	95.0% Normal CI Lower	Upper
Mean(MTTF)	642.3251	39.9357	568.6337	725.5663
Standard Deviation	183.0995	33.4948	127.9308	262.0591
Median	617.7180	37.6769	548.1158	696.1586
First Quartile(Q1)	511.5813	34.5704	448.1198	584.0300
Third Quartile(Q3)	745.8746	50.4030	653.3492	851.5033
Interquartile Range(IQR)	234.2933	39.2719	168.6875	325.4145

Table of Percentiles

Percent	Percentile	Standard Error	95.0% Normal CI Lower	Upper
1	322.4018	37.8558	256.1244	405.8297
5	390.0527	36.4920	324.7040	468.5532
10	431.7418	35.5375	367.4177	507.3271
50	617.7180	37.6769	548.1158	696.1586
90	883.8049	72.7476	752.1292	1038.533
95	978.2667	91.5234	814.3698	1175.149
99	1183.540	138.9690	940.2357	1489.805

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Appendix I

Distribution Analysis: ASIA"6XIST"

Variable: ASIA"6XIST"

Censoring Information	Count
Uncensored value	18

Type 1 (Time) Censored at 1000.000

Estimation Method: Maximum Likelihood
Distribution: Lognormal base e

Parameter Estimates

Parameter	Estimate	Standard Error	95.0% Normal CI Lower	Upper
Location	5.43641	0.08975	5.26050	5.61232
Scale	0.38078	0.06346	0.27467	0.52789

Log-Likelihood = -106.017

Goodness-of-Fit
Anderson-Darling (adjusted) = 0.6064

Characteristics of Distribution

	Estimate	Standard Error	95.0% Normal CI Lower	Upper
Mean(MTTF)	246.8809	22.9470	205.7645	296.2133
Standard Deviation	97.5206	21.6637	63.0966	150.7255
Median	229.6161	20.6083	192.5777	273.7780
First Quartile(Q1)	177.6074	17.6606	146.1573	215.8248
Third Quartile(Q3)	296.8545	29.5181	244.2886	360.7314
Interquartile Range(IQR)	119.2471	22.9570	81.7669	173.9075

Table of Percentiles

Percent	Percentile	Standard Error	95.0% Normal CI Lower	Upper
1	94.6871	16.3599	67.4872	132.8495
5	122.7412	16.8974	93.7148	160.7581
10	140.9517	17.0721	111.1661	178.7179
50	229.6161	20.6083	192.5777	273.7780
90	374.0540	45.3056	295.0098	474.2771
95	429.5504	59.1349	327.9682	562.5957
99	556.8186	96.2063	396.8665	781.2374

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Appendix I

Distribution Analysis: ASIA"Reflow"

Variable: ASIA"Reflow"

Censoring Information	Count
Uncensored value	21

Type 1 (Time) Censored at 1000.000

Estimation Method: Maximum Likelihood
Distribution: Lognormal base e

Parameter Estimates

Parameter	Estimate	Standard Error	95.0% Normal CI Lower	Upper
Location	5.96832	0.07912	5.81324	6.12340
Scale	0.36260	0.05595	0.26797	0.49064

Log-Likelihood = -133.829

Goodness-of-Fit
Anderson-Darling (adjusted) = 0.9447

Characteristics of Distribution

	Estimate	Standard Error	95.0% Normal CI Lower	Upper
Mean(MTTF)	417.4041	34.0953	355.6535	489.8761
Standard Deviation	156.4623	31.4756	105.4808	232.0846
Median	390.8474	30.9257	334.7003	456.4133
First Quartile(Q1)	306.0506	26.8294	257.7354	363.4229
Third Quartile(Q3)	499.1386	43.7561	420.3413	592.7072
Interquartile Range(IQR)	193.0880	34.0105	136.7177	272.7005

Table of Percentiles

Percent	Percentile	Standard Error	95.0% Normal CI Lower	Upper
1	168.1396	25.6113	124.7422	226.6348
5	215.2718	26.1270	169.6988	273.0833
10	245.5825	26.2233	199.2077	302.7531
50	390.8474	30.9257	334.7003	456.4133
90	622.0382	66.4212	504.5751	766.8462
95	709.6224	86.1251	559.3958	900.1927
99	908.5405	138.3905	674.0433	1224.619

Appendix I

Distribution Analysis: PWB "AR"

Variable: PWB "AR"

Censoring Information	Count
Uncensored value	19
Right censored value	2

Type 1 (Time) Censored at 1000.000

Estimation Method: Maximum Likelihood
Distribution: Lognormal base e

Parameter Estimates

Parameter	Estimate	Standard Error	95.0% Normal CI Lower	Upper
Location	6.40225	0.09036	6.22514	6.57935
Scale	0.41011	0.06817	0.29607	0.56805

Log-Likelihood = -132.583

Goodness-of-Fit
Anderson-Darling (adjusted) = 6.7682

Characteristics of Distribution

	Estimate	Standard Error	95.0% Normal CI Lower	Upper
Mean(MTTF)	656.1172	62.9447	543.6523	791.8475
Standard Deviation	280.7978	64.9962	178.3883	441.9988
Median	603.1983	54.5050	505.2957	720.0699
First Quartile(Q1)	457.4346	45.4140	376.5493	555.6946
Third Quartile(Q3)	795.4103	82.2851	649.4333	974.1995
Interquartile Range(IQR)	337.9757	66.5599	229.7485	497.1855

Table of Percentiles

Percent	Percentile	Standard Error	95.0% Normal CI Lower	Upper
1	232.3390	41.4698	163.7543	329.6488
5	307.2563	43.1340	233.3487	404.5722
10	356.6213	43.6690	280.5278	453.3552
50	603.1983	54.5050	505.2957	720.0699
90	1020.265	131.4549	792.5758	1313.364
95	1184.185	174.7199	886.8077	1581.283
99	1566.023	292.0279	1086.596	2256.982

Appendix I

Distribution Analysis: PWB"6XIST"

Variable: PWB"6XIST"

Censoring Information	Count
Uncensored value	18

Type 1 (Time) Censored at 1000.000

Estimation Method: Maximum Likelihood
Distribution: Lognormal base e

Parameter Estimates

Parameter	Estimate	Standard Error	95.0% Normal CI Lower	Upper
Location	5.51976	0.07017	5.38223	5.65730
Scale	0.29771	0.04962	0.21475	0.41273

Log-Likelihood = -103.087

Goodness-of-Fit
Anderson-Darling (adjusted) = 0.6509

Characteristics of Distribution

	Estimate	Standard Error	95.0% Normal CI Lower	Upper
Mean(MTTF)	260.8848	18.7078	226.6783	300.2532
Standard Deviation	79.4213	16.0069	53.5036	117.8939
Median	249.5759	17.5130	217.5069	286.3732
First Quartile(Q1)	204.1716	15.8730	175.3154	237.7773
Third Quartile(Q3)	305.0775	23.7177	261.9600	355.2920
Interquartile Range(IQR)	100.9060	18.4554	70.5074	144.4107

Table of Percentiles

Percent	Percentile	Standard Error	95.0% Normal CI Lower	Upper
1	124.8590	16.8666	95.8154	162.7063
5	152.9442	16.4619	123.8554	188.8647
10	170.4142	16.1377	141.5467	205.1690
50	249.5759	17.5130	217.5069	286.3732
90	365.5104	34.6127	303.5943	440.0538
95	407.2607	43.8349	329.8030	502.9101
99	498.8680	67.3896	382.8256	650.0852

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Appendix I

Distribution Analysis: PWB"Reflow"

Variable: PWB"Reflow"

Censoring Information	Count
Uncensored value	20
Right censored value	1

Type 1 (Time) Censored at 1000.000

Estimation Method: Maximum Likelihood
Distribution: Lognormal base e

Parameter Estimates

Parameter	Estimate	Standard Error	95.0% Normal CI Lower	Upper
Location	6.27830	0.07905	6.12336	6.43324
Scale	0.36104	0.05790	0.26366	0.49439

Log-Likelihood = -134.125

Goodness-of-Fit
Anderson-Darling (adjusted) = 2.6341

Characteristics of Distribution

	Estimate	Standard Error	95.0% Normal CI Lower	Upper
Mean(MTTF)	568.7676	46.7622	484.1187	668.2174
Standard Deviation	212.2246	44.4021	140.8333	319.8056
Median	532.8804	42.1250	456.3952	622.1835
First Quartile(Q1)	417.7067	36.5041	351.9521	495.7463
Third Quartile(Q3)	679.8108	60.4672	571.0526	809.2823
Interquartile Range(IQR)	262.1040	48.0216	183.0291	375.3422

Table of Percentiles

Percent	Percentile	Standard Error	95.0% Normal CI Lower	Upper
1	230.0723	35.5841	169.9078	311.5411
5	294.2530	36.0215	231.4832	374.0437
10	335.4948	35.9702	271.9091	413.9498
50	532.8804	42.1250	456.3952	622.1835
90	846.3964	92.7810	682.7568	1049.256
95	965.0252	120.7431	755.1567	1233.219
99	1234.228	194.6298	906.0792	1681.219

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Appendix I

Distribution Analysis: BBN"AR"

Variable: BBN"AR"

Censoring Information	Count
Uncensored value	19
Right censored value	1

Type 1 (Time) Censored at 1000.000

Estimation Method: Maximum Likelihood
Distribution: Lognormal base e

Parameter Estimates

Parameter	Estimate	Standard Error	95.0% Normal CI Lower	Upper
Location	6.17355	0.08872	5.99965	6.34745
Scale	0.39546	0.06516	0.28632	0.54621

Log-Likelihood = -127.109

Goodness-of-Fit
Anderson-Darling (adjusted) = 2.7357

Characteristics of Distribution

	Estimate	Standard Error	95.0% Normal CI Lower	Upper
Mean(MTTF)	518.9174	48.2359	432.4889	622.6178
Standard Deviation	213.5014	47.8445	137.6103	331.2459
Median	479.8871	42.5776	403.2895	571.0330
First Quartile(Q1)	367.5347	36.0583	303.2412	445.4598
Third Quartile(Q3)	626.5847	62.6021	515.1529	762.1201
Interquartile Range(IQR)	259.0500	49.8319	177.6818	377.6803

Table of Percentiles

Percent	Percentile	Standard Error	95.0% Normal CI Lower	Upper
1	191.2488	33.2552	136.0154	268.9117
5	250.4047	34.4476	191.2251	327.8991
10	289.0933	34.8194	228.3055	366.0664
50	479.8871	42.5776	403.2895	571.0330
90	796.5995	98.1612	625.6774	1014.214
95	919.6776	129.3931	698.0341	1211.698
99	1204.146	213.6004	850.5246	1704.793

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Appendix I

Distribution Analysis: BBN"6XIST"

Variable: BBN"6XIST"

Censoring Information	Count
Uncensored value	18

Type 1 (Time) Censored at 1000.000

Estimation Method: Maximum Likelihood
Distribution: Lognormal base e

Parameter Estimates

Parameter	Estimate	Standard Error	95.0% Normal CI Lower	Upper
Location	5.27283	0.06287	5.14961	5.39605
Scale	0.26673	0.04445	0.19240	0.36977

Log-Likelihood = -96.664

Goodness-of-Fit
Anderson-Darling (adjusted) = 0.6894

Characteristics of Distribution

	Estimate	Standard Error	95.0% Normal CI Lower	Upper
Mean(MTTF)	202.0275	12.9250	178.2189	229.0168
Standard Deviation	54.8587	10.6941	37.4381	80.3855
Median	194.9674	12.2572	172.3649	220.5339
First Quartile(Q1)	162.8661	11.3440	142.0832	186.6890
Third Quartile(Q3)	233.3960	16.2565	203.6130	267.5355
Interquartile Range(IQR)	70.5298	12.6819	49.5814	100.3291

Table of Percentiles

Percent	Percentile	Standard Error	95.0% Normal CI Lower	Upper
1	104.8295	12.6871	82.6925	132.8927
5	125.7263	12.1240	104.0743	151.8829
10	138.5193	11.7521	117.2987	163.5788
50	194.9674	12.2572	172.3649	220.5339
90	274.4189	23.2820	232.3791	324.0640
95	302.3417	29.1553	250.2738	365.2420
99	362.6108	43.8853	286.0376	459.6827

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Appendix I

Distribution Analysis: BBN"Reflow"

Variable: BBN"Reflow"

Censoring Information	Count
Uncensored value	15
Right censored value	1

Type 1 (Time) Censored at 1000.000

Estimation Method: Maximum Likelihood
Distribution: Lognormal base e

Parameter Estimates

Parameter	Estimate	Standard Error	95.0% Normal CI Lower	Upper
Location	5.8685	0.1061	5.6605	6.0765
Scale	0.42318	0.07909	0.29339	0.61039

Log-Likelihood = -96.776

Goodness-of-Fit
Anderson-Darling (adjusted) = 3.7272

Characteristics of Distribution

	Estimate	Standard Error	95.0% Normal CI Lower	Upper
Mean(MTTF)	386.8457	43.3671	310.5377	481.9048
Standard Deviation	171.3172	45.0058	102.3732	286.6921
Median	353.7122	37.5405	287.2826	435.5024
First Quartile(Q1)	265.8813	31.2546	211.1682	334.7706
Third Quartile(Q3)	470.5569	56.4699	371.9310	595.3355
Interquartile Range(IQR)	204.6755	45.3780	132.5405	316.0699

Table of Percentiles

Percent	Percentile	Standard Error	95.0% Normal CI Lower	Upper
1	132.1596	27.7566	87.5641	199.4670
5	176.3389	29.2299	127.4246	244.0298
10	205.6450	29.7888	154.8163	273.1615
50	353.7122	37.5405	287.2826	435.5024
90	608.3897	90.4263	454.6381	814.1378
95	709.4992	120.6124	508.4527	990.0411
99	946.6760	203.3082	621.4372	1442.134

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