Phase 1 Phase 2

5. Phases 1 and 2: Condensing Atmosphere and Thermal Cycling

5.1 Introduction. The test matrix in Figure 1.2 shows 160 LRSTF PWAs scheduled for exposure to 10 cycles in a condensing atmosphere (CA) chamber. Due to the size of the wiring harness needed for the interface of the LRSTF PWAs with the ATS, all LRSTF PWAs could not be subjected to in-situ testing simultaneously. Rather, the CA test was conducted by inserting two PWAs at a time into a small test chamber. Randomization procedures were used to select two PWAs for each test. Following Pre-test, these PWAs were tested in-situ during Cycles 1, 4, 7, and 10. A Post-test of the PWAs was completed following the CA test. Figure 5.1 shows the temperature and humidity profiles for one cycle of the CA test, which lasts 50 to 55 *min*. The CA test profile is summarized as follows.

Apply electrical bias to the PWAs.

1. Begin with PWAs at 25°*C* and 40% RH
2. Lower the temperature to -10°*C* over a period of 7 *min*—when the temperature reaches -10°*C*, discontinue the humidity
3. Stabilize the PWAs at -10°*C* and 0% RH for 15 *min*
4. Warm the PWAs to 25°*C* over a period of 3 *min*
5. At 5°*C*, turn humidity on to 99% to ensure maximum wetness
6. Test the PWAs at 25°*C* over a period of 25 to 30 min
7. Discontinue the humidity
8. Lower the temperature to -10°*C* over a period of 7 *min*
9. Steps 3 to 8 are repeated 10 times. Electrical performance measurements are recorded during Cycles 1, 4, 7, and 10

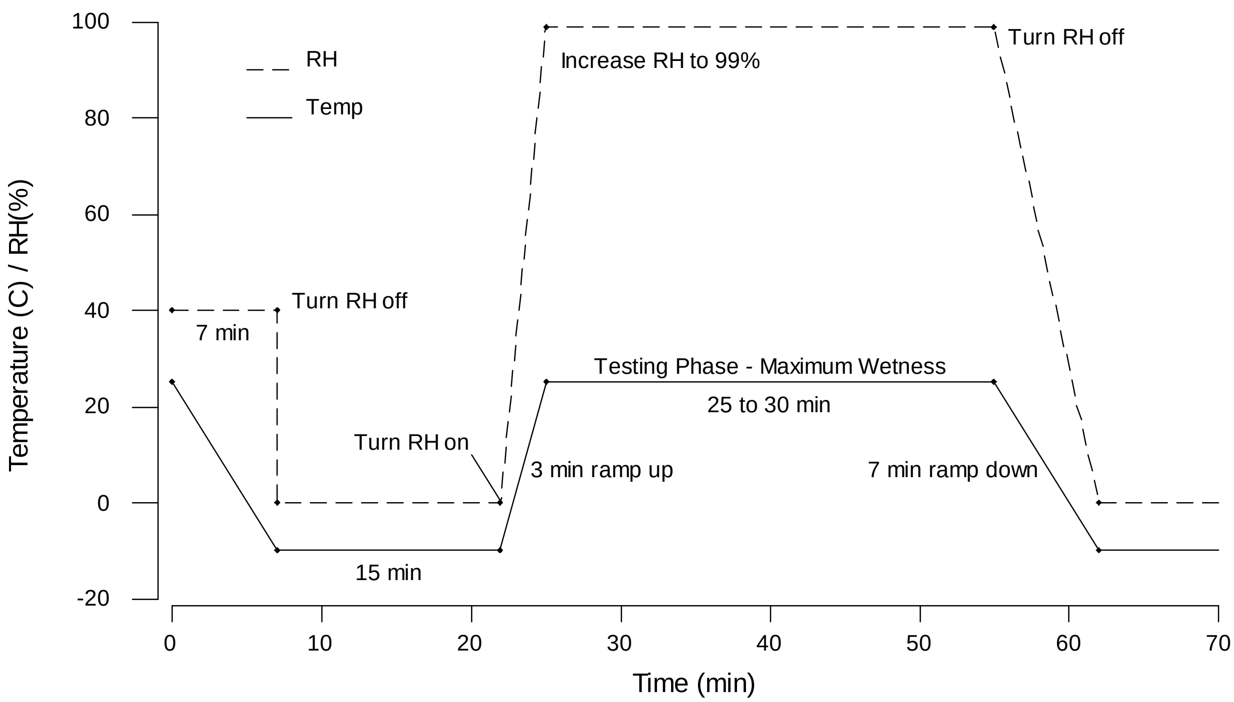

Figure 5.1 Temperature and Humidity Profiles for One Cycle of the Condensing Atmosphere Test

Following the CA test, the PWAs were subjected to 500 thermal cycles. Figure 5.2 shows the temperature profile for one thermal cycle (TC). The TC test profile is summarized as follows:

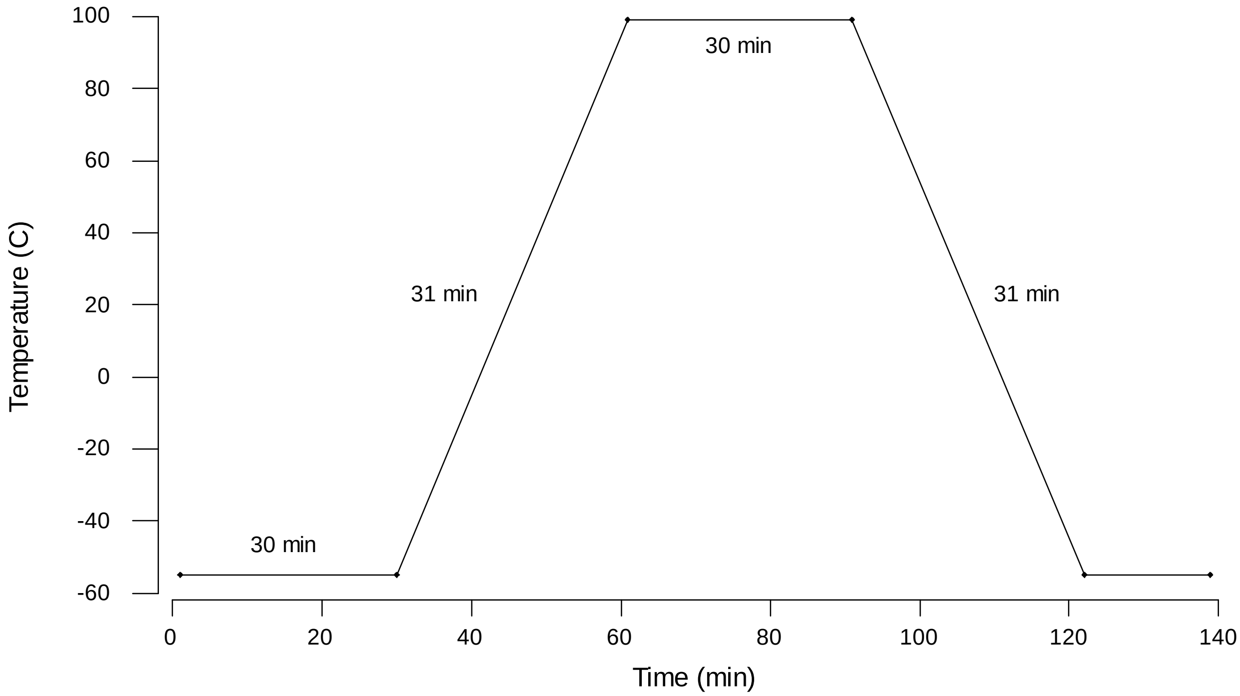

Figure 5.2 Temperature Profile for One Thermal Cycle

1. Lower the chamber temperature to -55°*C* at a rate of 5°*C*/*min*
2. Maintain the temperature at -55°*C* for 30 *min*
3. Raise the temperature to 100°*C* at a rate of 5°*C*/*min*
4. Maintain the temperature at 100°*C* for 30 *min*
5. Steps 1 to 4 are repeated 500 times

One complete thermal cycle takes 122 *min*. The PWAs were tested after 250TC and 500TC.

As was true of the previous environmental tests, the 40 urethane PWAs were added to the test matrix after the environmental tests were completed for uncoated, parylene, and silicone coated PWAs. In addition to be tested several months after the other PWAs, the urethane PWAs came from a second build of LRSTF PWAs. These facts should be kept in mind when interpreting the urethane results as effects apparently due to urethane, could be reflecting different test times or differences in builds or batches of components. There is no way to know for sure.

5.2 Overview of Test Results. Each of the 160 PWAs used in the CA-TC test sequence was tested eight times. These test times are summarized in the following four groups.

1. Pre-test to determine initial electrical functionality after processing
2. In-situ test during Cycles 1, 4, 7, and 10 of the CA test
3. Post-test following the CA test to determine a baseline for HF TLC circuits prior to TC testing
4. After 250 and after 500 thermal cycles

At each test time, 160×23 = 3680 electrical test measurements were recorded. An overview of the test results for each of the four testing groups is now given. Detailed results of the electrical performance for each of the 23 circuits listed in Table 1.1 appear in Sections 5.3 to 5.9 with a summary and conclusions given in Section 5.10.

Pre-test. Electrical measurements are compared to the JTP acceptance criteria given in Table 1.1 at each test time. These acceptance criteria require a comparison to Pre-test for 11 of the 23 electrical circuits (#'s 1, 2, 5, 6, 13-17, 22, and 23). This group of circuits was compared with historical performance data while the remaining 23-11 = 12 circuits were compared directly to the JTP acceptance criterion.

The remaining 12 electrical circuits produced 12 × 160 = 1920 Pre-test measurements. Nine anomalies in these measurements did not meet the JTP acceptance criterion. Four of these occurred on a single PWA. Seven of the nine anomalies occurred for leakage measurements (circuits 18-21 in Table 1.1). The remaining two anomalies occurred for HVLC PTH (circuit 3 in Table 1.1) and HF PTH f(-3dB) (circuit 8 in Table 1.1).

In addition to these nine anomalies, four PWAs produced measurements outside the norm observed for the HSD PTH and SMT circuits (circuits 5 and 6 in Table 1.1). Two of these four PWAs did not give a response for either HSD PTH or HSD SMT at Pre-test or at subsequent test times. These results are not test related, but are likely due to either a damaged component or trace (this occurs frequently with HSD circuits). The other PWAs produced high readings for HSD PTH and HSD SMT at Pre-test but returned to normal readings at subsequent test times, which indicates a possible problem with the Pre-test measurements.

The percentage of PWAs meeting the JTP acceptance criterion at Pre-test was (1920 - 9)/(12 × 160) = 99.5% for the 12 circuits for which such comparisons could be made.

In-Situ Testing During Cycles 1, 4, 7, and 10 of the Condensing Atmosphere Test. Each of the 23 circuits on the LRSTF PWA was tested 4 cycles × 160 PWAs = 640 times during the CA test. Six of these 23 circuits successfully met the JTP test criterion throughout the CA test. Ten additional circuits had a total of 86 anomalies. These 16 circuits were tested a total of 4 cycles × 11 circuits × 160 PWAs = 7040 times giving an overall success rate of 6954/7040 = 98.8%. The anomaly frequencies for these 16 circuits are summarized as follows.

Number of Anomalies	Circuit Number in Table 1.1
0	2, 7, 9, 11, 22, 23
1	10
2	8
3	5
4	1
≥ 8	6, 12, 13, 14, 15, 16

The remaining seven circuits (3, 4, 17, 18, 19, 20, and 21 in Table 1.1) experienced a total of 1412 anomalies relative to the JTP acceptance criterion out of 4 cycles × 7 circuits × 160 PWAs = 4480 tests. Thus, the success rate for these seven circuits was only 3068/4480 = 68.5%.

Several tables have been constructed to assist in interpreting the test results for the CA test. Tables 5.1 to 5.4 tabulate all anomalies for Cycles 1, 4, 7, and 10, respectively, by surface finish, flux, and coating status. These tables make it apparent that most of the anomalies are associated with PWAs without conformal coating, although coated PWAs also had many anomalies. The anomalies identified in Tables 5.1 to 5.4 are categorized by coating status as follows.

Cycle	No Coating	Parylene	Silicone	Urethane	Totals
1	166	40	22	80	308
4	196	43	40	100	379
7	211	47	28	108	394
10	225	46	34	117	422

It is readily apparent that the number of anomalies is significantly higher for uncoated PWAs than for coated PWAs at each test time. Silicone had the fewest anomalies followed by parylene and urethane.

PWAs processed with LR flux had significantly more anomalies throughout the CA test than those processed with WS flux. The anomalies in Tables 5.1 to 5.4 are categorized by flux type as follows.

Cycle	LR	WS	Totals
1	178	130	308
4	215	164	379
7	225	169	394
10	236	186	422

Table 5.1 Tabulation of the 308 Test Measurements Over All 23 Electrical Circuits That Did Not Meet the JTP Acceptance Criterion During Cycle 1 of the CA Test

Surface Finish	Flux	No Coating	Parylene	Silicone	Urethane	Totals
HASL (103)	**LR**	35	14	7	12	68
	WS	17	1	2	15	35
Benzimidazole (66)	**LR**	19	2	1	12	34
	WS	15	4	3	10	32
Immersion Ag (66)	**LR**	24	3	3	8	38
	WS	14	7		7	28
Immersion Au/Pd (73)	**LR**	27		4	7	38
	WS	15	9	2	9	35
LR = 178, WS = 130	**Totals**	166	40	22	80	308

Table 5.2 Tabulation of the 379 Test Measurements Over All 23 Electrical Circuits That Did Not Meet the JTP Acceptance Criterion During Cycle 4 of the CA Test

Surface Finish	Flux	No Coating	Parylene	Silicone	Urethane	Totals
HASL (115)	**LR**	35	11	8	17	71
	WS	22		7	15	44
Benzimidazole (78)	**LR**	21	2	1	16	40
	WS	20	4	4	10	38
Immersion Ag (96)	**LR**	28	4	12	11	55
	WS	19	10		12	41
Immersion Au/Pd (90)	**LR**	33	2	6	8	49
	WS	18	10	2	11	41
LR = 215, WS = 164	**Totals**	196	43	40	100	379

Table 5.3 Tabulation of the 394 Test Measurements Over All 23 Electrical Circuits That Did Not Meet the JTP Acceptance Criterion During Cycle 7 of the CA Test

Surface Finish	Flux	No Coating	Parylene	Silicone	Urethane	Totals
HASL (211)	**LR**	35	12	8	18	73
	WS	24		3	15	42
Benzimidazole (47)	**LR**	22	3	1	18	44
	WS	22	4	3	10	39
Immersion Ag (28)	**LR**	29	6	6	11	52
	WS	25	10		12	47
Imm. Au/Pd (108)	**LR**	35	3	6	12	56
	WS	19	9	1	12	41
LR = 225, WS = 169	**Totals**	211	47	28	108	394

Table 5.4 Tabulation of the 422 Test Measurements Over All 23 Electrical Circuits That Did Not Meet the JTP Acceptance Criterion During Cycle 10 of the CA Test

Surface Finish	Flux	No Coating	Parylene	Silicone	Urethane	Totals
HASL (225)	**LR**	36	12	8	18	74
	WS	25		4	16	45
Benzimidazole (46)	**LR**	22	3	1	17	43
	WS	25	4	5	11	45
Immersion Ag (34)	**LR**	35	6	7	13	61
	WS	25	10		12	47
Imm. Au/Pd (117)	**LR**	35	2	7	14	58
	WS	22	9	2	16	49
LR = 236, WS = 186	**Totals**	225	46	34	117	422

Table 5.5 Tabulation of the 107 Test Measurements Over All 23 Electrical Circuits That Did Not Meet the JTP Acceptance Criterion after Post-test

Surface Finish	Flux	No Coating	Parylene	Silicone	Urethane	Totals
HASL (22)	**LR**	5	1	4	2	12
	WS	2	2	5	1	10
Benzimidazole (28)	**LR**	3	8	4	2	17
	WS	1	5	1	4	11
Immersion Ag (28)	**LR**	4	3	3	1	11
	WS	6	5	4	2	17
Immersion Au/Pd (29)	**LR**	4	5	1	2	12
	WS	7	3	4	3	17
LR = 52, WS = 55	**Totals**	32	32	26	17	107

Table 5.6 Tabulation of the 100 Test Measurements Over All 23 Electrical Circuits That Did Not Meet the JTP Acceptance Criterion after 250 Thermal Cycles

Surface Finish	Flux	No Coating	Parylene	Silicone	Urethane	Totals
HASL (10)	**LR**		2		4	6
	WS		3	1		4
Benzimidazole (5)	**LR**		4			4
	WS	1				1
Immersion Ag (14)	**LR**	2			1	3
	WS	5	4	1	1	11
Immersion Au/Pd (13)	**LR**			2	2	4
	WS	4	1	3	1	9
LR = 17, WS = 25	**Totals**	12	14	7	9	42

Table 5.7 Tabulation of the 30 Test Measurements Over All 23 Electrical Circuits That Did Not Meet the JTP Acceptance Criterion after 500 Thermal Cycles

Surface Finish	Flux	No Coating	Parylene	Silicone	Urethane	Totals
HASL (4)	**LR**		1		1	2
	WS			2		2
Benzimidazole (3)	**LR**		2	0	1	3
	WS					
Immersion Ag (13)	**LR**	2				2
	WS	3	2	3	3	11
Immersion Au/Pd (10)	**LR**					
	WS	1	1	5	3	10
LR = 7, WS = 23	**Totals**	6	6	10	8	30

The number of anomalies in Tables 5.1 to 5.4 are categorized by surface finish as follows.

Cycle	HASL	Benzi	Imm Ag	Imm Au/Pd	Totals
1	103	66	66	73	308
4	115	78	96	90	379
7	115	83	99	97	394
10	119	88	108	107	422

Benzimidazole had the fewest anomalies throughout the CA test while HASL had the most. However, the actual number of PWAs with anomalies ranged from 26 to 32 for each surface finish with the following averages throughout the CA test: HASL (31.0), benzimidazole (28.5), immersion Ag (29.3), and immersion Au/Pd (29.8).

Approximately 95% of the anomalies noted in Tables 5.1 to 5.4 were associated with the following seven circuits (divisors for the yield have been adjusted to eliminate three HSD anomalies that occurred at Pre-test, since these anomalies were likely due to damaged components or traces and therefore cannot be attributed to the CA test).

Circuit	Cycle 1	Cycle 4	Cycle 7	Cycle 10
HVLC PTH	26	32	35	42
HVLC SMT	71	84	83	90
HF TLC RNR	24	28	32	37
10-Mil Pads	30	44	45	46
PGA-A	27	38	44	46
PGA-B	27	36	39	39
Gull Wing	85	95	93	99
Totals	290/305 (95.1%)	357/376 (94.9%)	371/391 (94.9%)	399/419 (95.2%)

Tables 5.8 to 5.14 provide a breakout of the anomalies for these seven circuits by coating status, surface finish, and flux for each test time. These tables are helpful in tracking the changes in circuit behavior over time. The influences of coating status, flux, and surface finish on the anomalies in Tables 5.8 to 5.14 are summarized as follows for Cycle 10:

HVLC PTH (42 anomalies)

- Coating: none (20), parylene (8), silicone (2), urethane (12)—these counts are significantly different
- LR flux (30) had significantly more anomalies than WS flux (12)
- No difference in the number of anomalies among the surface finishes: HASL (12), benzimidazole (9), immersion Ag (11), immersion Au/Pd (10)

HVLC SMT (89 anomalies)

- Coating: none (40), parylene (6), silicone (8), urethane (35)—these counts are significantly different
- LR flux (45) does not differ from WS flux (44)

- No difference in the number of anomalies among the surface finishes: HASL (24), benzimidazole (23), immersion Ag (22), immersion Au/Pd (21)

HF TLC RNR (37 anomalies)

- Coating: none (31), parylene (1), silicone (0), urethane (5)—these counts are significantly different
- LR flux (16) does not differ from WS flux (21)
- No difference in the number of anomalies among the surface finishes: HASL (11), benzimidazole (5), immersion Ag (10), immersion Au/Pd (11)

10-Mil Pads (46 anomalies)

- Coating: none (39), parylene (2), silicone (3), urethane (2)—these counts are significantly different
- LR flux (26) does not differ from WS flux (20)
- No difference in the number of anomalies among the surface finishes: HASL (13), benzimidazole (10), immersion Ag (12), immersion Au/Pd (11)

PGA-A (46 anomalies)

- Coating: none (31), parylene (11), silicone (0), urethane (4)—these counts are significantly different
- LR (25) does not differ from WS (21)
- No difference in the number of anomalies among the surface finishes: HASL (13), benzimidazole (6), immersion Ag (14), immersion Au/Pd (13)

PGA-B (38 anomalies)

- Coating: none (19), parylene (17), silicone (0), urethane (2)—these counts are significantly different
- LR (26) has significantly more anomalies than WS (12)
- No difference in the number of anomalies among the surface finishes: HASL (11), benzimidazole (7), immersion Ag (12), immersion Au/Pd (8)

Gull Wing (99 anomalies)

- Coating: none (39), parylene (1), silicone (19), urethane (40)—these counts are significantly different
- LR (51) does not differ from WS (48)
- No difference in the number of anomalies among the surface finishes: HASL (28), benzimidazole (23), immersion Ag (23), immersion Au/Pd (25)

Post-test. Post-test measurements were made following the CA test to determine the status of the electrical circuitry on the LRSTF PWA. That is, the CA test may have permanently altered the responses of some of the 23 circuits on the LRSTF PWA or may have caused some hard failures. In view of these possible changes, the Post-test measurements provide a statistically sound basis for quantifying the impact of changes due to the subsequent TC test.

Post-test measurements were compared to the JTP acceptance criterion, which identified 107 anomalies. These anomalies are summarized in Table 5.5 by surface finish, coating status, and flux type. A comparison of Tables 5.4 and 5.5 shows the number of anomalies decreased from 422 during Cycle 10 of the CA test to 107 at Post-test. Uncoated and parylene coated PWAs each had 32 anomalies at Post-test, followed by silicone with 26 and urethane with 17. The number of anomalies decreased for all but one of the seven problem circuits at Post-test relative to Cycle 10 as shown in the following summary.

Circuit	Cycle 10	Post-test
HVLC PTH	42	0
HVLC SMT	90	5
HF TLC RNR	37	45
10-Mil Pads	46	2
PGA-A	46	0
PGA-B	39	1
Gull Wing	99	27
Totals	399	80

Thirty-seven of the Post-test anomalies for these seven circuits were also anomalies during Cycle 10, but there were 43 new anomalies. Of these 43 new anomalies, 30 were associated with HF TLC RNR. The HF TLC RNR is recorded at the null point of the response function (see Figure 2.3). This measurement is made in a vertical

Table 5.8 Anomaly Summary for Condensing Atmosphere—Thermal Cycling Test Sequence for HVLC PTH

Coating	Surface Finish	Flux	Pre-Test	Cycle 1	Cycle 4	Cycle 7	Cycle 10	Post-Test	250 TC	500 TC
None	HASL	LR		5	5	5	5			
		WS		1			1			
	Benzi	LR		2	2	2	3			
		WS				1	1			
	Imm Ag	LR		4	4	4	5			
		WS								
	Imm Au	LR	1	5	5	5	5			
		WS								
	Totals		1	17	16	17	20	0	0	0
Parylene	HASL	LR		2	2	2	2			
		WS								
	Benzi	LR								
		WS		2	3	2	2			
	Imm Ag	LR					1			
		WS			1	1	1			
	Imm Au	LR				1	1			
		WS		1	1	1	1			
	Totals		0	5	7	7	8	0	0	0
Silicone	HASL	LR								
		WS								
	Benzi	LR								
		WS					1			
	Imm Ag	LR			2	1	1			
		WS								
	Imm Au	LR								
		WS								
	Totals		0	0	2	1	2	0	0	0
Urethane	HASL	LR		1	3	3	3			
		WS		1	1	1	1			
	Benzi	LR				1	1			
		WS					1			
	Imm Ag	LR			1	1	2			
		WS			1	1	1			
	Imm Au	LR		1		1	1			
		WS		1		2	2			
	Totals		0	4	7	10	12	0	0	0

Table 5.9 Anomaly Summary for Condensing Atmosphere—Thermal Cycling Test Sequence for HVLC SMT

Coating	Surface Finish	Flux	Pre-Test	Cycle 1	Cycle 4	Cycle 7	Cycle 10	Post-Test	250 TC	500 TC
None	HASL	LR		5	5	5	5			
		WS		5	5	5	5			
	Benzi	LR		5	5	5	5			
		WS		5	5	5	5			
	Imm Ag	LR		5	5	5	5	1	1	1
		WS		5	4	5	5			
	Imm Au	LR		5	5	5	5			
		WS		5	5	5	5			
	Totals		0	40	39	40	40	1	1	1
Parylene	HASL	LR		1	1	2	2			
		WS								
	Benzi	LR						1	1	1
		WS			1	1	1			
	Imm Ag	LR								
		WS		1	1	1	1	1		
	Imm Au	LR						1		
		WS		2	2	2	2			
	Totals		0	4	5	6	6	3	1	1
Silicone	HASL	LR		2	2	2	2			
		WS			1					
	Benzi	LR								
		WS		1	1	1	2			
	Imm Ag	LR		2	2	1	2			
		WS								
	Imm Au	LR		1	3	3	3			
		WS						1		
	Totals	0	0	6	9	7	8	1	0	0
Urethane	HASL	LR		3	5	5	5			
		WS		5	5	4	5			
	Benzi	LR		2	5	5	5			
		WS		5	5	5	5			
	Imm Ag	LR		2	3	3	4			
		WS		1	5	3	5			
	Imm Au	LR			1	2	2			
		WS		2	3	3	4			
	Totals		0	20	32	30	35	0	0	0

Table 5.10 Anomaly Summary for Condensing Atmosphere—Thermal Cycling Test Sequence for HF TLC RNR

Coating	Surface Finish	Flux	Pre-Test	Cycle 1	Cycle 4	Cycle 7	Cycle 10	Post-Test	250 TC	500 TC
None	HASL	LR		5	5	4	5	4		
		WS		3	3	5	5	2		
	Benzi	LR						1		
		WS		1	4	3	4	1		
	Imm Ag	LR			2	2	3	1		1
		WS		2	3	4	5	1	1	
	Imm Au	LR		2	3	4	4	1		
		WS		3	3	5	5	2		
	Totals		0	16	23	27	31	13	1	1
Parylene	HASL	LR							1	
		WS						1		
	Benzi	LR		1			1	4		
		WS						3		
	Imm Ag	LR						2		
		WS						2		
	Imm Au	LR						2		
		WS						1		
	Totals		0	1	0	0	1	15	1	0
Silicone	HASL	LR						2		
		WS			1					
	Benzi	LR						3		
		WS						1		
	Imm Ag	LR			1			2		
		WS						1		
	Imm Au	LR								
		WS						2		1
	Totals		0	0	2	0	0	11	0	1
Urethane	HASL	LR		2	1	1	1	2	2	
		WS						1		
	Benzi	LR						1		
		WS								
	Imm Ag	LR		1	1	1	1	1	2	
		WS		1	1	1	1	1		1
	Imm Au	LR		1		1	1			
		WS		2		1	1			
	Totals		0	7	3	5	5	6	3	1

Table 5.11 Anomaly Summary for Condensing Atmosphere—Thermal Cycling Test Sequence for 10-Mil Pads

Coating	Surface Finish	Flux	Pre-Test	Cycle 1	Cycle 4	Cycle 7	Cycle 10	Post-Test	250 TC	500 TC
None	HASL	LR		5	5	5	5			
		WS		2	5	5	5			
	Benzi	LR		4	4	5	5			
		WS		1	4	5	5			
	Imm Ag	LR		5	5	5	5			
		WS		2	4	5	5			
	Imm Au	LR		5	5	5	5			
		WS		2	4	3	4	2	1	1
	Totals		0	26	36	38	39	2	1	1
Parylene	HASL	LR		1	1	1	1			
		WS		1						
	Benzi	LR								
		WS								
	Imm Ag	LR								
		WS				1				
	Imm Au	LR								
		WS		1	1	1	1			
	Totals		0	3	2	3	2	0	0	0
Silicone	HASL	LR		1	2	2	2			
		WS			1					
	Benzi	LR								
		WS								
	Imm Ag	LR			2	1	1			
		WS								
	Imm Au	LR								
		WS								
	Totals		0	1	5	3	3	0	0	0
Urethane	HASL	LR								
		WS								
	Benzi	LR								
		WS								
	Imm Ag	LR			1	1	1			
		WS								
	Imm Au	LR					1			
		WS								
	Totals		0	0	1	1	2	0	0	0

Table 5.12 Anomaly Summary for Condensing Atmosphere—Thermal Cycling Test Sequence for PGA-A

Coating	Surface Finish	Flux	Pre-Test	Cycle 1	Cycle 4	Cycle 7	Cycle 10	Post-Test	250 TC	500 TC
None	HASL	LR		5	5	5	5			
		WS		1	2	3	3			
	Benzi	LR		2	3	3	3			
		WS		1	1	2	3			
	Imm Ag	LR		3	5	5	5			
		WS		2	2	5	4			
	Imm Au	LR	1	3	5	5	5			
		WS		1		1	3			
	Totals		1	18	23	29	31	0	0	0
Parylene	HASL	LR		4	3	3	3			
		WS								
	Benzi	LR								
		WS								
	Imm Ag	LR		1	1	3	2			
		WS		1	3	2	3			
	Imm Au	LR			1	1				
		WS		2	3	3	3			
	Totals		0	8	11	12	11	0	0	0
Silicone	HASL	LR								
		WS								
	Benzi	LR								
		WS								
	Imm Ag	LR			1					
		WS								
	Imm Au	LR								
		WS								
	Totals		0	0	1	0	0	0	0	0
Urethane	HASL	LR		1	1	1	1			
		WS			1	1	1			
	Benzi	LR								
		WS								
	Imm Ag	LR								
		WS				1				
	Imm Au	LR					1			
		WS			1		1			
	Totals		0	1	3	3	4	0	0	0

Table 5.13 Anomaly Summary for Condensing Atmosphere—Thermal Cycling Test Sequence for PGA-B

Coating	Surface Finish	Flux	Pre-Test	Cycle 1	Cycle 4	Cycle 7	Cycle 10	Post-Test	250 TC	500 TC
None	**HASL**	**LR**		**5**	**5**	**5**	**5**			
		WS			**1**	**1**	**1**			
	Benzi	**LR**		**2**	**2**	**2**	**1**			
		WS		**1**	**1**	**1**	**2**			
	Imm Ag	**LR**		**3**	**3**	**4**	**4**			
		WS			**2**	**1**	**1**			
	Imm Au	**LR**	**1**	**2**	**3**	**5**	**5**			
		WS								
	Totals		**1**	**13**	**17**	**19**	**19**	**0**	**0**	**0**
Parylene	**HASL**	**LR**	**1**	**3**	**4**	**4**	**4**			
		WS								
	Benzi	**LR**		**1**	**2**	**2**	**2**			
		WS		**1**	**1**	**1**	**1**			
	Imm Ag	**LR**		**2**	**3**	**3**	**3**			
		WS		**4**	**4**	**4**	**4**			
	Imm Au	**LR**			**1**	**1**	**1**			
		WS	**1**	**2**	**2**	**2**	**2**			
	Totals		**2**	**13**	**17**	**17**	**17**	**0**	**0**	**0**
Silicone	**HASL**	**LR**								
		WS								
	Benzi	**LR**								
		WS								
	Imm Ag	**LR**			**1**					
		WS								
	Imm Au	**LR**								
		WS						**1**		
	Totals		**0**	**0**	**1**	**0**	**0**	**1**	**0**	**0**
Urethane	**HASL**	**LR**								
		WS		**1**	**1**	**1**	**1**			
	Benzi	**LR**				**1**	**1**			
		WS								
	Imm Ag	**LR**								
		WS				**1**				
	Imm Au	**LR**								
		WS								
	Totals		**0**	**1**	**1**	**3**	**3**	**0**	**0**	**0**

Table 5.14 Anomaly Summary for Condensing Atmosphere—Thermal Cycling Test Sequence for the Gull Wing

Coating	Surface Finish	Flux	Pre-Test	Cycle 1	Cycle 4	Cycle 7	Cycle 10	Post-Test	250 Cycles	500 Cycles
None	HASL	LR		5	5	5	5			
		WS		5	5	5	5			
	Benzi	LR		4	5	5	5			
		WS	1	5	5	5	5			
	Imm Ag	LR		4	4	4	4	1	1	1
		WS		3	4	5	5	3	2	
	Imm Au	LR	1	5	5	5	5	1		
		WS		4	5	5	5	3	2	
	Totals		2	35	38	39	39	8	5	1
Parylene	HASL	LR		3						
		WS								
	Benzi	LR						1		
		WS						1		
	Imm Ag	LR								
		WS		1	1	1	1	2	2	2
	Imm Au	LR						1		
		WS								
	Totals		0	4	1	1	1	5	2	2
Silicone	HASL	LR		4	4	4	4			
		WS		2	3	3	4	1		
	Benzi	LR		1	1	1	1	1		
		WS		2	2	2	2			
	Imm Ag	LR	1	1	3	3	3			
		WS						2	1	1
	Imm Au	LR		3	3	3	4			
		WS		1	1		1			
	Totals		1	14	17	16	19	4	1	1
Urethane	HASL	LR		2	4	5	5			
		WS		5	5	5	5			
	Benzi	LR		5	5	5	5	1		
		WS		5	5	5	5	4		
	Imm Ag	LR		4	5	5	5			
		WS		5	5	3	5			
	Imm Au	LR		3	5	5	5	2		
		WS		3	5	4	5	3		1
	Totals		0	32	39	37	40	10	0	1

direction and is subject to great variability, which makes repeatability difficult for this circuit. In view of the number of anomalies for the HF TLC RNR circuits at Post-test, the subsequent TC measurements were compared to Post-test rather than Pre-test to ensure a statistical basis for determining the effect of TC.

The remaining 23 - 7 = 16 electrical circuits at Post-test had a total of 27 anomalies. Twenty-three of these 27 anomalies were associated with HF TLC 50Mhz. There were no significant effects differences due to surface finish, flux type, or coating status for these 23 HF TLC 50MHz anomalies.

250 and 500 Thermal Cycles. Test measurements were made after 250 and 500 thermal cycles. Each cycle lasted 122 *min* and followed the profile given in Figure 5.2. The JTP acceptance criterion require a comparison to Pre-test results for circuits 1, 2, 5, 6, 13-17, 22, and 23. However, as previously mentioned, the HF TLC responses (circuits 13-17 in Table 1.1) were compared to Post-test results to ensure a statistically sound basis for quantifying changes due to TC.

The 250TC measurements were compared to the JTP acceptance criterion and 42 anomalies were identified. These anomalies are summarized in Table 5.6 by surface finish, coating status, and flux type. Seventeen of these 42 anomalies carried over from Post-test, while 25 were new.

The 500TC measurements had 30 anomalies when compared to the JTP acceptance criterion. These anomalies are summarized in Table 5.7 by surface finish, coating status, and flux type. Sixteen of these 30 anomalies carried over from 250TC, while 14 were new.

A comparison of Tables 5.5, 5.6, and 5.7 shows that the number of anomalies decreased from 107 at Post-test to 42 at 250TC and to 30 at 500TC. After 500TC, uncoated PWAs and parylene coated PWAs each had six anomalies, silicone had 10, and urethane had eight.

There was a dramatic decrease in the number of anomalies during the TC test for the seven circuits that experienced the most anomalies during Cycle 10. Much of this decrease is a direct result of comparing the HF TLC responses to Post-test rather than Pre-test. The number of anomalies for these seven circuits is summarized below. All anomalies in the following summary at 250TC were carry overs from Post-Test as were six of the 11 anomalies at 500TC.

Circuit	**Cycle 10**	**Post-test**	**250TC**	**500TC**
HVLC PTH	42	0	0	0
HVLC SMT	90	5	2	2
HF TLC RNR	37	45	5	3
10-Mil Pads	46	2	1	1
PGA-A	46	0	0	0
PGA-B	39	1	0	0
Gull Wing	99	27	8	5
Totals	399	80	16	11

Results are now presented by major circuit type for each test environment.

5.3 HCLV Circuitry. The JTP acceptance criterion for HCLV PTH and HCLV SMT (responses 1 and 2 in Table 1.1) are based on the following differences between test measurements.

Delta 1 = Cycle 1 - Pre-test
Delta 4 = Cycle 4 - Pre-test
Delta 7 = Cycle 7 - Pre-test
Delta 10 = Cycle 10 - Pre-test

Delta Post = Post-test - Pre-test
Delta 250 = 250 TC Cycles - Pre-test
Delta 500 = 500 TC Cycles - Pre-test

Specifically, these differences are not to exceed 0.50V. Pre-test measurements and these differences (deltas) were analyzed using the GLM in Equation 1.1. The base case for this GLM was defined in Section 1.9 as HASL surface finish without conformal coating and processed with LR flux.

Table G.1 in Appendix G shows the coefficients that are significantly different from the base case for the HCLV PTH circuit. Summaries similar to Table G.1 have been constructed to summarize the GLM results for each of the 23 electrical responses for the LRSTF PWA. Since each summary table fills one page, these tables have been placed in Appendix G for ease of reference and to improve the readability of this section. Subsequent discussions of the GLM results for the remaining circuitry make reference to Tables G.2 to G.23. The model R^2s in these tables are summarized as follows for each test time.

Circuit	Pre-test	Cycle 1	Cycle 4	Cycle 7	Cycle10	Post-test	250TC	500TC
HCLV PTH	30.3%	2.4%	2.6%	18.0%	3.7%	1.1%	5.7%	4.2%
HCLV SMT	15.2%	12.8%	14.8%	6.3%	4.2%	4.6%	12.9%	17.6%

These low R^2 values imply that the experimental parameters did not differ significantly from the base case in terms of their impact on the HCLV PTH and HCLV SMT circuits. That is, there is no practical difference from the base case voltage measurements due to surface finishes, coating status (i.e., no coating, parylene, or silicone), or flux type.

Displays. Boxplots for the condensing atmosphere—thermal cycling test sequence have been created in a 47-page Appendix H for each of the 23 electrical responses listed in Table 1.1. Figure H.1 presents boxplots (see Section 1.10) for the HCLV PTH voltage measurements for the HASL surface finish. These measurements are plotted versus test time with LR flux results on the left and WS results on the right. Four overlapping boxplots are used at each test time to show the effect of coating status. Figures H.2, H.3, and H.4 give similar results for benzimidazole, immersion Ag, and immersion Au/Pd, respectively. Note that the measurements exhibit approximately the same amount of variability throughout and that the voltages in these figures vary over a reasonably small range. The urethane coated PWAs run about 0.1V higher throughout the graphs. Similar boxplots of can be generated for each of the Deltas defined above, but these graphs are not included in Appendix H since the graphs of the raw voltage measurements occupy 47 pages. Boxplots of the deltas overlapped throughout and did not exhibit any strong effects due to surface finish, coating status, or flux time. This behavior is consistent with the results of the GLM analyses.

The corresponding boxplots for HCLV SMT appear in Figures H.5 to H.8. Theses graphs show that urethane coated PWAs do not exhibit any increase in voltage as was the case for HCLV PTH. As with HCLV PTH, these boxplots overlap throughout and did not exhibit any strong effects due to surface finish, coating status, or flux time. This behavior is consistent with the results of the GLM analyses.

Comparison to JTP Acceptance Criterion. The JTP acceptance criterion for HCLV is $\Delta V < 0.50V$. The number of anomalies for HCLV PTH during Cycles 1, 4, 7, and 10, were 1, 2, 1, and 0, respectively. There was one HVLC PTH anomaly at Post-test, two after 250TC, and one after 500TC. All of these anomalies were just above the upper limit of 0.50V at 0.52V and not serious enough to be of concern. There were two anomalous HCLV SMT measurements (1.08V and 1.12V) that exceeded the JTP acceptance criterion at 500TC, but were not serious enough to be of concern.

5.4 HVLC Circuitry. The JTP acceptance criterion for HVLC PTH and HVLC SMT (responses 3 and 4 in Table 1.1) require these measurements to be between 4µA and 6µA (there are no comparisons to Pre-test for HVLC circuits). The summary given in Section 5.2 indicated multiple anomalies associated with the HVLC measurements starting at Cycle 1 of the CA test. Some of these anomalies were quite large relative to the other observations. These large, or outlying, observations can unduly influence the least squares calculations used to estimate the coefficients in the GLM. A logarithmic transformation of the data can be used to ameliorate the effect of these large observations on the least squares estimates. Thus, all GLM analyses for HVLC were based on the logs of the measurements. Therefore, the coefficients are interpreted in terms of logarithms rather than the original scale. The JTP acceptance criterion for the HVLC circuits are from 0.60 to 0.78 when expressed in terms of logarithms since $10^{0.60}$ = 4µA and $10^{0.78}$ = 6µA.

Results of the GLM analyses for HVLC PTH and HVLC SMT circuits are given in Tables 5.15 and 5.16 (also Tables G.3 and G.4 in Appendix G), respectively. The penultimate rows in these tables show the model R^2 values, which are summarized as follows.

Circuit	Pre-test	Cycle 1	Cycle 4	Cycle 7	Cycle10	Post-test	250TC	500TC
HVLC PTH	28.1%	45.0%	22.8%	34.6%	42.4%	38.6%	33.3%	40.0%
HVLC SMT	15.0%	57.0%	63.5%	66.0%	67.1%	18.6%	19.5%	42.5%

The coefficients in the Pre-test column of Tables 5.15 and 5.16 show that surface finish, flux, and coating status do not influence the Pre-test HVLC measurements. The GLM analyses for HVLC PTH during Cycles 1, 4, 7, and 10 of the CA test show that coating, flux, benzimidazole, and several interactions were significantly different from the base case. The GLM analyses for HVLC SMT identified all coatings as significantly different from the base

Table 5.15 Significant Coefficients for the GLM Analyses by Test Time for HVLC PTH (all analyses except Pre-test are based on logarithms)

Electrical Response: HVLC PTH	Condensing Atmosphere						Thermal Cycling	
Experimental Variables	**Pre-Test**	**Cycle 1**	**Cycle 4**	**Cycle 7**	**Cycle 10**	**Post-CA**	**250 Cycles**	**500 Cycles**
Constant	0.704	1.095	1.053	1.236	1.252	0.703	0.703	0.703
Benzimidazole		-0.392		-0.273	-0.468			
Immersion Ag		-0.053						
Immersion Au/Pd						-0.001	-0.001	-0.001
Parylene		-0.379	-0.327	-0.441	-0.517			0.001
Silicone		-0.375	-0.274	-0.385	-0.473			
Urethane	-0.004	-0.318	-0.250			-0.003	-0.003	-0.003
Flux		-0.376	-0.365	-0.529	-0.513			
Benzi*Parylene		0.381			0.440		-0.001	-0.002
Imm Ag*Parylene								
Imm Au/Pd*Parylene								
Benzi*Silicone		0.374			0.390			
Imm Ag*Silicone							-0.001	
Imm Au/Pd*Silicone								
Benzi*Urethane		0.321						
Imm Ag* Urethane				-0.42	-0.380			
Imm Au/Pd* Urethane				-0.49	-0.460	0.001	0.001	0.001
Benzi*Flux		0.382		0.274	0.530			
Imm Ag*Flux								
Imm Au/Pd*Flux								
Parylene*Flux		0.443	0.410	0.510	0.552			-0.002
Silicone*Flux		0.378	0.290	0.380	0.440			
Urethane*Flux		0.380	0.280					
Benzi*Parylene*Flux		-0.370			-0.500			0.003
Imm Ag*Parylene*Flux								
Imm Au/Pd*Parylene*Flux	0.004							
Benzi*Silicone*Flux		-0.380			-0.420			
Imm Ag*Silicone*Flux								
Imm Au/Pd*Silicone*Flux								
Benzi*Urethane*Flux		-0.390						
Imm Ag*Urethane*Flux			0.540	0.630	0.510			
Imm Au/Pd*Urethane*Flux				0.490	0.500			
Model R^2	28.1%	45.0%	22.8%	34.6%	42.4%	38.6%	33.3%	40.0%
Standard Deviation	0.003	0.128	0.258	0.259	0.205	0.005	0.001	0.001

case in addition to immersion Ag and several interactions. The predicted currents based on the GLM analyses during Cycle 10 for HVLC PTH and HVLC SMT provide more insight into the significant experimental parameters. These predictions are summarized in Tables 5.17 and 5.18, respectively.

The constant term (1.252) in Table 5.15 for Cycle 10 corresponds to a base case estimate of $10^{1.252} = 17.9$ for HVLC PTH, which is clearly outside the JTP acceptance criterion. Table 5.17 shows this same value occurring for immersion Ag with LR and no coating, for immersion Au/Pd with LR and no coating, and for HASL with LR and urethane. All other predictions are either within the JTP limits or just above the upper limit (most notably immersion Ag with urethane and either flux).

Table 5.16 Significant Coefficients for the GLM Analyses by Test Time for HVLC SMT (all analyses except Pre-test are based on logarithms)

Electrical Response: HVLC SMT	Condensing Atmosphere						Thermal Cycling	
Experimental Variables	Pre-Test	Cycle 1	Cycle 4	Cycle 7	Cycle 10	Post-CA	250 Cycles	500 Cycles
Constant	0.695	1.679	2.084	2.121	2.479	0.706	0.696	0.695
Benzimidazole		-0.281						0.006
Immersion Ag		-0.175	-0.219	-0.271	-0.780	-0.750	-0.740	
Immersion Au/Pd		-0.156			-0.890			
Parylene		-0.743	-1.294	-1.311	-1.760			
Silicone		-0.716	-1.270	-1.340	-1.710			
Urethane	0.004	-0.752	-0.530	-0.557	-0.610			0.005
Flux		-0.156						
Benzi*Parylene								-0.006
Imm Ag*Parylene					0.560	0.740	0.740	
Imm Au/Pd*Parylene					0.950			
Benzi*Silicone								-0.005
Imm Ag*Silicone			1.070	0.750	1.040	0.740	0.740	
Imm Au/Pd*Silicone					0.880			
Benzi*Urethane		0.310						-0.008
Imm Ag* Urethane						0.740	0.750	
Imm Au/Pd* Urethane			-0.760	-0.770				
Benzi*Flux		0.230						-0.006
Imm Ag*Flux					0.420	0.740	0.740	
Imm Au/Pd*Flux								
Parylene*Flux								
Silicone*Flux								
Urethane*Flux		0.260						
Benzi*Parylene*Flux								0.006
Imm Ag*Parylene*Flux						-0.690	-0.740	
Imm Au/Pd*Parylene*Flux	0.015							
Benzi*Silicone*Flux								0.005
Imm Ag*Silicone*Flux			-0.960	-0.560	-0.740	-0.740	-0.740	
Imm Au/Pd*Silicone*Flux								
Benzi*Urethane*Flux								0.008
Imm Ag*Urethane*Flux						-0.740	-0.740	
Imm Au/Pd*Urethane*Flux								
Model R^2	15.0%	57.0%	63.5%	66.0%	67.1%	18.6%	19.5%	42.5%
Standard Deviation	0.007	0.289	0.424	0.409	0.463	0.282	0.270	0.003

The constant term (2.479) in Table 5.16 for Cycle 10 corresponds to a base case estimate of $10^{2.479}$ = 301.3 for HVLC SMT, which is well above the upper JTP acceptance limit. Table 5.18 also shows this same value occurring for both HASL cases and both benzimidazole cases without coating. In addition, the uncoated PWAs for immersion Ag and immersion Au/Pd are well above the upper JTP limit. All urethane cases are also above the upper limit, but all are better than the respective uncoated PWAs. Parylene has all but one (immersion Ag with WS) of its eight predictions within the JTP criterion as does silicone PWAs with its lone exception being immersion Ag with LR flux.

The coefficients in Table 5.15 for HVLC PTH at Post-test and 250TC do not indicate any significant influence due to surface finish, coating status, or flux. On the other hand, the coefficients in Table 5.16 for HVLC SMT at Post-test

Table 5.17 Predicted Current (μA) for HVLC PTH During Cycle 10

		No Coating	Parylene	Silicone	Urethane
HASL	**LR**	17.9	5.4	6.0	17.9
	WS	5.5	5.9	5.1	5.5
Benzimidazole	**LR**	6.1	5.1	5.0	6.1
	WS	6.3	6.0	5.5	6.3
Immersion Ag	**LR**	17.9	5.4	6.0	7.4
	WS	5.5	5.9	5.1	7.4
Immersion Au/Pd	**LR**	17.9	5.4	6.0	6.2
	WS	5.5	5.9	5.1	6.0

Table 5.18 Predicted Current (μA) for HVLC SMT During Cycle 10

		No Coating	Parylene	Silicone	Urethane
HASL	**LR**	301.3	5.2	5.9	74.0
	WS	301.3	5.2	5.9	74.0
Benzimidazole	**LR**	301.3	5.2	5.9	74.0
	WS	301.3	5.2	5.9	74.0
Immersion Ag	**LR**	50.0	3.2	10.7	12.3
	WS	131.5	8.3	5.1	32.3
Immersion Au/Pd	**LR**	38.8	6.0	5.7	9.5
	WS	38.8	6.0	5.7	9.5

and 250TC show several significant parameters. However, the corresponding predictions indicate that only one case fails to meet the JTP acceptance criterion—immersion Ag without coating and with LR flux, which had a predicted current of 0.9μA. All other predictions for HVLC SMT were very close to 5.0μA.

Displays. Figures 5.3 to 5.7 (also Figures H.9 to H.12 in Appendix H) present boxplots for the HVLC PTH current measurements versus test time for HASL, benzimidazole, immersion Ag, and immersion Au/Pd, respectively. The vertical axis in these plots represent the logs of the measurements (note that due to software limitations the actual scale is linear, not logarithmic). The corresponding boxplots for HVLC SMT appear in Figures 5.8 to 5.11 (also Figures H.13 to H.16). These figures show the adverse effect of the CA test on the HVLC current measurements. They also show the impact of coating and flux type for each of the surface finishes.

A comparison of Figure 5.3 to 5.6 with Table 5.17 shows good agreement with the results of the GLM analyses. As an illustration of how the boxplots agree with the GLM analyses, consider the base case (HASL, LR, no coating) that is represented by the clear boxes on the left-hand side of Figure 5.3. The predicted currents in Table 5.17 show a value of 17.9 for the base case (HASL, LR, no coating). The log of this number is 1.25, which is close to the median in the clear box at Cycle 10 in Figure 5.3. This prediction changes to 5.5 for HASL without coating and processed with WS flux. The log of this prediction is 0.74, which is at the median of the clear box on the right-hand side of Figure 5.3 at Cycle 10. Similar comparisons can be made for each of the predictions in Tables 5.17 and 5.18. Note that the HVLC PTH and HVLC SMT responses are near normal at Post-test for all surface finish and flux combinations and are normal after 250TC and 500TC.

Comparison to JTP Acceptance Criterion. During Cycle 10 of the CA test there were 42 HVLC PTH and 90 HVLC SMT measurements that did not meet the JTP acceptance criterion. These numbers were reduced respectively reduced to 0 and 5 at Post-test, 0 and 2 at 250TC, and 2 and 0 at 500TC. The two anomalous HVLC PTH measurements after 500TC were both hard failures, with current recorded as 0.00μA. The failure analysis for these two circuits is summarized in Table 5.19.

Table 5.19 Failure Analysis Results for HVLC PTH Circuits after 500 Thermal Cycles

MSN	Surface Finish	Coating	Flux	Current	Failure Analysis Results
103	Benzimidazole	Parylene	LR	0μA	
155	Immersion Au/Pd	None	WS	0μA	

5.5 HSD Circuitry. The JTP acceptance criterion for HSD PTH and HSD SMT (responses 5 and 6 in Table 1.1) requires the increase in total propagation delay (*nanoseconds*) to be less than 20% from Pre-test measurements. As was explained in Section 2.5, Pre-test measurements for the urethane PWAs showed that the TPD was approximately 4*ns* longer for these PWAs than for the PWAs that were either uncoated, coated with parylene, or coated with silicone. Even though the TPD is longer, the same JTP acceptance criterion was applied to both groups of PWAs.

Tables G.5 and G.6 present the results of the GLM analyses for the HSD circuits. The model R^2s in these tables are summarized as follows:

Circuit	Pre-test	Cycle 1	Cycle 4	Cycle 7	Cycle10	Post-test	250TC	500TC
HSD PTH	87.8%	15.4%	13.1%	8.2%	16.6%	10.6%	32.1%	36.0%
HSD SMT	89.3%	10.3%	5.1%	2.3%	6.6%	27.9%	39.1%	44.7%

Since the GLM analyses at Pre-test were based on the actual TPDs, the high R^2 values at this test time simply reflect the differences in the TPD for the HSD components on the urethane coated PWAs versus the non-urethane PWAs (see Section 2.5). After Pre-test the GLM analyses were based on the percentage change specified in the JTP acceptance criterion. The model R^2 values are all quite small for the remaining test times, which imply that the experimental parameters did not differ significantly from the base case in terms of their impact on the HSD circuits. That is, there is no practical difference from the base case total propagation delay measurements due to surface finishes, coating status, or flux type. The coefficients in Tables G.5 and G.6 were too small to be of concern relative to the JTP acceptance criterion.

Displays. Figures H.17 to H.20 present boxplots for the HSD PTH total propagation delay measurements for HASL, benzimidazole, immersion Ag, and immersion Au/Pd, respectively. These figures illustrate the difference in total propagation delay due to different HSD components on urethane PWAs as previously explained in Section 2.5. Boxplots of the percentage change in total propagation delay at subsequent test times for HASL, benzimidazole, immersion Ag, and immersion Au/Pd, are not shown in Appendix H due to the large number of pages required. Such graphs show a lot of overlap in the boxplots, which tend to be centered about zero. The corresponding boxplots for HSD SMT appear in Figures H.21 to H.24.

The boxplots in Figure H.17 to H.24 agree with the results of the GLM analyses for HSD circuits given in Tables G.5 and G.6.

Comparison to JTP Acceptance Criterion. There was one anomalous HSD PTH measurement and four anomalous HSD SMT measurements that did not meet the JTP acceptance criterion during Cycle 10 of the CA test. There were no HSD anomalies at Post-test. There were two HSD PTH anomalies at 250TC and no HSD anomalies at 500TS. Five PWAs had a total of nine HSD circuits that did not produce a response at 500TC. Failure analysis results after 500TC are summarized in Table 5.20 for these nine circuits. The HSD anomalies were not associated with surface finish, coating status, or flux.

Table 5.20 Failure Analysis Results for HSD Circuits after 500 Thermal Cycles

9	Surface Finish	Coating	Flux	Propagation Delay	Failure Analysis Results
			HSD PTH		
16	HASL	None	LR	No response	
34	HASL	Parylene	LR	No response	
815	Immersion Ag	Urethane	WS	No response	
234	Immersion Au/Pd	None	LR	No response	
261	Immersion Au/Pd	Parylene	LR	No response	
			HSD SMT		
9	HASL	None	LR	No response	
34	HASL	Parylene	LR	No response	
234	Immersion Au/Pd	None	LR	No response	
261	Immersion Au/Pd	Parylene	LR	No response	

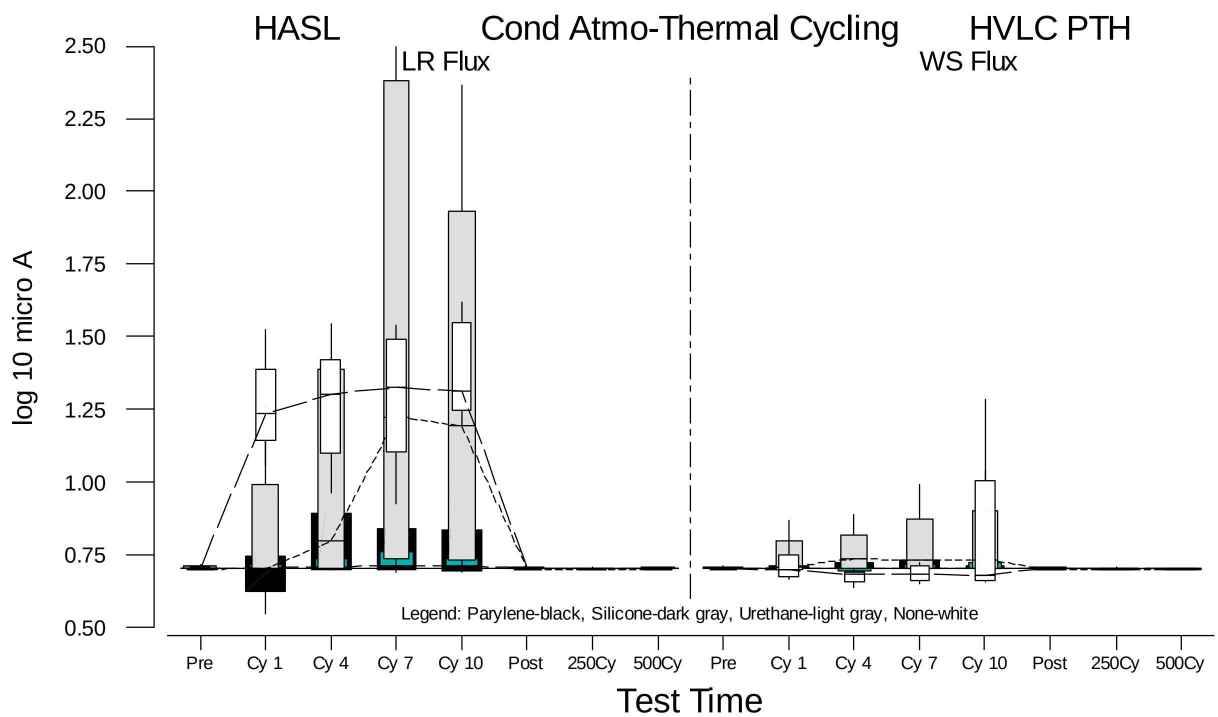

Figure 5.3 Boxplots of HVLC PTH Measurements versus Test Time for HASL

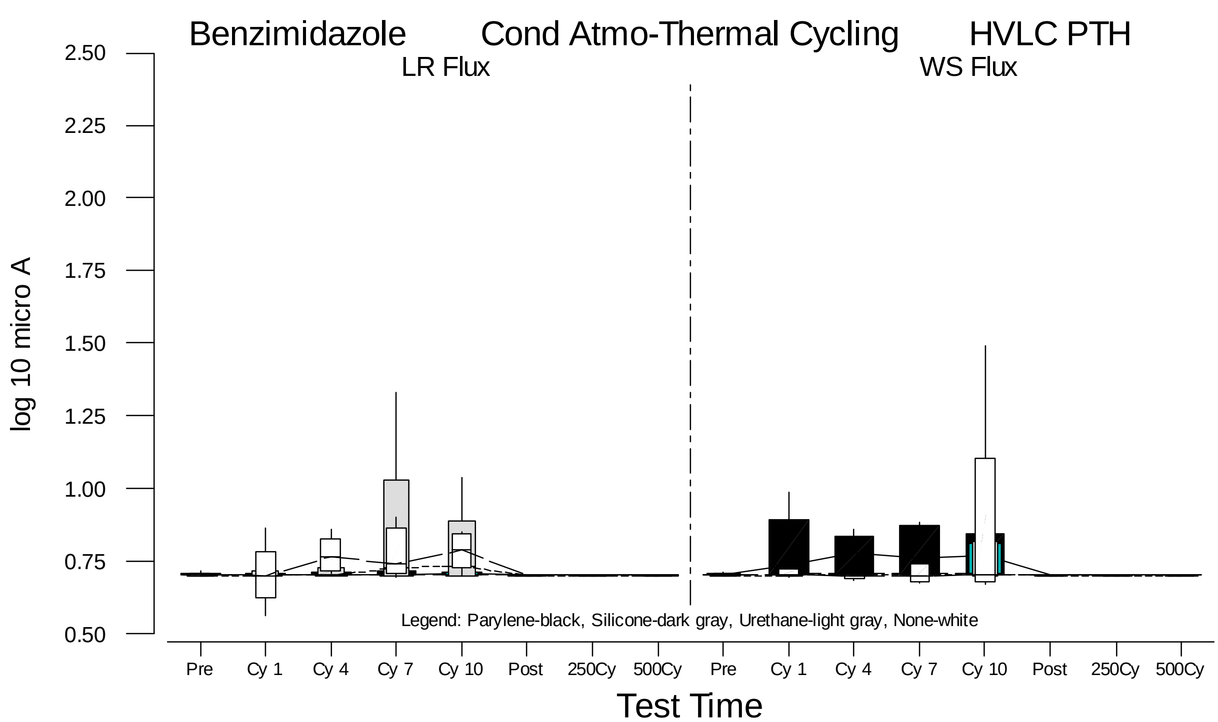

Figure 5.4 Boxplots of HVLC PTH Measurements versus Test Time for Benzimidazole

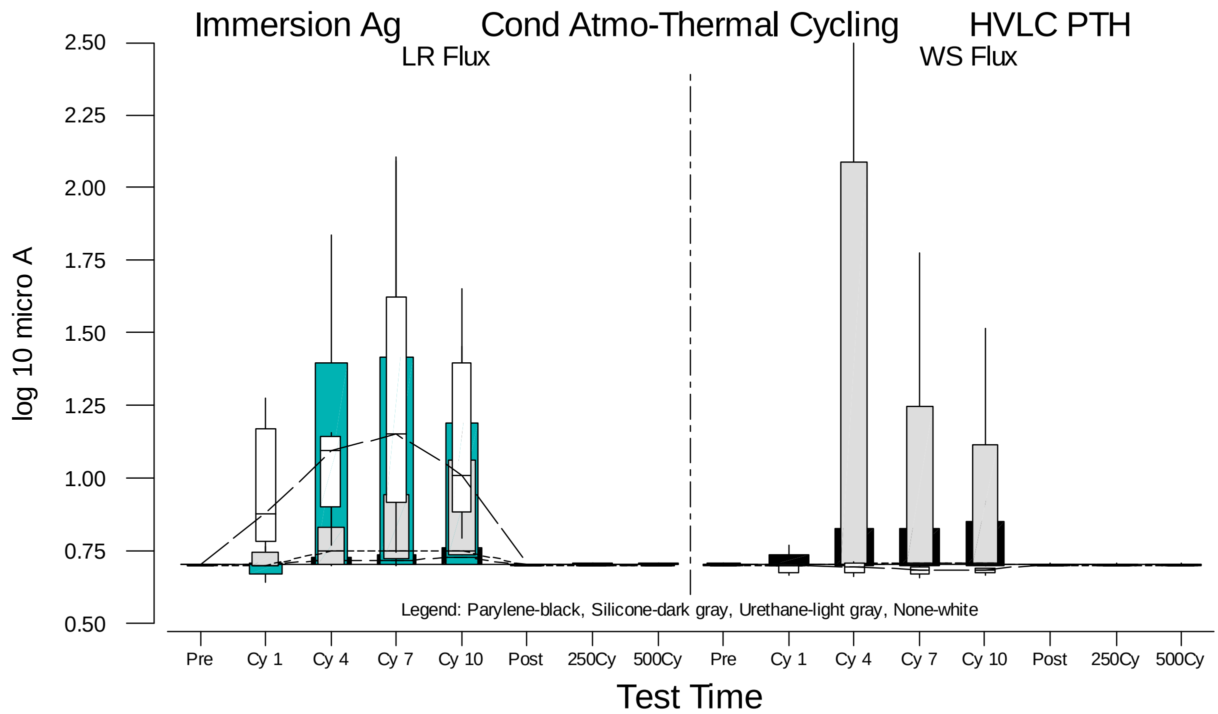

Figure 5.5 Boxplots of HVLC PTH Measurements versus Test Time for Immersion Ag

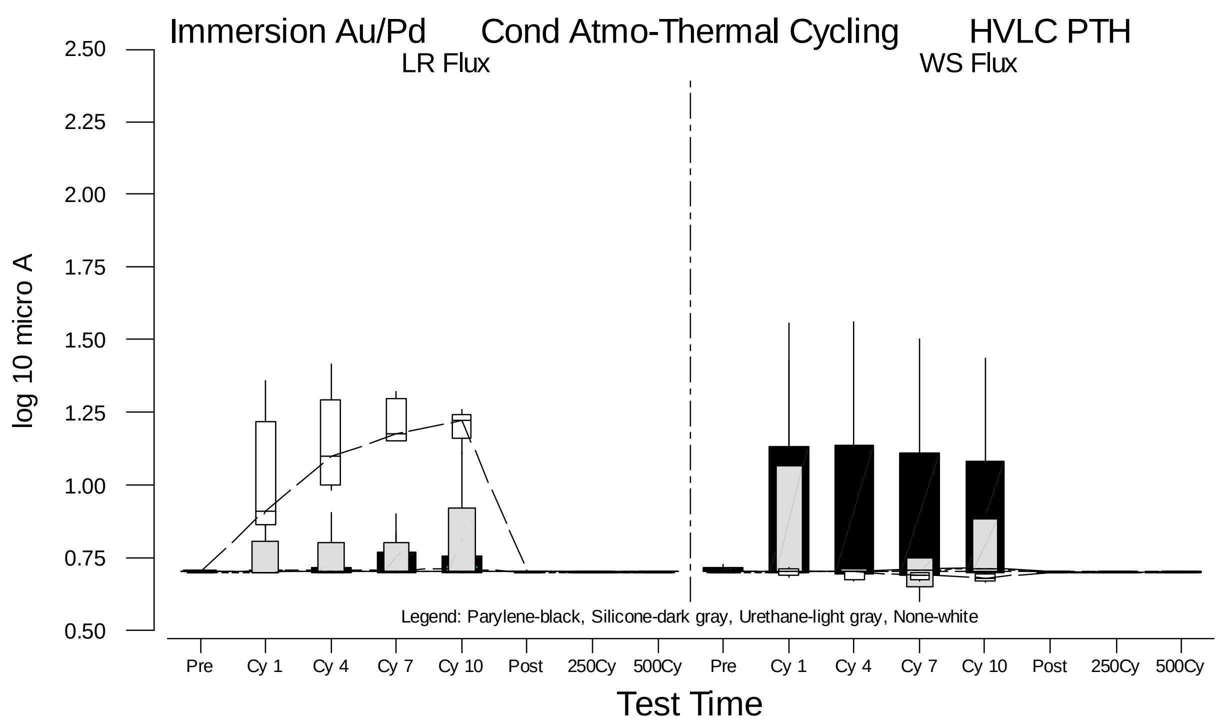

Figure 5.6 Boxplots of HVLC PTH Measurements versus Test Time for Immersion Au/Pd

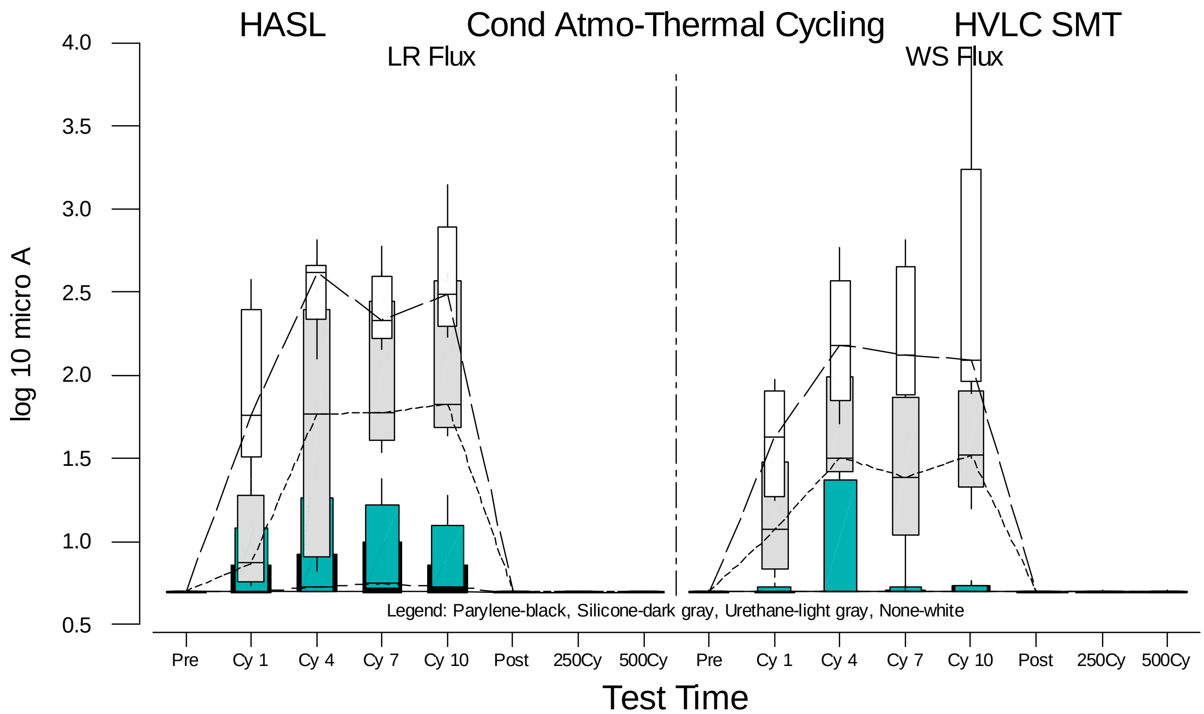

Figure 5.7 Boxplots of HVLC SMT Measurements versus Test Time for HASL

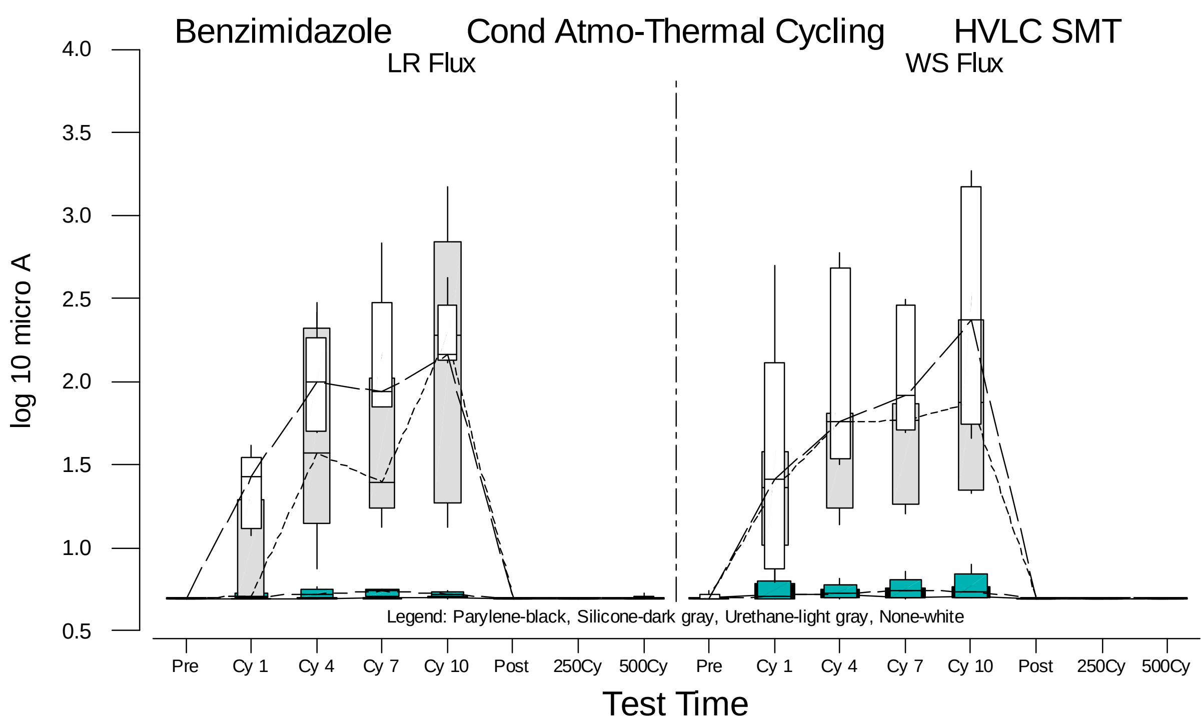

Figure 5.8 Boxplots of HVLC SMT Measurements versus Test Time for Benzimidazole

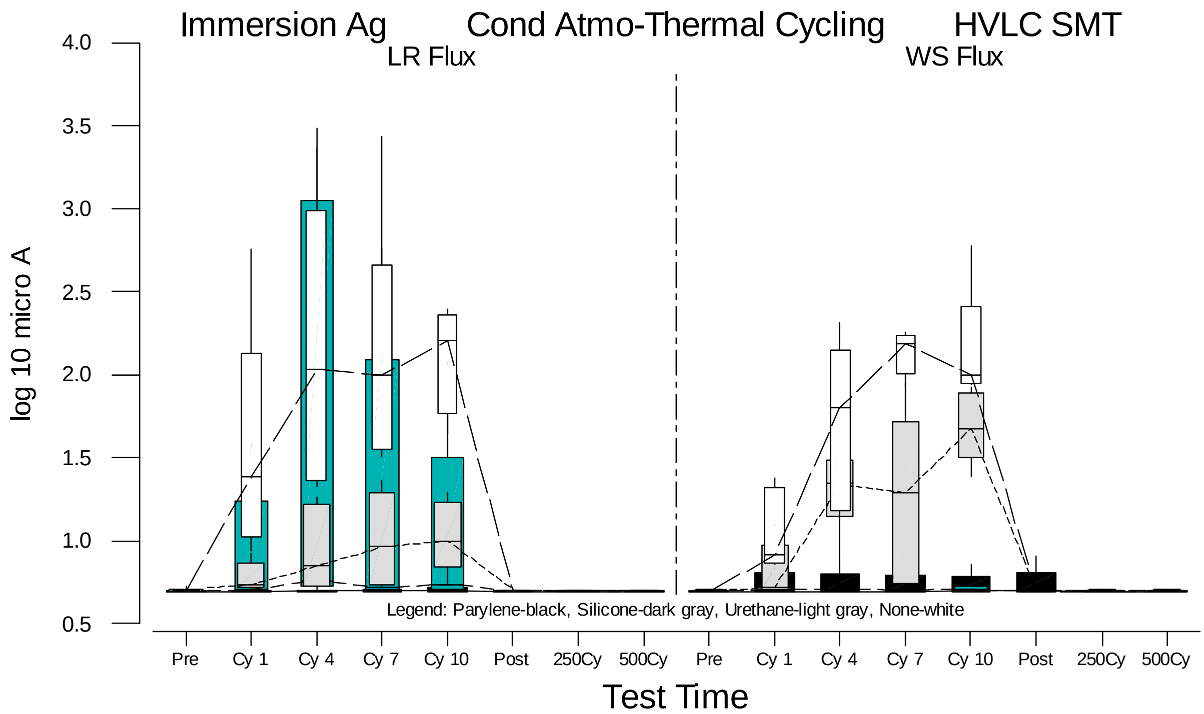

Figure 5.9 Boxplots of HVLC SMT Measurements versus Test Time for Immersion Ag

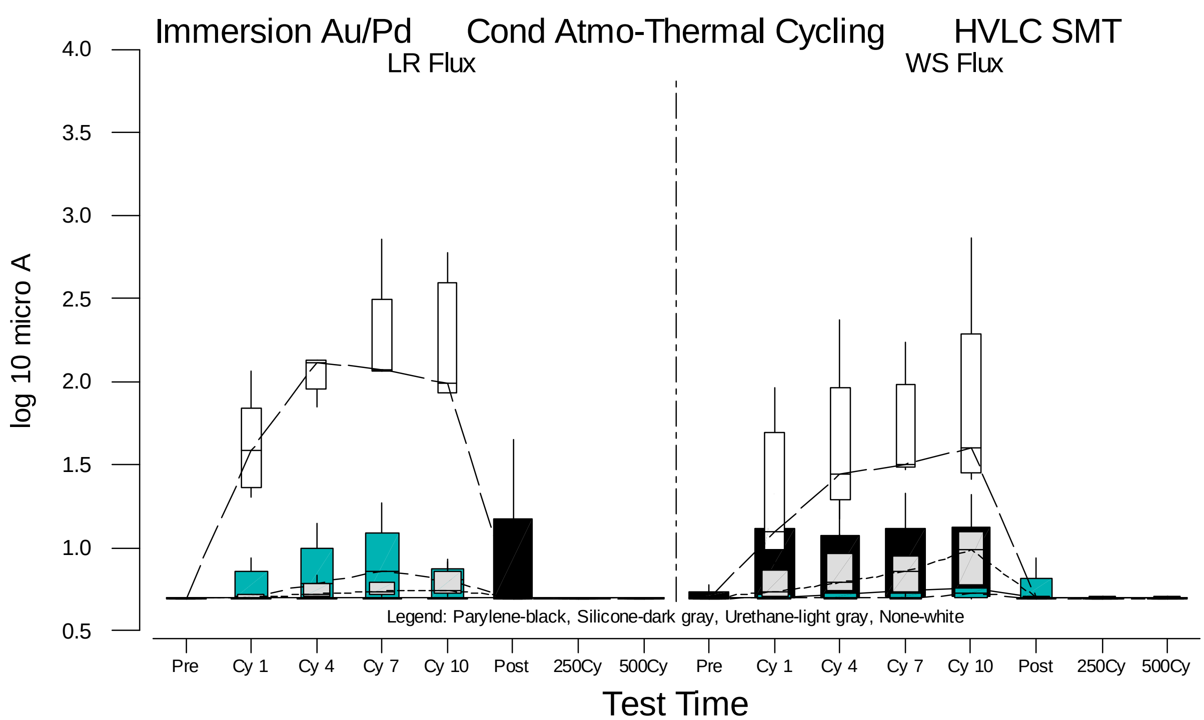

Figure 5.10 Boxplots of HVLC SMT Measurements versus Test Time for Immersion Au/Pd

5.6 HF LPF Circuitry. The JTP acceptance criteria for HF LPF PTH 50MHz and HF LPF SMT 50MHz (responses 7 and 10 in Table 1.1) are based on deviations from the average response of the five HASL PWAs coated with parylene and processed with LR flux. Specifically, these deviations must be within ±5dB of this average computed at the current test time.

The JTP acceptance criteria for HF LPF PTH f(-3dB), HF LPF PTH f(-40dB), HF LPF SMT f(-3dB), and HF LPF SMT f(-40dB) (responses 8, 9, 11, and 12 in Table 1.1) are also based on deviations from the average response of the five HASL PWAs coated with parylene and processed with LR flux. Specifically, these deviations must be within ±50MHz of this average computed at the current test time.

Pre-test measurements for all six HF LPF circuits were subjected to GLM analyses, as were the deviations during Cycles 1, 4, 7, and 10 of the CA test, at Post-test, and after 250 and 500 thermal cycles. The results of the GLM analyses are given in Tables G.7 to G.12. The model R^2s from those tables are summarized as follows.

HF LPF Circuit	Pre-test	Cycle 1	Cycle 4	Cycle 7	Cycle 10	Post-test	250TC	500TC
PTH 50MHz	32.4%	4.8%	5.8%	12.0%	19.2%	11.6%	10.1%	35.1%
PTH f(-3dB)	16.3%	10.3%	10.9%	1.7%	2.3%	1.8%	0.7%	9.9%
PTH f(-40dB)	22.0%	12.2%	10.4%	16.3%	27.6%	0.6%	3.6%	4.0%
SMT 50MHz	31.5%	35.5%	26.5%	36.8%	27.4%	11.3%	12.6%	12.0%
SMT f(-3dB)	35.6%	8.2%	12.2%	13.2%	16.9%	3.4%	9.5%	10.7%
SMT f(-40dB)	45.0%	39.7%	36.7%	38.5%	37.5%	18.6%	13.7%	17.3%

These model R^2s range from quite small to 45%. However, the estimated coefficients in all models were too small to be of practical significance relative to the JTP acceptance criteria.

Displays. Figures H.25 to H.48 present boxplots for the HF LPF measurements for the HASL, benzimidazole, immersion Ag, and immersion Au/Pd surface finishes, respectively. Note that the effect of the CA test is more apparent for SMT components than for PTH components. Boxplots of the deltas (not shown) were close to zero throughout. The boxplots in Figure H.25 to H.48 agree with the results of the GLM analyses for HSD circuits given in Tables G.7 to G.12.

Comparison to JTP Acceptance Criterion. There were only three anomalous HF LPF measurements that did not meet the JTP acceptance criterion during Cycle 10 of the CA test and one of these was on the borderline of the limit. At Post-test there was only one anomalous HF LPF measurement. After 250TC there were 13 anomalies on seven PWAs. Twelve of these 13 anomalies occurred for HF LPF PTH. There were no significant effects due to surface finish, flux, or coating status at 250TC. There were only five anomalies after 500TC and four of these occurred on a single PWA. Failure analysis results for these circuits are given in Table 5.21.

Table 5.21 Failure Analysis Results for HF LPF Circuits after 500 Thermal Cycles

MSN	Surface Finish	Coating	Flux	Deviation	Failure Analysis Results
			HF LPF PTH 50MHZ		
582	Immersion Au/Pd	Silicone	WS	-36.7dB	
			HF LPF PTH f(-3dB)		
582	Immersion Au/Pd	Silicone	WS	-203.1MHz	
			HF LPF PTH f(-40dB)		
582	Immersion Au/Pd	Silicone	WS	-86.8MHz	
			HF LPF SMT f(-3dB)		
582	Immersion Au/Pd	Silicone	WS	-56.9MHz	
			HF LPF SMT f(-40dB)		
32	HASL	Parylene	LR	80.4MHz	

5.7 HF TLC Circuitry. The JTP acceptance criteria for HF TLC circuitry (responses 13 to 17 in Table 1.1) are all based on changes from their Pre-test measurements. The changes for HF TLC 50MHz, HF TLC 500MHz, and HF TLC 1GHz must be within ±5dB of the Pre-test values. The changes for HF TLC Reverse Null Frequency must be within ±50MHz. Finally, the changes for HF TLC Reverse Null Response must be less than 5dB if both responses are greater than -50dB, otherwise they must be less than 10dB. Thermal cycle measurements were compared to Post-test measurements rather than Pre-test to ensure a sound statistical basis for quantifying changes due to thermal cycling.

Pre-test measurements for all five HF TLC circuits were subjected to GLM analyses, as were the deviations during Cycles 1, 4, 7, and 10 of the CA test, at Post-test, and after 250 and 500 thermal cycles. The results of the GLM analyses appear in Tables G.13 to G.17. The model R^2s from those tables are summarized as follows.

HF LPF Circuit	Pre-test	Cycle 1	Cycle 4	Cycle 7	Cycle 10	Post-test	250TC	500TC
50MHz	76.8%	31.6%	19.7%	25.7%	1.6%	44.0%	28.9%	8.8%
500MHz	77.1%	4.3%	3.0%	15.1%	17.5%	45.1%	8.7%	8.7%
1GHz	78.7%	10.9%	13.3%	27.8%	29.1%	46.6%	18.0%	8.2%
RNF	81.4%	44.2%	36.2%	51.0%	68.7%	40.2%	43.0%	32.0%
RNR	16.0%	11.1%	22.9%	49.2%	57.0%	8.9%	18.9%	8.1%

The model R^2s are high for the first four HF TLC circuits at Pre-test. The magnitudes of these R^2s are attributable to the different electrical properties of conformal coatings as previously discussed in Section 2.7. Of more importance, are the larger R^2 values during Cycle 10 for the deltas on the last two HF TLC circuits. Examination of tables G.13 to G.17 shows that the magnitudes of the estimated coefficients during Cycle 10 are too small to be of practical significance relative to the JTP acceptance criterion except for possibly HF TLC RNF and HF TLC RNR. The predicted changes from the base case values for these two circuits are given in Tables 5.22 and 5.23. The predicted changes in Table 5.22 show an increase for coated PWAs, but these increases are still below the upper JTP limit of 50MHz. The predicted changes in Table 5.23 show a decrease (desirable) for coated PWAs, which is an indication of better performance.

Table 5.22 Predicted Changes in Frequency (MHz) Relative to the Base Case for HVLC RNF During Cycle 10

		No Coating	Parylene	Silicone	Urethane
HASL	**LR**		31.6	29.9	31.0
	WS		31.6	29.9	31.0
Benzimidazole	**LR**	26.5	30.9	30.2	21.7
	WS	7.0	29.4	30.4	29.8
Immersion Ag	**LR**	9.9	29.9	29.8	27.3
	WS	9.9	29.9	29.8	41.0
Immersion Au/Pd	**LR**		31.6	29.9	31.0
	WS		31.6	29.9	31.0

Table 5.23 Predicted Changes in Response (dB) Relative to the Base Case for HVLC RNR During Cycle 10

		No Coating	Parylene	Silicone	Urethane
HASL	**LR**		-22.4	-21.6	-19.0
	WS		-22.4	-21.6	-19.0
Benzimidazole	**LR**	-18.1	-18.4	-21.7	-22.7
	WS	-3.0	-23.7	-20.8	-25.9
Immersion Ag	**LR**		-22.4	-21.6	-19.0
	WS		-22.4	-21.6	-19.0
Immersion Au/Pd	**LR**		-22.4	-21.6	-19.0
	WS		-22.4	-21.6	-19.0

The model R^2s for the first four HF TLC circuits at Post-test all decrease dramatically relative to Pre-test, but still reflect the different electrical properties of conformal coatings. The coefficients for the models after 250TC and 500TC are too small to be of practical importance relative to the JTP acceptance criteria. Recall that the 250TC and 500TC models were based on comparisons to Post-test, whereas the preceding models were based on comparisons to Pre-test.

Displays. Figures H.49 to H.68 present boxplots for the HF TLC measurements for HASL, benzimidazole, immersion Ag, and immersion Au/Pd, respectively. These boxplots clearly illustrate the differences in the electrical properties for coatings shown in Table 2.7. The plots for HF TLC 50MHz show greater variability with LR flux at Post-test and TC than those for WS flux. The plots for HF TLC 500MHz and HF TLC 1GHz have increased variability at Post-test and TC for both flux types. The boxplots in Figure H.49 to H.68 support the results of the GLM analyses for HSD circuits given in Tables G.13 to G.17.

Comparison to JTP Acceptance Criterion. There were 52 anomalies for the HF TLC circuitry that did not meet the JTP acceptance criterion during Cycle 10 of the CA test. All but 15 of these anomalies were associated with HF TLC RNR. At Post-test there were 70 anomalies, 23 of which were for HF TLC 50MHz and 45 of which were for HF TLC RNR. Fifteen of the HF TLF RNR anomalies at Post-test were carry overs from Cycle 10. After 500TC, there were only 14 HF TLC anomalies. Much of this reduction is due to comparing TC measurements to Post-test rather than Pre-test measurements. (Note: a comparison to Pre-test rather than Post-test produces 40 HF TLC RNR anomalies at 500TC, six of which would have warranted failure analysis.) Only five of the 14 anomalies at 500TC were severe enough to warrant failure analysis and four of these occurred on a single PWA. The failure analysis results are presented in Table 5.24.

Table 5.24 Failure Analysis Results for HF TLC Circuits after 500 Thermal Cycles

MSN	Surface Finish	Coating	Flux	Deviation	Failure Analysis Results
HF TLC 50GHz					
457	Immersion Ag	None	WS	-8.3dB	FA not required
832	Immersion Ag	Urethane	WS	8.7dB	FA not required
572	Immersion Au/Pd	Parylene	WS	-5.2dB	FA not required
834	Immersion Au/Pd	Urethane	WS	-11.0dB	FA not required
HF TLC 1GHz					
351	HASL	Silicone	WS	-5.0dB	FA not required
359	HASL	Silicone	WS	10.1dB	FA not required
619	HASL	Urethane	LR	-9.5dB	FA not required
106	Benzimidazole	Parylene	LR	-8.4dB	FA not required
897	Immersion Au/Pd	Urethane	WS	-6.0dB	FA not required
917	Immersion Au/Pd	Urethane	WS	-12.0dB	FA not required
HF TLC RNF					
457	Immersion Ag	None	WS	546.3MHz	
HF TLC RNR					
457	Immersion Ag	None	WS	22.6dB	
832	Immersion Ag	Urethane	WS	18.1dB	FA not required
600	Immersion Au/Pd	Silicone	WS	12.1dB	FA not required

5.8 Leakage Measurements. Four features were included in the design of the LRSTF PWA to specifically check for current leakage: 10-mil pads, a PGA socket (PGA-A, PGA-B), and a gull wing component (responses 18 to 21 in Table 1.1). The PGA hole pattern has four concentric squares that are electrically connected by traces on the top layer of the board. Two leakage current measurements were made: (1) between the two inner squares (PGA-A) and (2) between the two outer squares (PGA-B). Solder mask covers the pattern of the PGA-B, allowing a direct comparison of similar patterns with and without solder mask. Rather than an actual PGA device, a socket was used since it provided the same soldering connections as a PGA device. Also, obtaining leakage measurements on an actual PGA is nearly impossible due to complexity of its internal semiconductor circuits.

The JTP acceptance criterion for the leakage measurements requires the resistance to be greater than 7.7 when expressed as $\log_{10}$ ohms. The leakage measurements were subjected to GLM analyses at Pre-test, during Cycles 1, 4, 7, and 10 of the CA test, at Post-test, after 250TC, and after 500TC. The results of the GLM analyses appear in Tables G.18 to G.21. The model R^2s from those tables are summarized as follows.

Circuit	Pre-test	Cycle 1	Cycle 4	Cycle 7	Cycle 10	Post-test	250TC	500TC
10-Mil Pads	50.9%	75.8%	70.4%	70.1%	70.4%	20.1%	6.0%	9.1%
PGA-A	48.1%	52.9%	49.2%	60.4%	58.1%	6.2%	13.4%	13.1%
PGA-B	40.0%	49.9%	44.6%	45.8%	44.6%	3.6%	13.4%	13.7%
Gull Wing	9.4%	70.4%	77.1%	78.0%	81.6%	24.8%	14.9%	17.9%

10-Mil Pads. The predicted base case value at Pre-test is given in Table G.18 as 11.44, which is well above the JTP acceptance criterion of 7.70. There were no anomalies at Pre-test. The predicted changes from the base case at Pre-test are given in Table 5.25. This table shows that resistance for parylene coated PWAs varies from approximately 0.77 to 1.81 orders of magnitude higher than the base case, except when WS flux is used with immersion Au/Pd, which is about 0.8 orders of magnitude lower than the base case. On the other hand, silicone does not increase resistance. Urethane gives an increase in resistance of approximately 1.2 orders of magnitude. The resistance for uncoated PWAs increases for non-HASL surface finishes except for immersion Au/Pd processed with WS flux.

Table 5.25 Predicted Changes from the Base Case for 10-Mil Pads at Pre-test

		No Coating	Parylene	Silicone	Urethane
HASL	**LR**		0.77		1.20
	WS		0.77		1.20
Benzimidazole	**LR**	0.85	1.62	-0.23	1.18
	WS	0.85	1.62	-0.23	1.18
Immersion Ag	**LR**	1.04	1.81	-0.49	1.14
	WS	1.04	1.81	-0.49	1.14
Immersion Au/Pd	**LR**		2.00		1.20
	WS	1.60	-0.82	-0.29	1.16

The predicted base case value in Table G.18 during Cycle 10 is only 5.70, which is well below the JTP acceptance criterion. A predicted increase of two orders of magnitude is needed to meet the JTP acceptance criterion. The predicted changes during Cycle 10 given in Table 5.26 show that all coated PWAs meet the criterion with increase of approximately 3 to 7 orders of magnitude.

Table 5.26 Predicted Changes from the Base Case for 10-Mil Pads During Cycle 10

		No Coating	Parylene	Silicone	Urethane
HASL	**LR**		4.42	4.31	3.70
	WS	0.56	4.98	4.87	4.26
Benzimidazole	**LR**		4.42	4.31	3.70
	WS	0.56	4.98	4.87	4.26
Immersion Ag	**LR**		4.42	4.31	3.70
	WS	0.56	4.98	4.87	4.26
Immersion Au/Pd	**LR**		7.07	4.31	3.70
	WS	0.56	3.13	4.87	4.26

The predicted base case value in Table G.18 at Post-test is 11.69, which is four orders of magnitude above the JTP acceptance criterion. The predicted changes at Post-test in Table 5.27 show that all cases meet the JTP acceptance criterion.

Table 5.27 Predicted Changes from the Base Case for 10-Mil Pads at Post-Test

		No Coating	Parylene	Silicone	Urethane
HASL	**LR**		0.82		0.84
	WS		0.82		0.84
Benzimidazole	**LR**		-0.58		0.84
	WS		-0.58		0.84
Immersion Ag	**LR**	-1.43	-0.61	0.53	0.78
	WS	-1.43	-0.61	0.53	0.78
Immersion Au/Pd	**LR**		-1.28		0.84
	WS		0.76		0.84

The predicted base case value in Table G.18 after 500TC is 12.80, which is 5.1 orders of magnitude above the JTP acceptance criterion and approximately 1.1 orders of magnitude higher than at Post-test. The predicted changes at 500TC in Table 5.28 show that all cases meet the JTP acceptance criterion. The resistance for immersion Ag is approximately an order of magnitude lower for uncoated and parylene coated PWAs. The worst case is immersion Au/Pd with parylene, but it still exceeds the acceptance criterion.

Table 5.28 Predicted Changes from the Base Case for 10-Mil Pads after 500 Thermal Cycles

		No Coating	Parylene	Silicone	Urethane
HASL	**LR**				
	WS				
Benzimidazole	**LR**				
	WS				
Immersion Ag	**LR**	-0.95	-0.95	0.21	0.31
	WS	-0.95	-0.95	0.21	0.31
Immersion Au/Pd	**LR**		-1.74		
	WS		0.24		

Displays. Figures 5.11 to 5.14 (also Figures H.69 to H.72) present boxplots for the 10-mil pad resistance measurements versus test time for HASL, benzimidazole, immersion Ag, and immersion Au/Pd, respectively. These graphs support the conclusions of the GLM analyses and provide useful information relative to the influence of surface finish, coating status, and flux. These figures are summarized as follows.

- The negative impact of the CA environment is apparent in all graphs, particularly for uncoated PWAs
- Coated PWAs gave significantly better results than uncoated PWAs throughout the CA test and the increase in performance was approximately three to seven orders of magnitude
- Silicone gives excellent results and low variability throughout the CA test when applied to benzimidazole with LR flux, immersion Au/Pd with LR flux, and immersion Ag with WS flux
- Resistance measurements varied over several orders of magnitude during the CA test for PWAs coated with parylene for the following cases: HASL with LR or WS, benzimidazole with WS, immersion Ag with WS, and immersion Au/Pd with WS
- Resistance measurements for uncoated PWAs were unacceptable during Cycle 10 for all surface finish and flux combinations
- Resistance measurements improved from Post-test to thermal cycling and all measurements met the JTP acceptance criterion during TC

Comparison to JTP Acceptance Criterion. There were 46 anomalies for the 10-mil pads that did not meet the JTP acceptance criterion during Cycle 10 of the CA test. On the other hand, there were only two anomalies at Post-test, both of which occurred for uncoated immersion Au/Pd PWAs processed with WS flux. There was only one slight anomaly (7.23) at 500TC, which was a carry over from Post-test.

PGA-A. The predicted base case value at Pre-test is given in Table G.19 as 10.56, which is nearly three orders of magnitude above the JTP acceptance criterion of 7.70. There was one anomaly at Pre-test. The predicted changes from the base case at Pre-test are given in Table 5.29. All cases in this table meet the JTP acceptance criterion. Uncoated PWAs give approximately the same increase in resistance over the base case as coated PWAs except for immersion Au/Pd processed with LR flux, where there is no change.

Table 5.29 Predicted Changes from the Base Case for PGA-A at Pre-test

		No Coating	Parylene	Silicone	Urethane
HASL	**LR**				0.85
	WS	2.11	1.16	0.26	1.17
Benzimidazole	**LR**	1.68	1.68	0.30	1.10
	WS	1.38	1.96	0.41	1.11
Immersion Ag	**LR**	0.76	0.76	0.76	1.61
	WS	2.03	1.08	0.18	1.09
Immersion Au/Pd	**LR**		1.63		0.85
	WS	2.11	-0.34	0.26	1.17

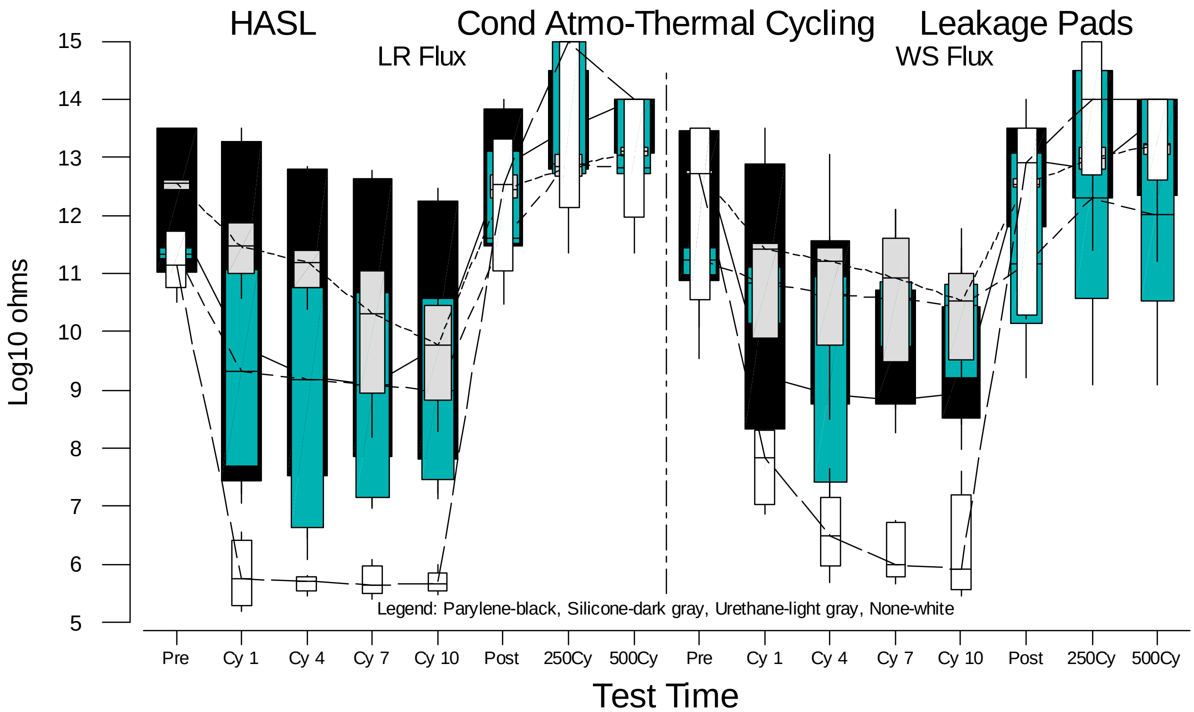

Figure 5.11 Boxplots of Leakage Measurements for 10-Mil Pads versus Test Time for HASL

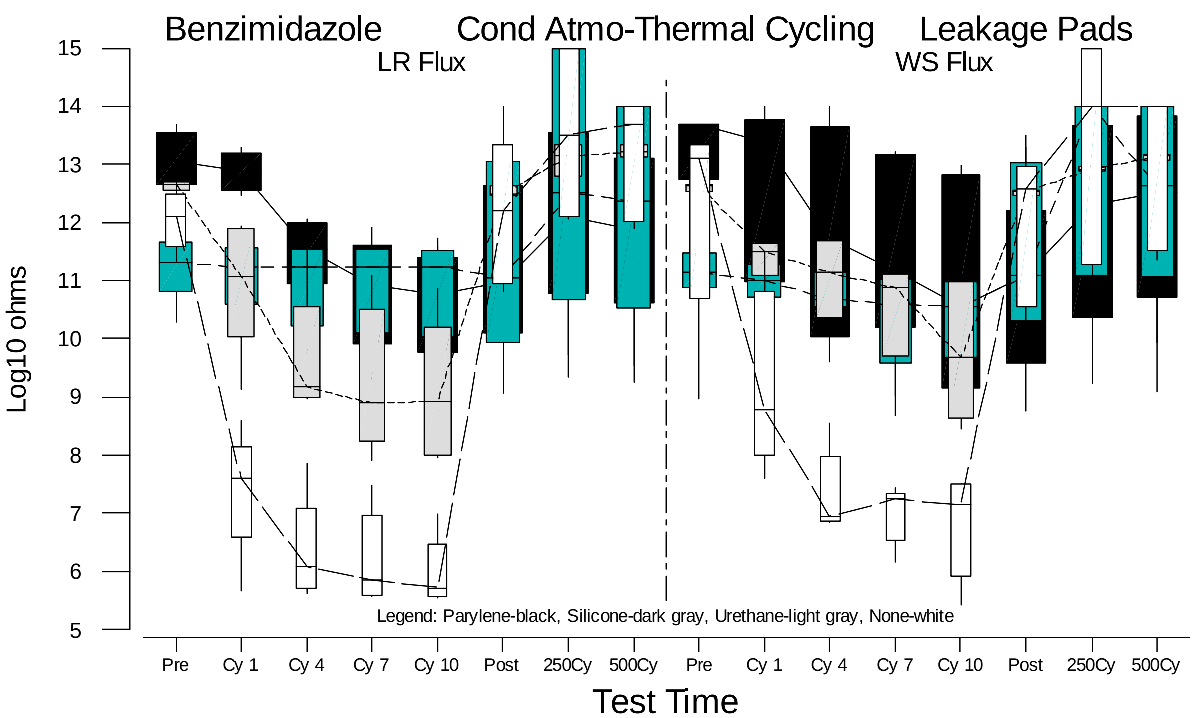

Figure 5.12 Boxplots of Leakage Measurements for 10-Mil Pads versus Test Time for Benzimidazole

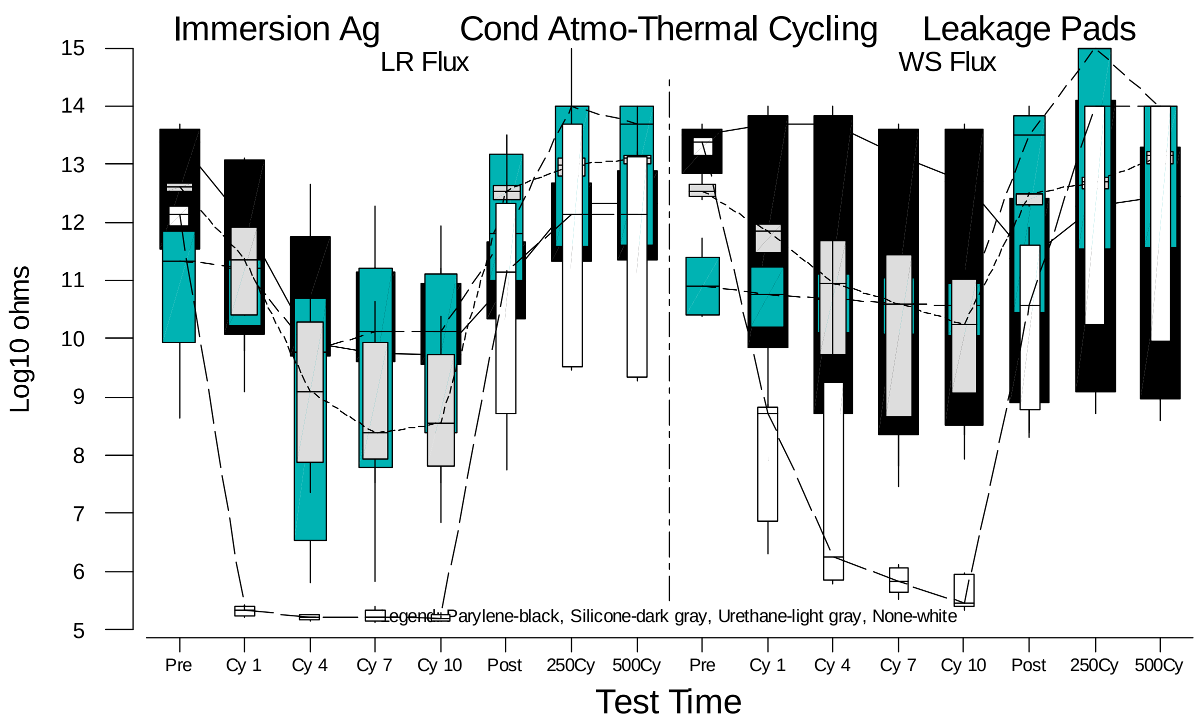

Figure 5.13 Boxplots of Leakage Measurements for 10-Mil Pads versus Test Time for Immersion Ag

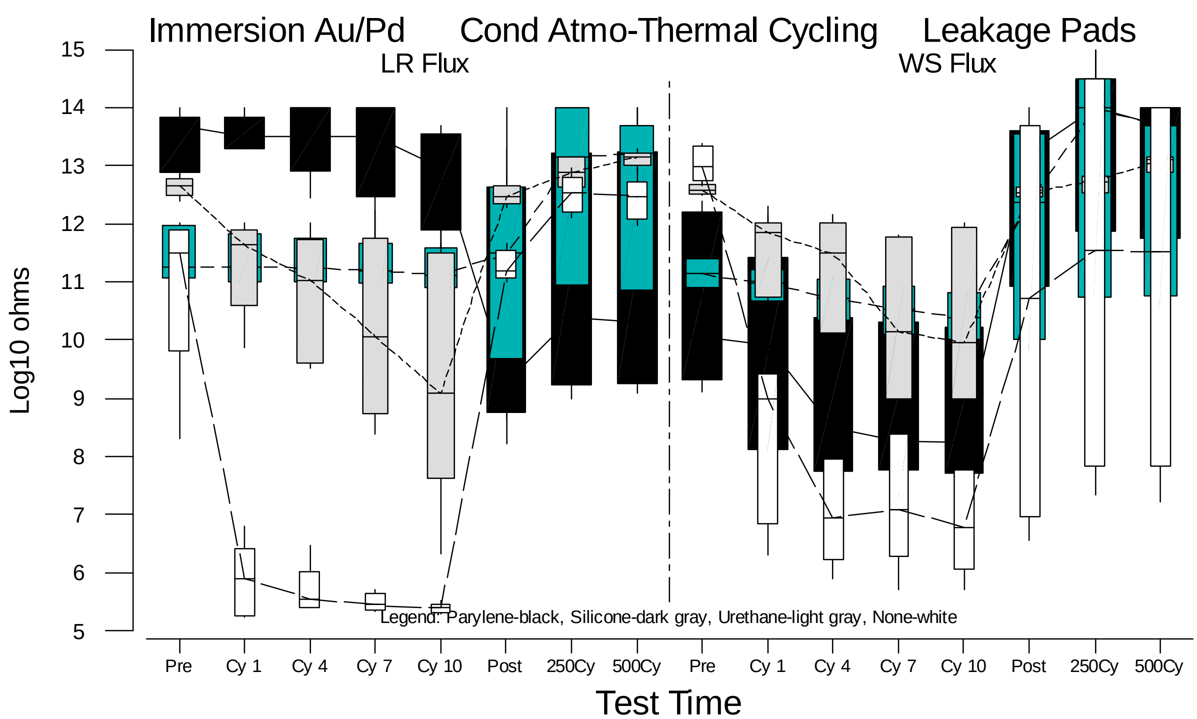

Figure 5.14 Boxplots of Leakage Measurements for 10-Mil Pads versus Test Time for Immersion Au/Pd

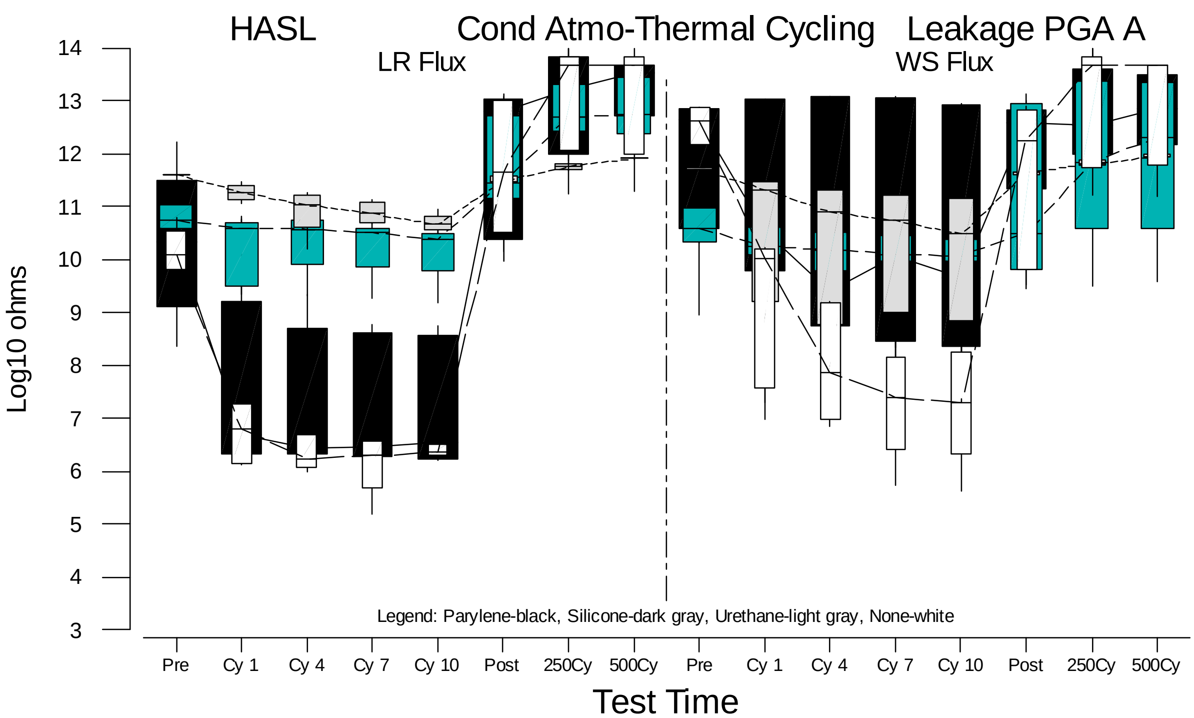

Figure 5.15 Boxplots of Leakage Measurements for PGA-A versus Test Time for HASL

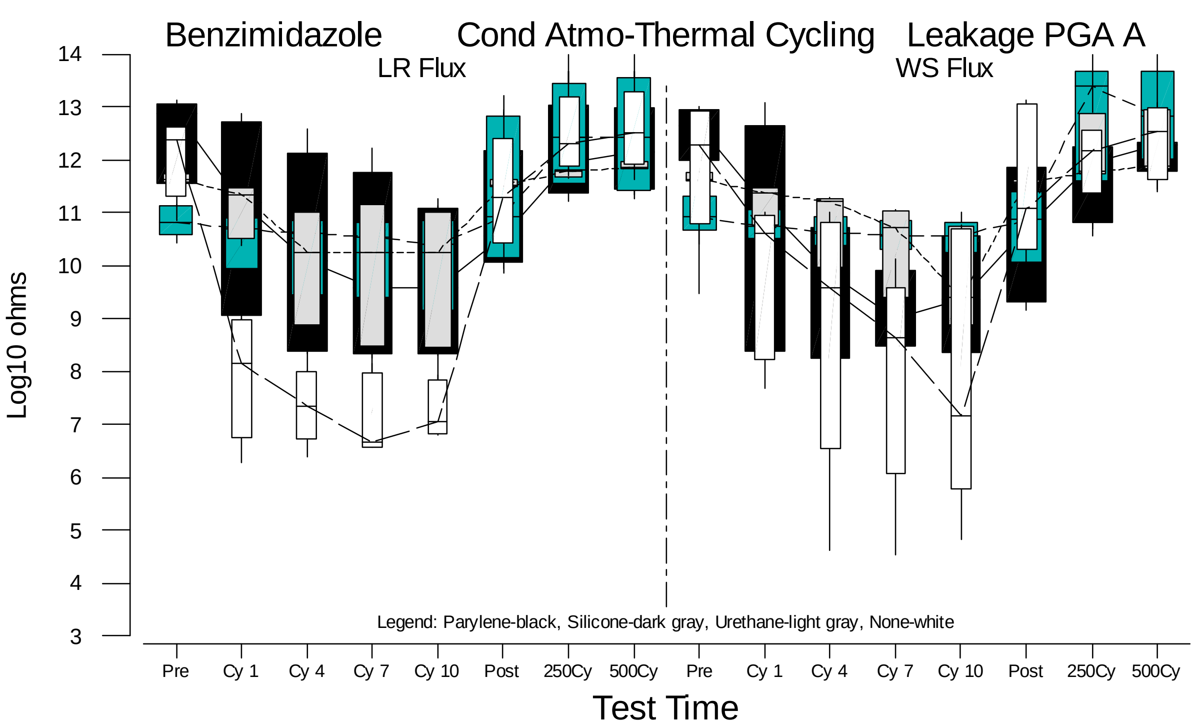

Figure 5.16 Boxplots of Leakage Measurements for PGA-A versus Test Time for Benzimidazole

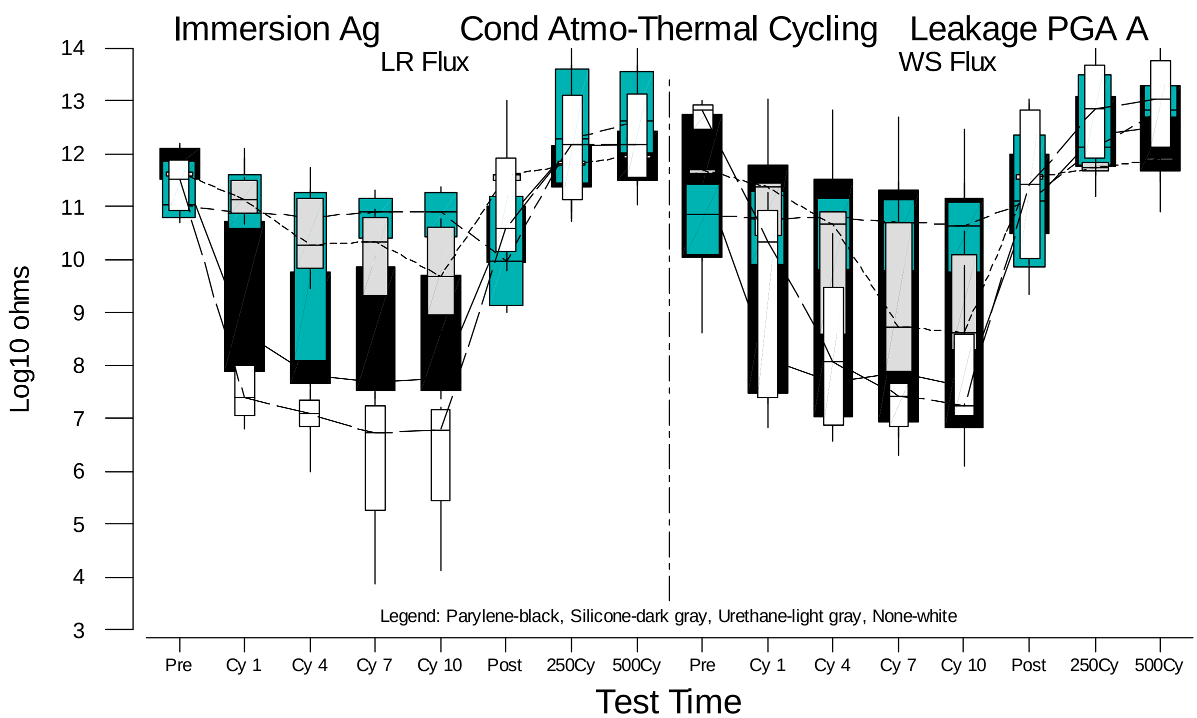

Figure 5.17 Boxplots of Leakage Measurements for PGA-A versus Test Time for Immersion Ag

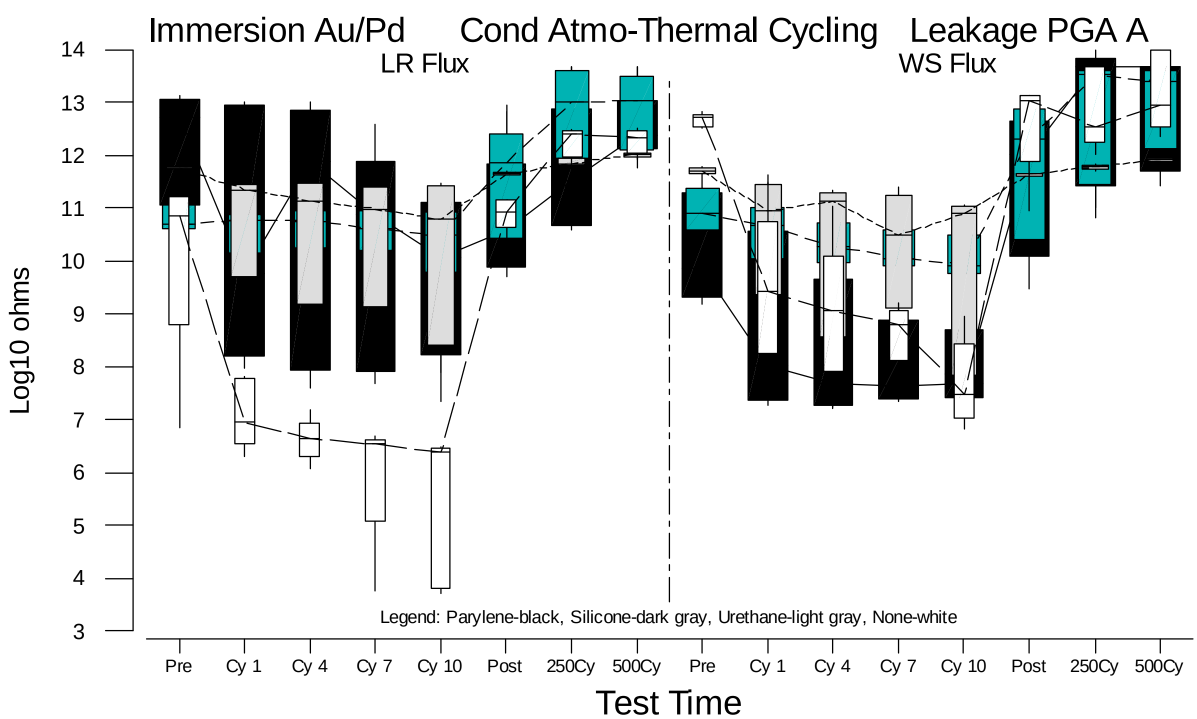

Figure 5.18 Boxplots of Leakage Measurements for PGA-A versus Test Time for Immersion Au/Pd

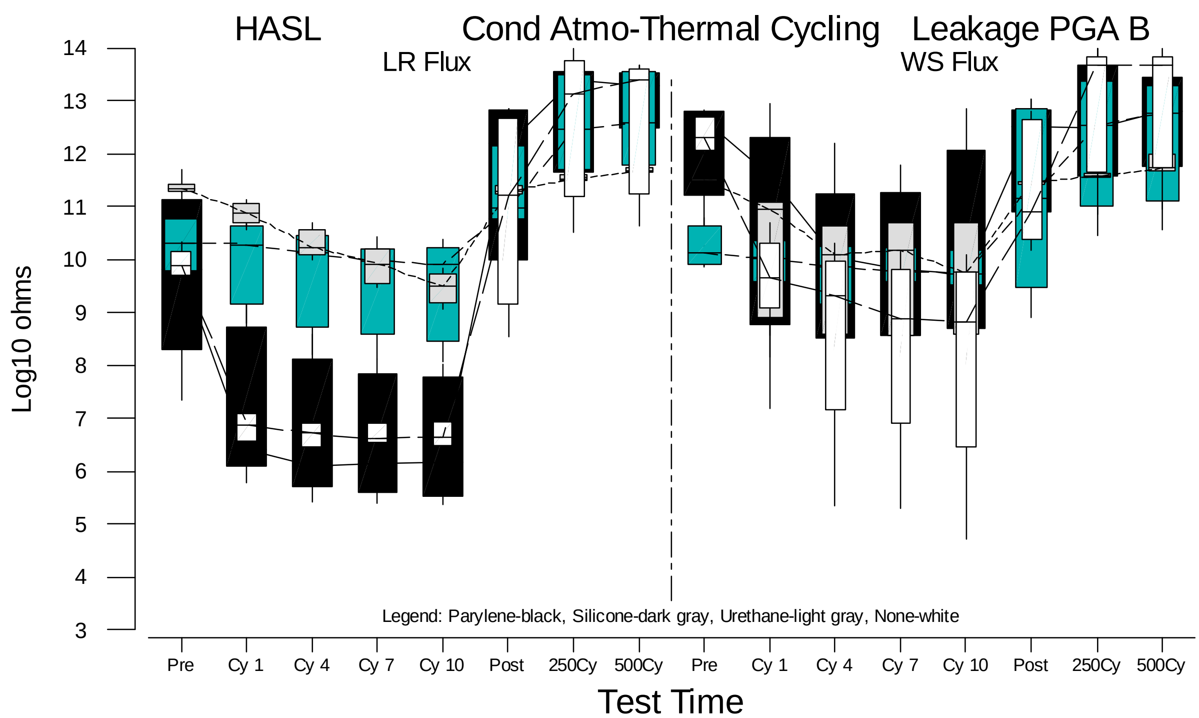

Figure 5.19 Boxplots of Leakage Measurements for PGA-B versus Test Time for HASL

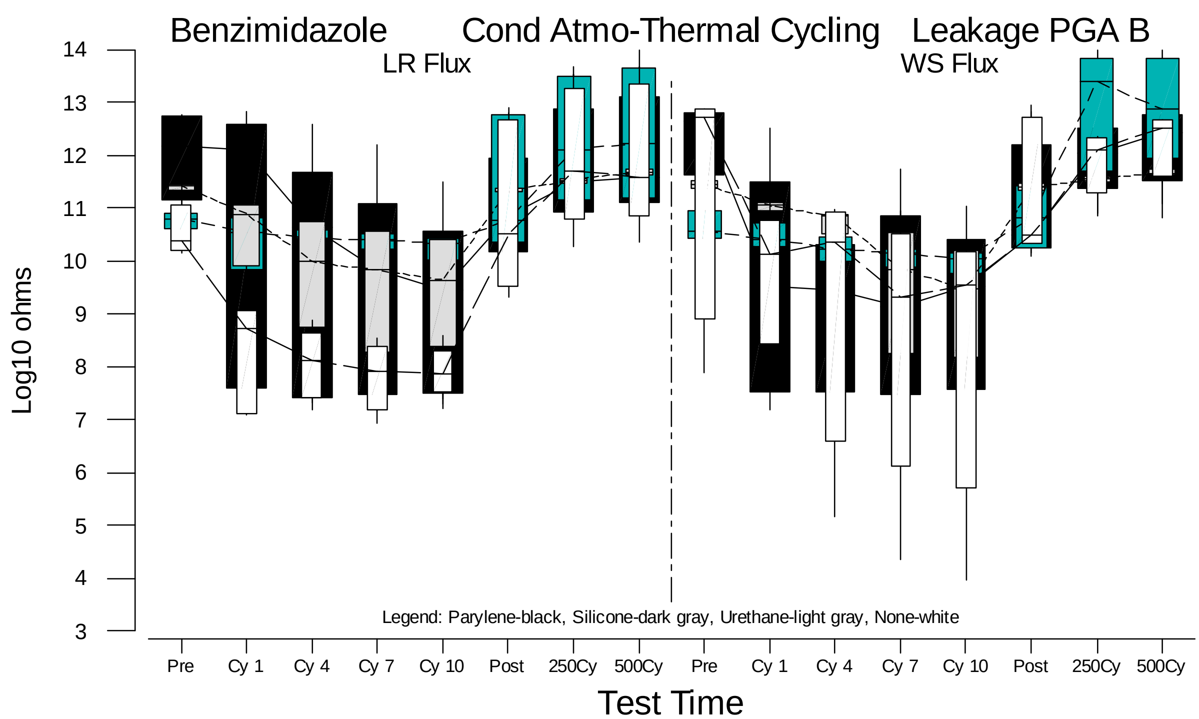

Figure 5.20 Boxplots of Leakage Measurements for PGA-B versus Test Time for Benzimidazole

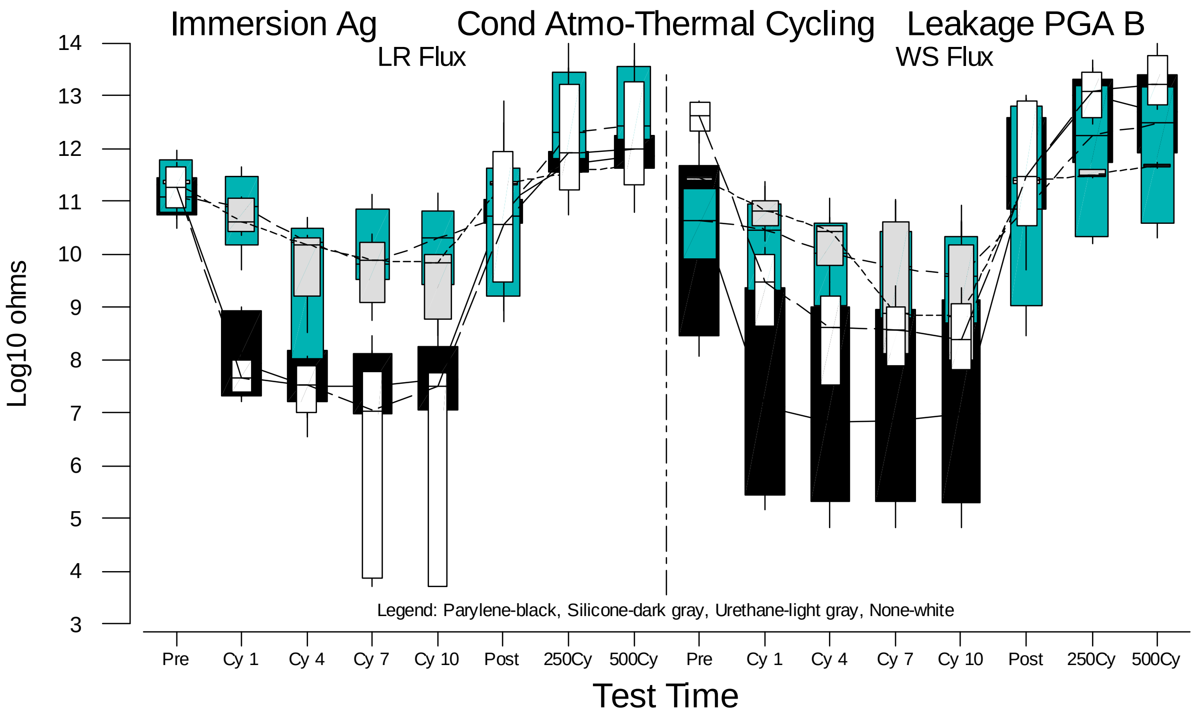

Figure 5.21 Boxplots of Leakage Measurements for PGA-B versus Test Time for Immersion Ag

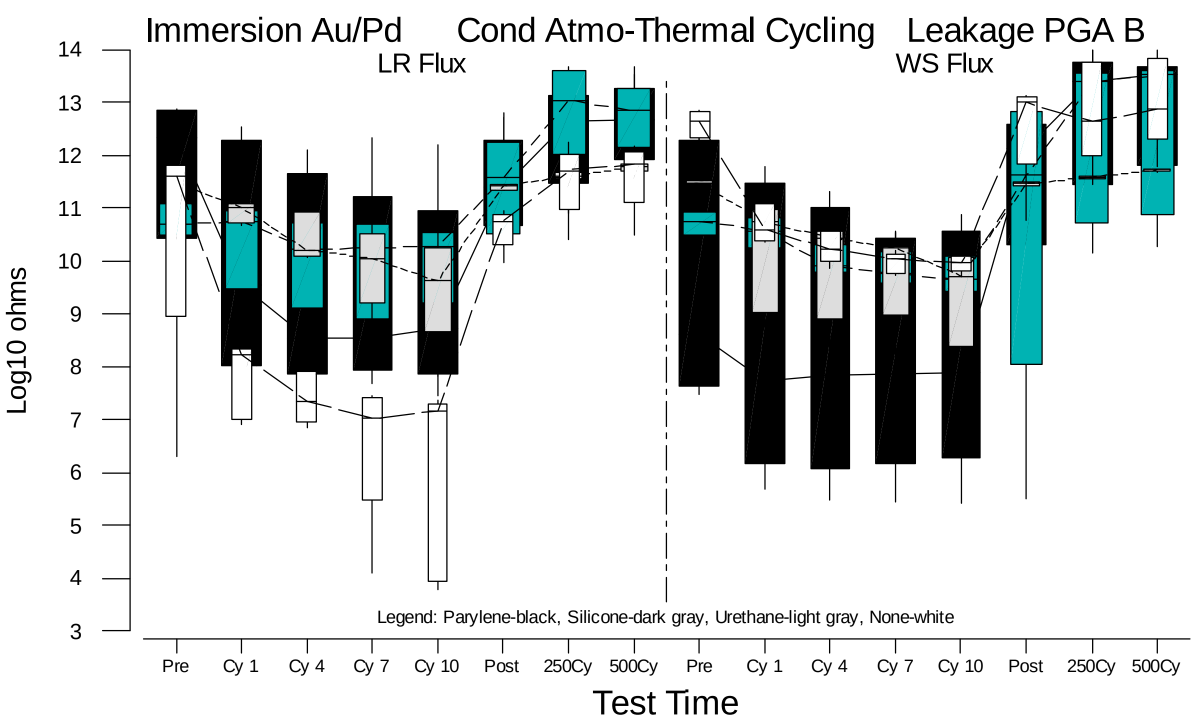

Figure 5.22 Boxplots of Leakage Measurements for PGA-B versus Test Time for Immersion Au/Pd

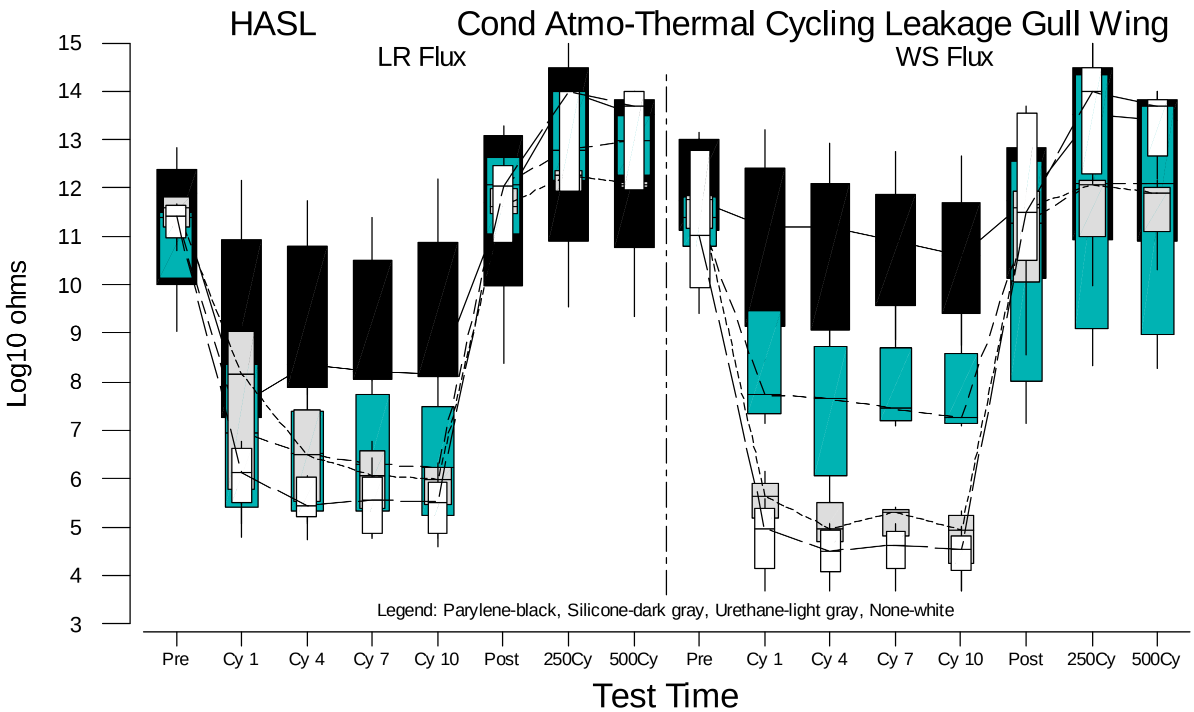

Figure 5.23 Boxplots of Leakage Measurements for the Gull Wing versus Test Time for HASL

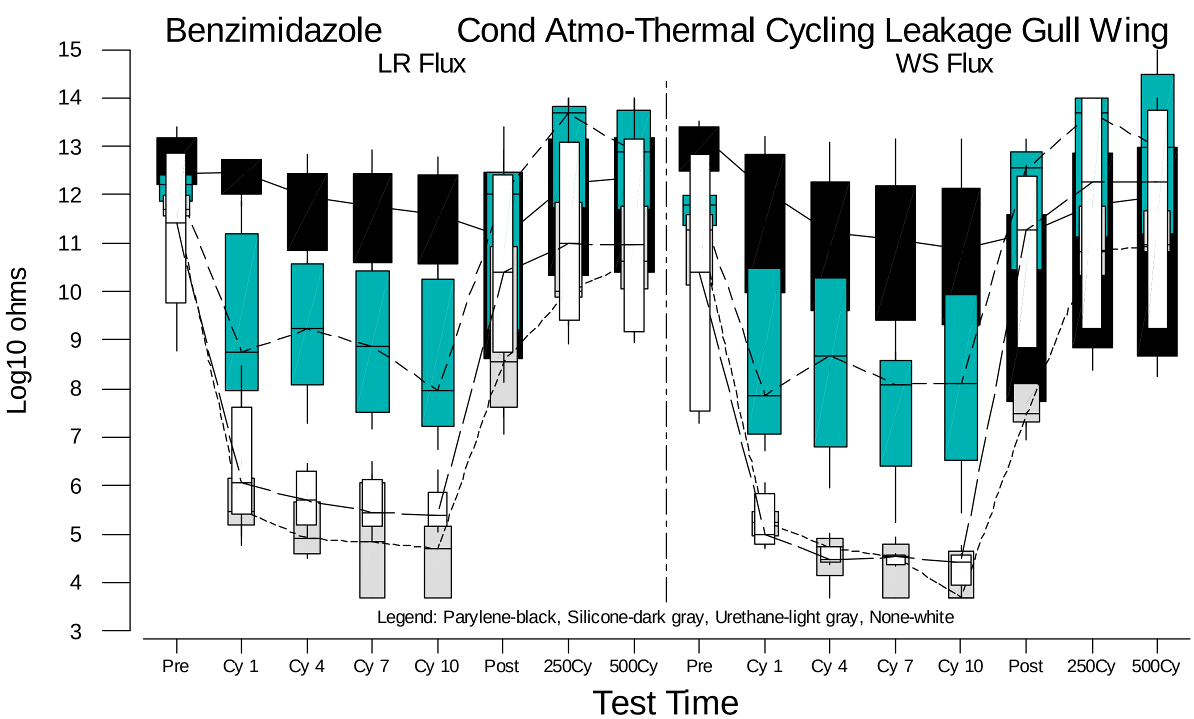

Figure 5.24 Boxplots of Leakage Measurements for the Gull Wing versus Test Time for Benzimidazole

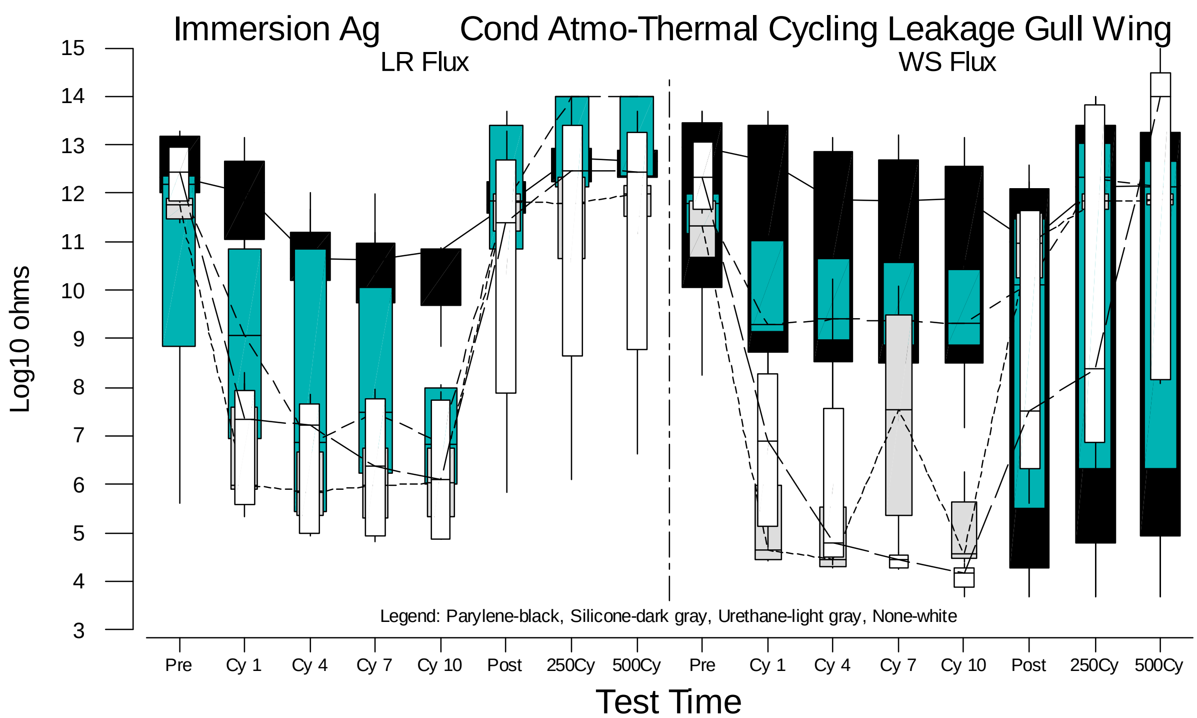

Figure 5.25 Boxplots of Leakage Measurements for the Gull Wing versus Test Time for Immersion Ag

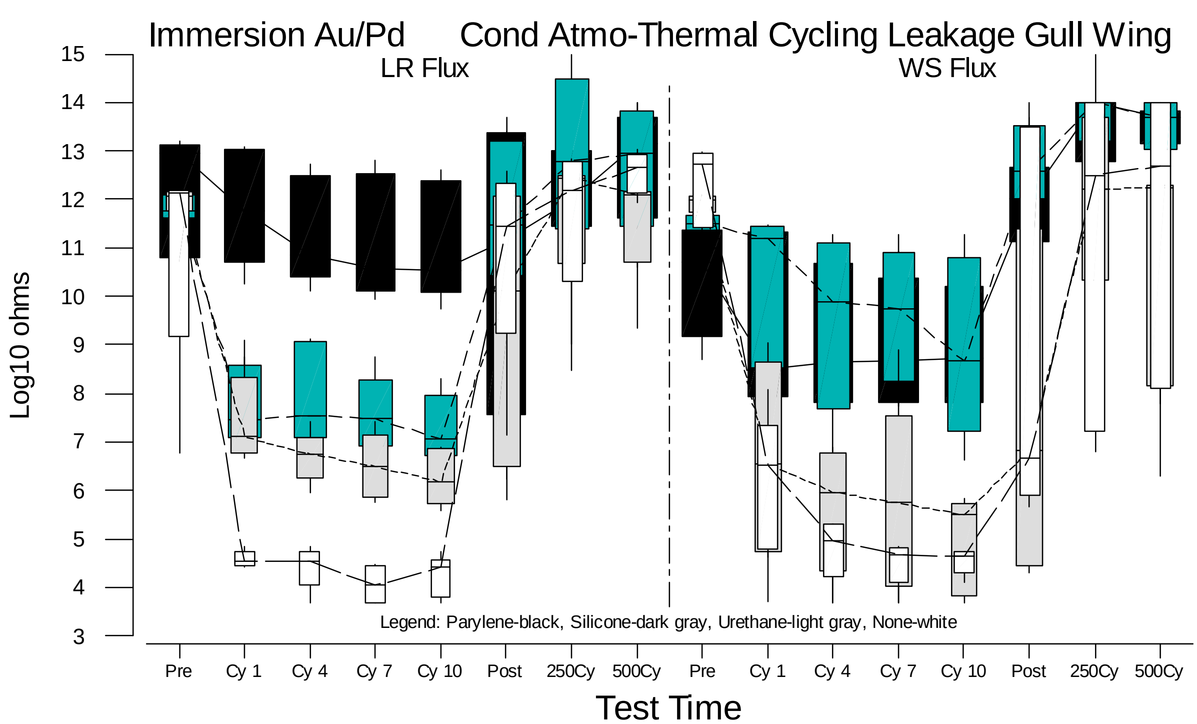

Figure 5.26 Boxplots of Leakage Measurements for the Gull Wing versus Test Time for Immersion Au/Pd

Table 5.30 Predicted Changes from the Base Case for PGA-A During Cycle 10

		No Coating	Parylene	Silicone	Urethane
HASL	**LR**			3.84	3.56
	WS	1.14	3.92	3.78	3.13
Benzimidazole	**LR**		3.15	3.84	3.56
	WS	1.14	2.87	3.78	3.13
Immersion Ag	**LR**		1.92	3.84	3.56
	WS	1.14	2.14	3.78	3.13
Immersion Au/Pd	**LR**		3.22	3.84	3.56
	WS	1.14	1.44	3.78	3.13

The predicted base case value in Table G.19 during Cycle 10 is 6.54, which is above that for the 10-mil pads at the same test time, but still below the JTP acceptance criterion. The predicted changes during Cycle 10 in Table 5.30 show that the resistance for silicone and urethane coated PWAs is approximately 3 orders of magnitude higher for all cases, which puts them well above the JTP acceptance criterion. Parylene does not give as much increase in resistance over the base case as the other coatings, but the increase is sufficient to meet the JTP acceptance criterion in all cases except for HASL processed with LR flux. Use of WS flux with uncoated PWAs increases resistance by approximately 1.14 orders of magnitude for all surface finishes.

The predicted base case value in Table G.19 at Post-test is 11.37, which is approximately 3.7 orders of magnitude above the JTP acceptance criterion. The predicted changes at Post-test in Table 5.31 show that all cases meet the JTP acceptance criterion and there is very little variability in the predictions.

Table 5.31 Predicted Changes from the Base Case for PGA-A at Post-Test

		No Coating	Parylene	Silicone	Urethane
HASL	**LR**				
	WS				
Benzimidazole	**LR**				
	WS				
Immersion Ag	**LR**			-0.75	
	WS			-0.75	
Immersion Au/Pd	**LR**				
	WS	0.52	0.52	0.52	0.52

The predicted base case value in Table G.19 after 500TC is 12.66, which is nearly five orders of magnitude above the JTP acceptance criterion. The predicted changes after 500TC in Table 5.32 show that all non-urethane cases are the same as the base case while urethane coated PWAs are about 0.7 orders of magnitude less than the base case. All cases meet the JTP acceptance criterion.

Table 5.32 Predicted Changes from the Base Case for PGA-A after 500 Thermal Cycles

		No Coating	Parylene	Silicone	Urethane
HASL	**LR**				-0.68
	WS				-0.68
Benzimidazole	**LR**				-0.68
	WS				-0.68
Immersion Ag	**LR**				-0.68
	WS				-0.68
Immersion Au/Pd	**LR**				-0.68
	WS				-0.68

Displays. Figures 5.15 to 5.18 (also Figures H.73 to H.76) present boxplots for the PGA-A resistance measurements versus test time for the HASL, benzimidazole, immersion Ag, and immersion Au/Pd surface finishes, respectively. These graphs support the conclusions of the GLM analyses and provide useful information relative to the influence of surface finish, coating status, and flux. These figures are summarized as follows.

- The negative impact of the CA environment is apparent in all graphs, particularly for uncoated PWAs and parylene coated PWAs with HASL finish
- Silicone generally gives excellent results and low variability throughout the CA test for all surface finishes and fluxes
- Resistance varied over several orders of magnitude during the CA test for PWAs coated with parylene
- Resistance for uncoated PWAs were unacceptable during Cycle 10 for most surface finish and flux combinations
- Resistance measurements improved from Post-test to thermal cycling and all measurements met the JTP acceptance criterion during TC

Comparison to JTP Acceptance Criterion. There was one PGA-A anomaly at Pre-test that did not meet the JTP acceptance criterion. During Cycle 10 of the CA test there were 46 anomalies. There were no anomalies at Post-test or after thermal cycling.

PGA-B. The predicted base case value at Pre-test is given in Table G.20 as 10.54, which is well above the JTP acceptance criterion of 7.70. There were three anomalies at Pre-test. The predicted changes from the base case at Pre-test are given in Table 5.33. All cases in this table meet the JTP acceptance criterion. Uncoated PWAs give approximately the same increase in resistance over the base case as coated PWAs except for benzimidazole and immersion Au/Pd processed with LR flux, where there is no change. Recall that the pattern on PGA-B was covered with solder mask.

Table 5.33 Predicted Changes from the Base Case for PGA-B at Pre-Test

		No Coating	Parylene	Silicone	Urethane
HASL	**LR**				0.77
	WS	1.80	1.80	-0.14	0.83
Benzimidazole	**LR**		1.33		0.77
	WS	0.58	1.91	0.12	0.92
Immersion Ag	**LR**	0.39	0.39	0.39	1.16
	WS	2.19	-0.29	0.25	1.22
Immersion Au/Pd	**LR**		1.24		0.77
	WS	1.80	-0.86	-0.14	0.83

The predicted basecase value in Table G.20 during Cycle 10 is 6.80, which is below the JTP acceptance criterion. As was the case for PGA-A, the predicted changes during Cycle 10 in Table 5.34 show that the resistance for silicone and urethane coated PWAs is approximately three orders of magnitude higher for all cases, which puts them well above the JTP acceptance criterion. Parylene does not give as much increase in resistance over the base case as the other coatings, but the increase is sufficient to meet the JTP acceptance criterion in all cases except HASL processed with LR flux and immersion Ag processed with either flux. Use of WS flux with uncoated PWAs increases resistance by approximately 1.92 orders of magnitude for all surface finishes, which is sufficient to meet the acceptance criterion for all surface finishes.

Table 5.34 Predicted Changes from the Base Case for PGA-B During Cycle 10

		No Coating	Parylene	Silicone	Urethane
HASL	**LR**			3.16	2.67
	WS	1.92	3.45	2.97	2.52
Benzimidazole	**LR**		2.32	3.16	2.67
	WS	1.92	2.27	2.97	2.52
Immersion Ag	**LR**			3.16	2.67
	WS	1.92	0.36	2.97	2.52
Immersion Au/Pd	**LR**		2.47	3.16	2.67
	WS	1.92	1.52	2.97	2.52

The predicted base case value in Table G.19 at Post-test is 11.23, which is approximately 3.5 orders of magnitude above the JTP acceptance criterion. The predicted changes at Post-test in Table 5.35 show that all cases meet the JTP acceptance criterion and very little variability in the predictions.

Table 5.35 Predicted Changes from the Base Case for PGA-B at Post-Test

		No Coating	Parylene	Silicone	Urethane
HASL	**LR**				
	WS				
Benzimidazole	**LR**				
	WS				
Immersion Ag	**LR**				
	WS				
Immersion Au/Pd	**LR**				
	WS	0.65	0.65	-0.56	0.65

Table 5.36 Predicted Changes from the Base Case for PGA-B after 500 Thermal Cycles

		No Coating	Parylene	Silicone	Urethane
HASL	**LR**				-0.79
	WS				-0.79
Benzimidazole	**LR**				-0.79
	WS				-0.79
Immersion Ag	**LR**				-0.79
	WS				-0.79
Immersion Au/Pd	**LR**				-0.79
	WS				-0.79

The predicted base case value in Table G.20 after 500TC is 12.51, which is approximately 4.8 orders of magnitude above the JTP acceptance criterion. The predicted changes after 500TC in Table 5.36 show that all cases meet the JTP acceptance criterion with urethane being approximately 0.79 orders of magnitude lower than all the other cases, but still well above the JTP acceptance criterion.

Displays. Figures 5.19 to 5.22 (also Figures H.77 to H.80) present boxplots for the PGA-B resistance measurements versus test time for HASL, benzimidazole, immersion Ag, and immersion Au/Pd, respectively. These graphs support the conclusions of the GLM analyses and provide useful information relative to the influence of surface finish, coating status, and flux. These figures are summarized as follows.

- The negative impact of the CA environment is apparent in all graphs
- Resistance for uncoated PWAs was unacceptable during Cycle 10 for HASL LR, immersion Ag LR, and immersion Au/Pd LR, but generally had resistance at or above the JTP acceptance criterion for all other surface finish and flux combinations
- Resistance for parylene coated PWAs was unacceptable during Cycle 10 for the following surface finish and flux combinations: HASL with LR, immersion Ag with WS, and immersion Au/Pd with WS
- Silicone gives excellent results and low variability throughout the CA test for all surface finishes and fluxes
- Resistance varied over several orders of magnitude during the CA test for PWAs coated with parylene
- Resistance measurements improved from Post-test to TC and all measurements met the JTP acceptance criterion during TC

Comparison to JTP Acceptance Criterion. There were three anomalies for PGA-B that did not meet the JTP acceptance criterion at Pre-test. During Cycle 10 of the CA test there were 39 anomalies. There was only one anomaly at Post-test and none at 500TC.

Gull Wing. The predicted base case value for the gull wing at Pre-test is given in Table G.21 as 11.62, which is well above the JTP acceptance criterion of 7.70. There were three anomalies at Pre-test. The model R^2 at Pre-test was only 9.4%. Even though this model R^2 is quite small, the predicted changes from the base case at Pre-test are given in Table 5.37 for purposes of comparison with model results for other Pre-test leakage measurements. This table shows an increase in resistance for benzimidazole coated with parylene and processed with either flux. Also, immersion Au/Pd coated with parylene and processed with WS flux had a decrease in resistance, but were still well above the acceptance criterion.

Table 5.37 Predicted Changes from the Base Case for the Gull Wing at Pre-test

		No Coating	Parylene	Silicone	Urethane
HASL	**LR**				
	WS				
Benzimidazole	**LR**		1.21		
	WS		1.21		
Immersion Ag	**LR**				
	WS				
Immersion Au/Pd	**LR**				
	WS		-1.25		

The predicted base value during Cycle 10 in Table G.21 is 5.25. This is the lowest predicted value among the four leakage circuits at this test time and is well below the JTP acceptance criterion. The predicted changes during Cycle 10 in Table 5.38 must be at least 7.70 - 5.25 = 2.45 to meet the acceptance criterion. These predictions show that all of the uncoated and urethane coated cases fail to meet the acceptance criterion. The resistance for parylene coated PWAs is approximately 3.7 to 6 orders of magnitude higher than the base case for all surface finish/flux combinations, which puts them well above the JTP acceptance criterion. Resistance increases by approximately 1.4 to 3.9 orders of magnitude for silicone, with the following three cases failing to meet the acceptance criterion: HASL, immersion Ag, and immersion Au/Pd all processed with LR flux.

Table 5.38 Predicted Changes from the Base Case for the Gull Wing During Cycle 10

		No Coating	Parylene	Silicone	Urethane
HASL	**LR**		4.52	1.41	
	WS	-0.99	4.86	3.30	-0.99
Benzimidazole	**LR**		5.72	3.34	
	WS	-0.99	6.06	2.96	-0.99
Immersion Ag	**LR**	0.63	5.15	2.04	0.63
	WS	-0.36	5.49	3.93	-0.36
Immersion Au/Pd	**LR**		5.85	1.41	0.84
	WS	-0.99	3.72	3.30	-0.15

The predicted base case value at Post-test in Table G.21 is 11.25, which is well above the JTP acceptance criterion. The predicted changes given in Table 5.39 for Post-test show urethane with the poorest results, including one case (immersion Au/Pd with WS) that does not meet the acceptance criterion. Use of WS flux has a negative effect on both immersion Ag and immersion Au/Pd.

Table 5.39 Predicted Changes from the Base Case for the Gull Wing at Post-test

		No Coating	Parylene	Silicone	Urethane
HASL	**LR**				
	WS				
Benzimidazole	**LR**				-2.85
	WS				-2.85
Immersion Ag	**LR**				
	WS	-1.95	-1.95	-1.95	-1.95
Immersion Au/Pd	**LR**				-1.66
	WS	-2.02	0.68	1.48	-3.68

The predicted base case value after 500TC in Table G.21 is 12.35. This value is approximately 4.6 orders of magnitude above the JTP acceptance criterion and leaves little room for improvement. All entries in Table 5.40 meet the acceptance criterion. Benzimidazole runs about an order of magnitude lower than the base case except for PWAs coated with silicone. The predicted changes given in Table 5.40 for 500TC show an adverse effect for immersion Ag coated with either parylene or silicone and processed with WS flux. Immersion Au/Pd with WS has lower resistance for uncoated and urethane but higher for parylene and silicone.

Table 5.40 Predicted Changes from the Base Case for the Gull Wing after 500TC

		No Coating	Parylene	Silicone	Urethane
HASL	**LR**				
	WS				
Benzimidazole	**LR**	-1.04	-1.04	0.48	-1.04
	WS	-1.04	-1.04	0.48	-1.04
Immersion Ag	**LR**				
	WS		-2.63	-2.33	
Immersion Au/Pd	**LR**				
	WS	-1.34	1.16	1.16	-1.34

Displays. Figures 5.23 to 5.26 (also Figures H.81 to H.84) present boxplots for the gull wing resistance measurements versus test time for HASL, benzimidazole, immersion Ag, and immersion Au/Pd, respectively. These graphs support the conclusions of the GLM analyses and provide useful information relative to the influence of surface finish, coating status, and flux. These figures are summarized as follows.

- The negative impact of the CA environment is apparent in all graphs
- Parylene coated PWAs had the best performance throughout the CA test
- Uncoated PWAs and urethane coated PWAs had the worst performance throughout the CA test
- Resistance for uncoated and urethane coated PWAs was unacceptable during Cycle 10 for all surface finish and flux combinations
- Resistance for silicone coated PWAs was unacceptable during Cycle 10 for the following surface finish and flux combinations: HASL with LR, immersion Ag with LR, and immersion Au/Pd with LR
- Resistance varied from one to seven orders of magnitude during the CA test for PWAs coated with parylene or silicone
- The resistance measurements improved from Post-test to TC and all measurements met the JTP acceptance criterion during TC except for immersion Ag with WS flux

Comparison to JTP Acceptance Criterion. There were three anomalies for the gull wing that did not meet the JTP acceptance criterion at Pre-test. During Cycle 10 of the CA test there were 99 anomalies. There were 27 anomalies at Post-test, but only eight at 250TC and five at 500TC. The failure analysis results for the later five anomalies are summarized in Table 5.41. Only two of these anomalies are severe enough to justify failure analysis: MSNs 483 and 511.

Table 5.41 Failure Analysis Results for the Gull Wing after 500 Thermal Cycles

MSN	Surface Finish	Coating	Flux	Resistance	Failure Analysis Results
155	Immersion Ag	None	LR	6.63	FA not required
483	Immersion Ag	Parylene	WS	3.69	
478	Immersion Ag	Parylene	WS	5.91	FA not required
511	Immersion Ag	Silicone	WS	3.69	
892	Immersion Au/Pd	Urethane	WS	7.67	FA not required

5.9 Stranded Wires. Two stranded wires were hand soldered on the LRSTF PWA (responses 22 and 23 in Table 1.1). One wire was soldered into plated through holes and the other was soldered to two terminals. The JTP acceptance criterion requires changes in voltage to be within 0.356V of their Pre-test measurements. Pre-test measurements for both stranded wires were subjected to GLM analyses, as were the deviations during Cycles 1, 4, 7, and 10 of the CA test, at Post-test, and after 250TC and 500TC. The results of the GLM analyses appear in Tables G.22 and G.23. The model R^2s in those tables are summarized as follows.

Circuit	Pre-test	Cycle 1	Cycle 4	Cycle 7	Cycle 10	Post-test	250TC	500TC
Stranded Wire 1	2.2%	11.8%	19.8%	10.5%	27.5%	0.7%	3.0%	4.3%
Stranded Wire 2	16.8%	12.9%	6.9%	5.5%	6.5%	17.2%	21.8%	13.6%

These R^2 values are quite small and imply that the experimental parameters do not differ significantly from the base case in terms of their impact on the stranded wire voltages.

Displays. Figures H.85 to H.88 present boxplots for stranded wire 1 voltage measurements versus test time for HASL, benzimidazole, immersion Ag, and immersion Au/Pd, respectively. The corresponding boxplots for stranded wire 2 voltage measurements appear in Figures H.89 to H.92. All boxplots overlap throughout the CA-TC test sequence and do not appear to be influenced by the test environments.

Comparison to JTP Acceptance Criterion. There were no anomalous measurements for stranded wires during the CA test or at Post-test. After thermal cycling there two slight anomalies on a single PWA. These values were both just above the upper JTP acceptance limit of 0.356V at 0.375V and 0.366V, neither of which is of sufficient magnitude to be of concern.

5.10 Summary and Conclusions. Detailed results of the electrical performance of 160 LRSTF PWAs have been presented after they were exposed to 10 cycles in a condensing atmosphere environment followed by 500 thermal cycles. These PWAs were each tested at Pre-test, during Cycles 1, 4, 7, and 10 of the CA test, at Post-test following the CA test, and after 250TC and 500TC. At each test time, 3680 electrical measurements were recorded and compared to their respective JTP acceptance criteria.

Summary of Success Rates by Circuit Type. At the completion of the CA/TC test sequence, nine of the 23 LRSTF PWA circuits had no anomalies while an additional 11 circuits had three or fewer anomalies. The three remaining circuits had four, five, and six anomalies. Table 5.42 provides a summary of the success rates in meeting the JTP acceptance criterion by major circuit type during Cycle 10, at Post-test, and after 250TC and 500TC. This summary shows that the CA test adversely affected the HVLC and leakage circuits, and to a lesser extent the HF TLC circuit. On the other hand, the yields were high for all circuits for the TC test.

Table 5.42 Summary of the Success Rates for Major Circuit Groups in Meeting the JTP Acceptance Criterion During the Condensing Atmosphere/Thermal Cycling Test Sequence

Circuitry	CA Cycle 10	Post-Test	250TC	500TC
HCLV	320/320 = 100.0%	319/320 = 99.7%	318/320 = 99.4%	317/320 = 99.1%
HVLC	188/320 = 58.8%	315/320 = 98.4%	318/320 = 99.4%	318/320 = 99.4%
HSD	315/320 = 98.4%	320/320 = 100.0%	318/320 = 99.4%	320/320 = 100.0%
HF LPF	957/960 = 99.7%	959/960 = 99.9%	947/960 = 98.6%	955/960 = 99.5%
HF TLC	748/800 = 93.5%	730/800 = 91.3%	788/800 = 98.5%	788/800 = 98.3%
ON	410/640 = 64.1%	610/640 = 95.3%	631/640 = 98.6%	634/640 = 99.1%
SW	320/320 = 100.0%	320/320 = 100.0%	318/320 = 99.4%	318/320 = 99.4%
Totals	3258/3680 = 88.5%	3573/3680 = 97.1%	3638/3680 = 98.9%	3650/3680 = 99.2%

Summary of Anomalies by Experimental Parameters. During Cycle 10 of the CA test, there were 422 anomalies that did not meet the JTP acceptance criterion. The number of anomalies at Post-test was reduced to 107. After 250TC and 500TC there were only 42 and 30 anomalies, respectively. Most of the decrease at 500TC was due to improvements in the performance of the HVLC and ON circuits. The anomalies are summarized by surface finish, coating status, and flux type for each test time in Table 5.43.

Summary of the Anomalies by PWA. Thirty-seven of the 160 PWAs survived the CA test without any anomalies. The remaining 123 PWAs each had from one to 11 anomalies. At Post-test there were 76 PWAs without anomalies and the remaining 84 PWAs had from one to three anomalies. After 250TC there were 133 PWAs without anomalies and the remaining 27 PWAs had from one to three anomalies. After 500TC there were 138 PWAs without anomalies and the remaining 22 PWAs had from one to four anomalies. The complete frequency distribution of the number of anomalies per PWA is given in Table 5.44 for these test times.

Table 5.45 tabulates PWAs that had at least one anomaly by surface finish during Cycle 10, at Post-test, after 250TC, and after 500TC. This table shows that all 40 of the PWAs without coating and all 40 with urethane coating at least one anomaly during Cycle 10, while parylene and silicone had 21 and 22, respectively. The corresponding numbers at Post-test were: uncoated (26), parylene (23), silicone (19), and urethane (16). The respective counts after 250TC were: uncoated (12), parylene (6), and silicone (5) and urethane (7). After 500TC, the counts were: uncoated (3), parylene (6), and silicone (6) and urethane (7).

Table 5.43 Tabulation of Anomalies that Did Not Meet the JTP Acceptance Criterion by Test Time

Test Time	Surface Finish		Coating Status		Flux Type	
Cycle 10	HASL	119	None	225	LR	236
	Benzimidazole	88	Parylene	46	WS	186
	Immersion Ag	108	Silicone	34		
	Immersion Au/Pd	107	Urethane	117		
	Totals	422		422		422
Post-Test	HASL	22	None	32	LR	52
	Benzimidazole	28	Parylene	32	WS	55
	Immersion Ag	28	Silicone	26		
	Immersion Au/Pd	29	Urethane	17		
	Totals	107		107		107
250TC	HASL	10	None	12	LR	17
	Benzimidazole	5	Parylene	14	WS	25
	Immersion Ag	14	Silicone	7		
	Immersion Au/Pd	13	Urethane	9		
	Totals	42		42		42
500TC	HASL	4	None	6	LR	7
	Benzimidazole	3	Parylene	6	WS	23
	Immersion Ag	13	Silicone	10		
	Immersion Au/Pd	10	Urethane	8		
	Totals	30		30		30

Table 5.44 Number of Anomalies per PWA by Test Time

Anomalies per PWA	Cycle 10	Post-Test	250 TC	500 TC
0	37	76	133	138
1	26	66	17	17
2	24	13	5	3
3	22	5	5	1
4	14			1
5	15			
6	9			
7	10			
8	2			
11	1			
Totals	160	160	160	160

Chi-Square Tests of Independence. A chi-square test can be used to determine if the number of anomalies at each test time is independent of surface finish (the interested reader can find complete details of this test in Chapter 10 of Iman, 1994). Table 5.46 presents the anomaly frequencies by surface finish at each test time. The chi-square analysis of the frequencies in Table 5.46 for Cycle 10 shows that the number of anomalies and surface finish are independent of one another (p-value = 0.814, the p-value is a measure of statistical significance and should be < 0.05 to declare a statistical difference). The same is true at Post-test, after 250TC, and after 500TC where the respective p-values were 0.896, 0.296, and 0.310.

The chi-square test was also be used to determine if the number of anomalies at each test time was independent of coating status. Table 5.47 presents the anomaly frequencies by coating status at each test time. The chi-square analysis of the frequencies in Table 5.47 for Cycle 10 indicates a strong relationship between the number of anomalies and coating status (p-value = 0.000). That is, uncoated and urethane coated PWAs have significantly more anomalies than those coated with either parylene or silicone during the CA test. There is independence between coating status and the number of anomalies at Post-test, after 250TC, and after 500TC

Table 5.45 Tabulation of the PWAs That Had At Least One Anomaly at Each Test Time

Cycle 10

Surface Finish	Flux	No Coating	Parylene	Silicone	Urethane	Totals
HASL (32)	**LR**	5	4	4	5	18
	WS	5		4	5	14
Benzimidazole (29)	**LR**	5	3	1	5	14
	WS	5	2	3	5	15
Immersion Ag (30)	**LR**	5	3	3	5	16
	WS	5	4		5	14
Immersion Au/Pd (32)	**LR**	5	2	5	5	17
	WS	5	3	2	5	15
LR = 65, WS = 58	**Totals**	40	21	22	40	12

Post-Test

Surface Finish	Flux	No Coating	Parylene	Silicone	Urethane	Totals
HASL (19)	**LR**	5	1	3	2	11
	WS	2	2	3	1	8
Benzimidazole (22)	**LR**	3	4	3	2	12
	WS	1	4	1	4	10
Immersion Ag (22)	**LR**	3	3	3	1	10
	WS	5	3	3	1	12
Immersion Au/Pd (21)	**LR**	3	3	1	2	9
	WS	4	3	2	3	12
LR = 42, WS = 42	**Totals**	26	23	19	16	84

250 Thermal Cycles

Surface Finish	Flux	No Coating	Parylene	Silicone	Urethane	Totals
HASL (7)	**LR**		2		3	5
	WS		1	1		2
Benzimidazole (3)	**LR**		2			2
	WS	1				1
Immersion Ag (9)	**LR**	1			1	2
	WS	3	2	1	1	7
Immersion Au/Pd (8)	**LR**			2	1	3
	WS	2	1	1	1	5
LR = 12, WS = 15	**Totals**	12	6	5	7	27

500 Thermal Cycles

Surface Finish	Flux	No Coating	Parylene	Silicone	Urethane	Totals
HASL (4)	**LR**		1		1	2
	WS			2		2
Benzimidazole (3)	**LR**		2		1	3
	WS					
Immersion Ag (8)	**LR**	1				1
	WS	1	2	2	2	7
Immersion Au/Pd (7)	**LR**					
	WS	1	1	2	3	7
LR = 6, WS = 16	**Totals**	3	6	6	7	22

Table 5.46 Summary of Anomalies by Surface Finish at Each Test Time

Test Time	Anomalies	HASL	Benzi	Imm Ag	Imm Au/Pd	Totals
Cycle 10	None	8	11	10	8	37
	At least 1	32	29	30	32	123
	Totals	40	40	40	40	160
Post-Test	None	21	18	18	19	76
	At least 1	19	22	22	21	84
	Totals	40	40	40	40	160
250TC	None	33	37	31	32	133
	At least 1	7	3	9	8	27
	Totals	40	40	40	40	160
500TC	None	36	37	32	33	138
	At least 1	4	3	8	7	22
	Totals	40	40	40	40	160

Table 5.47 Summary of Anomalies by Coating Status at Each Test Time

Test Time	Anomalies	None	Parylene	Silicone	Urethane	Totals
Cycle 10	None	0	19	18	0	37
	At least 1	40	21	22	40	123
	Totals	40	40	40	40	160
Post-Test	None	14	17	21	24	76
	At least 1	26	23	19	16	84
	Totals	40	40	40	40	160
250TC	None	28	34	35	33	130
	At least 1	12	6	5	7	30
	Totals	40	40	40	40	160
500TC	None	37	34	34	33	138
	At least 1	3	6	6	7	22
	Totals	40	40	40	40	160

Table 5.48 Summary of Anomalies by Flux Type at Each Test Time

Test Time	Anomalies	LR	WS	Totals
Cycle 10	None	15	22	37
	At least 1	65	58	123
	Totals	80	80	160
Post-Test	None	38	38	76
	At least 1	42	42	84
	Totals	80	80	160
250TC	None	68	65	133
	At least 1	12	15	27
	Totals	80	80	160
500TC	None	74	64	138
	At least 1	6	16	22
	Totals	80	80	160

where the respective p-values were 0.121, 0.190, and 0.594. Thus, parylene and silicone coating helped during the CA test, but coating did not help at Post-test or during the TC test.

The chi-square test was also be used to determine if the number of anomalies at each test time was independent of flux type. Table 5.48 presents the anomaly frequencies by flux type at each test time. The chi-square analysis of the frequencies in Table 5.48 for Cycle 10 shows that the number of anomalies was independent of flux type at all test times up to TC500. The respective p-values were 0.189, 1.000, and 0.527. The p-value at TC500 was 0.022, which indicates that WS flux had significantly more anomalies than LR flux. A word of caution is order with regard to this latter result. Table 5.48 shows 6 LR anomalies out of 80 and 16 WS anomalies out of 80. If this split were adjusted by switching only one WS to LR, that is, 7 LR anomalies out of 80 and 15 WS anomalies out of 80, the p-value is 0.057, which is no longer significant at the 0.05 level. Hence, the observed outcome is right on the border of statistical significance.

GLM Analysis of Anomalies. GLM analyses summarized in Sections 5.3 to 5.9 were based on the electrical responses for each of the 23 LRSTF PWA circuits. These analyses provided very useful information about the influence of surface finish, coating status, flux, and their interactions on the electrical responses for each circuit. The GLM analysis can also be used with the actual *number of anomalies on each PWA* rather than on the electrical responses of specific circuits. Such an analysis allows the influence of surface finish, coating status, flux, and their interactions to be viewed in a holistic sense with respect to the functioning of the LRSTF PWA.

Table 5.45 provided simple counts for each experimental cell of the number of PWAs having at least one anomaly at each test time, but it does not indicate the number of anomalies for each PWA. For example, the five PWAs identified for HASL LR in Table 5.45 during Cycle 10 had the following number of anomalies: 7, 7, 7, 7, and 8. Table 5.49 has been constructed to show the number of anomalies for each PWA in a given experimental cell during Cycle 10 (summaries of the number of anomalies at Post-test, after 250TC, and after 500TC are not given since the number of anomalies was smaller at each of these test times). The numbers in Table 5.49 were subjected to a GLM analysis with Equation 1.1 during Cycle 10 to provide holistic information about the LRSTF PWA.

The model R^2 for the GLM analysis of the counts in Table 5.49 was 75.2% during Cycle 10. The predicted value for the base case (HASL without coating and processed with LR flux) was 6.6 anomalies per PWA. Table 5.50 summarizes the predicted changes from the base case value by surface finish, coating status, and flux type.

The Table 5.50 shows that conformal coating has the biggest impact on the number of anomalies. In particular parylene reduces the predicted base case value by 4.6 to 6.4 anomalies per PWA with an average reduction of 5.5 when taken over all 23 electrical circuits during Cycle 10. Silicone reduces the predicted base case value by nearly identical amounts, 4.8 to 6.5 anomalies per PWA with an average reduction of 5.8. Urethane reduces the predicted base case value by 3.2 to 4.4 anomalies per PWA with an average reduction of 3.7.

Table 5.51 gives the actual predicted number of anomalies per PWA by adding the base value (6.6) to the entries in Table 5.50. Table 5.51 shows a slight reduction in the number of anomalies with WS flux for all surface finishes except benzimidazole. In addition, the average number of anomalies for the four surface finishes is: HASL (2.7), benzimidazole (2.2), immersion Ag (2.9), and immersion Au/Pd (2.7). This indicates there is no strong effect due to surface finish.

The predicted number of anomalies for each surface finish can be obtained by multiplying the row averages in Table 5.51 by the number of PWAs in each row (20) and then summing these products for each surface finish. In the case of HASL, the row averages in Table 5.51 are 3.3 for LR and 2.1 for WS. Thus, the predicted number of anomalies for HASL is found as 3.3(20) + 2.1(20) = 108. The averages for the other surface finishes are found in a similar manner: benzimidazole (90), immersion Ag (116), and immersion Au/Pd (110). These predictions show excellent agreement with the respective counts in the summaries in Section 5.2: HASL (119), benzimidazole (88), immersion Ag (108), and immersion Au/Pd (107). Similar predictions can be made for coating and flux by using the corresponding averages and counts in Table 5.51.

There are some interesting interactions in Table 5.51 between coating status and flux type whose interpretations apply to the LRSTF PWA in a holistic sense, but do not necessarily have the same interpretation for any specific circuit type. Their interpretations are as follows.

- WS flux is the best choice for use with uncoated PWAs for all surface finishes except benzimidazole, where LR flux is a slightly better choice

Table 5.49 Tabulation of the Number of Anomalies for Each PWA by Experimental Cell During Cycle 10

Surface Finish	Flux	No Coating	Parylene	Silicone	Urethane
HASL	**LR**	7, 7, 7, 7, 8	0, 1, 3, 3, 5	0, 1, 1, 3, 3	2, 3, 3, 3, 7
	WS	4, 4, 5, 5, 7	0, 0, 0, 0, 0	0, 1, 1, 1, 1	2, 2, 3, 4, 5
Benzimidazole	**LR**	3, 4, 4, 5, 6	0, 0, 1, 1, 1	0, 0, 0, 0, 1	2, 2, 2, 5, 6
	WS	4, 4, 5, 6, 6	0, 0, 0, 1, 3	0, 0, 1, 1, 3	2, 2, 2, 2, 3
Immersion Ag	**LR**	5, 6, 6, 7, 11	0, 0, 1, 2, 3	0, 0, 1, 2, 4	1, 2, 3, 3, 4
	WS	4, 5, 5, 5, 6	0, 1, 2, 2, 5	0, 0, 0, 0, 0	2, 2, 2, 3, 3
Immersion Au/Pd	**LR**	6, 7, 7, 7, 8	0, 0, 0, 1, 1	1, 1, 1, 2, 2	1, 2, 2, 3, 6
	WS	3, 4, 5, 5, 5	0, 0, 2, 3, 4	0, 0, 0, 1, 1	2, 3, 3, 4, 4

Table 5.50 Predicted Changes from the Base Case for Number of Anomalies per PWA During Cycle 10

		No Coating	Parylene	Silicone	Urethane	Averages
HASL	**LR**		-4.7	-4.8	-3.6	-4.4
	WS	-1.7	-6.4	-6.5	-3.7	-4.5
Benzimidazole	**LR**	-1.7	-6.4	-6.5	-3.2	-4.5
	WS	-1.2	-5.9	-6.0	-4.4	-4.4
Immersion Ag	**LR**		-4.7	-4.8	-3.6	-3.3
	WS	-1.7	-4.6	-6.5	-3.7	-4.1
Immersion Au/Pd	**LR**		-6.2	-4.8	-3.6	-3.7
	WS	-1.7	-4.8	-6.5	-3.7	-4.2
	Averages	-1.1	-5.5	-5.8	-3.7	

Table 5.51 Predicted Number of Anomalies per PWA During Cycle 10

		No Coating	Parylene	Silicone	Urethane	Averages
HASL	**LR**	6.6	1.9	1.8	3.0	3.3
	WS	4.9	0.2	0.2	2.9	2.1
Benzimidazole	**LR**	4.9	0.2	0.1	3.4	2.2
	WS	5.4	0.7	0.6	2.2	2.3
Immersion Ag	**LR**	6.6	1.9	1.8	3.0	3.3
	WS	4.9	2.0	0.2	2.9	2.5
Immersion Au/Pd	**LR**	6.6	0.4	1.8	3.0	3.0
	WS	4.9	1.8	0.2	2.9	2.5
	Averages	5.6	1.1	0.8	2.9	2.7

- When the PWAs are coated with parylene, WS flux is the best choice for HASL, LR flux is the best choice for benzimidazole and immersion Au/Pd, and there is no difference in flux choices for immersion Ag
- When the PWAs are coated with silicone, WS flux is the best choice for HASL, immersion Ag, and immersion Au/Pd, while LR flux is the best choice for benzimidazole
- When the PWAs are coated with urethane, WS flux is the best choice for benzimidazole, but there are no differences in flux choices for HASL, immersion Ag, and immersion Au/Pd

References

1. Iman, R. L. (1994). **A Data-Based Approach to Statistics**, Duxbury Press.