Phase 1	Phase 2

2. Phase 1: Diesel Fuel and Hydraulic Fluid Exposure

2.1 Introduction. The test matrix in Figure 1.2 shows 160 LRSTF PWAs utilized with each of the five environmental tests. Results of these tests are presented in Sections 2 to 6 of this report:

Section 2: Diesel fuel and hydraulic fluid
Section 3: Branch water and salt fog
Section 4: 85/85 and thermal shock
Section 5: Condensing atmosphere and thermal cycling
Section 6: Accelerated life, vibration, mechanical shock, and abbreviated Branch water

All tests took place in two stages except salt fog, and the entire accelerated life test sequence. The non-urethane PWAs (120) were tested in the first stage and urethane PWAs (40) were tested in a second stage. The reason that two stages were used is that urethane was added to the test matrix after the non-urethane PWAs were either tested or were in the process of being testing. A second build of LRSTF PWAs was required to supply PWAs to be coated with urethane.

The use of a second build introduces an element of uncertainty into the analysis of the test results that cannot be resolved with certitude. That is, if a significant effect involves urethane, it is possible that this effect is actually attributable to something associated with the second built, such as a change in materials or changes due to new batches of components. Since the two sets of tests were conducted several months apart, this could also be a contributing factor to differences in test results. In statistical parlance, results for urethane are completely confounded with the second build. The reader is cautioned to keep this in mind when interpreting the results presented in Sections 2 to 5. This is not an issue in Section 6, as all PWAs used in this test sequence came from the second build of PWAs.

This section presents results for exposure to diesel fuel (DF) and hydraulic fluid (HF). Following Pre-test, these PWAs were twice dipped in DF, dried, and retested. Next, they were twice dipped in HF, dried, and retested. The test protocols for fluid exposure are as follows.

Diesel Fuel

1. Perform Pre-test
2. Mask all connectors
3. Equilibrate the DF at room temperature
4. Dip the PWA into the DF and soak for 10 *min*
5. Record the fluid temperature, ambient temperature, and relative humidity
6. Remove the PWA from the DF and let it drip dry for 30 *min*
7. Remove any remaining fluid by wiping with a lint free cloth
8. Repeat steps 4-7 with fresh fluid
9. Remove masking
10. Air dry for 24 *hr*
11. Record the electrical performance on the CCAMTF ATS

Hydraulic Fluid

1. Mask all connectors
2. Equilibrate the HF at room temperature
3. Dip the PWA into the HF and soak for 10 *min*
4. Record the fluid temperature, ambient temperature, and relative humidity
5. Remove the PWA from the HF and let it drip dry for 30 *min*
6. Remove any remaining fluid by wiping with a lint free cloth
7. Repeat steps 3-6 with fresh fluid
8. Remove masking
9. Air dry for 24 *hr*
10. Record the electrical performance on the CCAMTF ATS

2.2 Overview of Test Results. Each of the 160 PWAs used in the DF-HF exposure test sequence was tested three times.

1. Pre-test to determine electrical functionality after processing
2. Electrical functionality testing after exposure to DF
3. Electrical functionality testing after exposure to HF

At each test time, 160×23 = 3680 electrical test measurements were recorded. An overview of the test results for each of these three test times is now given. Detailed results of the electrical performance for each of the 23 circuits listed in Table 1.1 appear in Sections 2.3 to 2.9. Summary and conclusions are given in Section 2.10.

Pre-test. The electrical measurements were compared to the JTP acceptance criteria given in Table 1.1 at each test time. The JTP acceptance criteria require a comparison to Pre-test for 11 of the 23 electrical circuits (responses 1, 2, 5, 6, 13-17, 22, and 23). Hence, comparisons could not be made to the JTP acceptance criteria for these 11 circuits at Pre-test, but their measurements were compared to baseline results in the CCAMTF GR&R study (Iman et al, 1998).

The remaining 23 - 11 = 12 electrical circuits produced 12×160 = 1920 Pre-test measurements. There were 10 anomalies on seven PWAs among these measurements that did not meet the JTP acceptance criteria. All these anomalies occurred for HF LPF circuits (responses 8, 9, 11, and 12 in Table 1.1) with HF PTH f(-3dB) having five anomalies; HF PTH f(-40dB) had three while HF SMT f(-3dB) and HF SMT f(-40dB) each had one.

In addition to these 10 anomalies, five PWAs produced measurements outside the norm observed for HF PTH 50MHz (circuit 7 in Table 1.1), but still within the JTP acceptance criterion. HF SMT f(-3dB) and HF SMT f(-40dB) each had one measurement outside the norm, but still within the acceptance criterion.

The percentage of electrical responses meeting the JTP acceptance criteria at Pre-test was (1920 - 10)/(12 × 160) = 99.5% for the 12 circuits for which such comparisons could be made.

Exposure to Diesel Fuel. Each of the 23 circuits on the LRSTF PWA was tested after two dips in DF. Twelve of these circuits had no anomalies after the DF test. The remaining 11 circuits had a combined total 22 anomalies that did not meet the JTP acceptance criteria. As explained in the next subsection, 11 of these 22 anomalies tested normally following exposure to HF.

These 22 anomalies were spread among the following circuits: HCLV (3), HVLC (6), HF LPF (8), and HF TLC (5). The six HVLC anomalies occurred on just three PWAs and were severe enough to be candidates for failure analysis following exposure to DF. However, all six tested normally following exposure to HF, so the validity of the HVLC measurements following DF is questionable.

Since there were a total of 23 circuits × 160 PWAs = 3680 tests, the overall yield for DF was 3658/3680 = 99.4%. In addition to the 22 anomalies, there were three HSD circuits that did not give a response. This is a common occurrence for HSD circuits and is usually due to a damaged component or trace. The 22 anomalies are summarized by surface finish, coating status, and flux type in Table 2.1. The 22 anomalies occurred on 14 PWAs, which are summarized by surface finish, coating status, and flux type as follows with the frequencies of the PWAs with questionable HVLC shown in parentheses.

Surface Finish		Coating Status		Flux Type	
HASL	1	None	2	Low-residue	7(2)
Benzimidazole	2(1)	Parylene	3(3)	Water soluble	4(1)
Immersion Ag	6(2)	Silicone	3		
Immersion Au/Pd	2	Urethane	3		

There are no significant differences due to surface finish, coating status, or flux type in this summary. However, if the questionable frequencies in parentheses for HVLC are included, there would be a slight significant difference due to surface finish (p-value = 0.028), which would imply that immersion Ag had more anomalies than the other surface finishes. The p-value is a measure of statistical significance and should be < 0.05 to declare a statistical difference.

Exposure to Hydraulic Fluid. Each of the 23 circuits on the LRSTF PWA was tested after two dips in HF. Sixteen of these circuits had no anomalies after the HF test. The remaining seven circuits had a total of 14 anomalies that did not meet the acceptance criteria. Eleven of these 14 anomalies carried over from the DF test, so the HF did not have an adverse impact on the electrical responses. These 14 anomalies all occurred in just

Table 2.1 Tabulation of the 22 Test Measurements Over All 23 Electrical Circuits that did not Meet the JTP Acceptance Criteria after Exposure to Diesel Fuel

Surface Finish	Flux	No Coating	Parylene	Silicone	Urethane	Totals
HASL (2)	**LR**					
	WS		2			2
Benzimidazole (5)	**LR**		4	1		5
	WS					
Immersion Ag (12)	**LR**	2	3	1	2	8
	WS		4			4
Immersion Au/Pd (3)	**LR**					
	WS			1	2	3
LR = 13, WS = 9	**Totals**	2	13	3	4	22

Table 2.2 Tabulation of the 14 Test Measurements Over All 23 Electrical Circuits that did not Meet the JTP Acceptance Criteria after Exposure to Hydraulic Fluid

Surface Finish	Flux	No Coating	Parylene	Silicone	Urethane	Totals
HASL (3)	**LR**					
	WS	1	2			3
Benzimidazole (3)	**LR**		2	1		3
	WS					
Immersion Ag (4)	**LR**	1			1	2
	WS		2			2
Immersion Au/Pd (4)	**LR**		1		1	2
	WS				2	2
LR = 7, WS = 7	**Totals**	2	7	1	4	14

two circuit groups: HF LPF (8) and HF TLC (6). The overall success rate for HF was 3666/3680 = 99.6%, which is just slightly higher than the results after exposure to DF.

In addition to the 14 anomalies, there were 13 HSD circuits that did not give a response. This is a common occurrence for HSD circuits and is usually due to a damaged component or trace and not related to surface finish, coating status, or flux type. The 14 anomalies are summarized by surface finish, coating status, and flux type in Table 2.2. The 14 anomalies occurred on 10 PWAs, which are summarized as follows.

Surface Finish		Coating Status		Flux Type	
HASL	2	None	2	Low-residue	6
Benzimidazole	2	Parylene	4	Water soluble	4
Immersion Ag	3	Silicone	1		
Immersion Au/Pd	3	Urethane	3		

There are no significant differences due to surface finish, coating status, or flux type in this summary. Of the 14 anomalies summarized in Table 2.2, only two were possible candidates for failure analysis. Both of these occurred for the HF RNR circuit.

The anomalies in Tables 2.1 and 2.2 are summarized by the seven major circuit groups as follows.

Circuit Group	DF	HF
HCLV	3	0
HVLC	6	0
HSD	0	0
HF LPF	8	8
HF TLC	5	6
ON	0	0
SW	0	0
Totals	22	14

HCLV and HVLC circuits had the biggest changes in the number of anomalies from DF to HF. The three HCLV anomalies after DF were just above the upper JTP limit and were within the limit after HF. The decrease in HVLC anomalies is most likely due to erroneous measurements after DF as these anomalous measurements could not be repeated after exposure to HF.

Results are now presented for exposure to DF and HF by major circuit group.

2.3 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 = Diesel fuel - Pre-test Delta 2 = Hydraulic fluid - Pre-test

Specifically, these differences are not to exceed 0.50V.

The deltas and the Pre-test measurements were analyzed with the GLM in Equation 1.1. The *base case* for this GLM was defined in Section 1.9 as *HASL surface finish processed with LR flux without conformal coating*. Table A.1 in Appendix A summarizes the results of the GLM analyses for HVLC PTH. The row labeled “Constant” in Table A.1 contains the least squares estimates of β_0 in Equation 1.1 for each test time (Pre-test, after DF, and after HF). The numbers in the columns beneath the “Constants” are the estimated coefficients of the terms in Equation 1.1 that are significantly different from the base case. Shaded cells in this table signify that the corresponding term in the GLM is not significantly different from the base case. The “Model R^2” in the penultimate row of Table A.1 shows the percent of variation in the voltage measurements that is explained by the respective estimated model. This value can range from 0% to 100% with values near zero indicating that the experimental parameters (surface finish, coating status, and flux type) and their interactions do no influence the test measurements.

Summaries similar to Table A.1 have been constructed for the GLM results for each of the 23 electrical responses measured on the LRSTF PWA. Since each summary table fills one page, these tables have been placed in Appendix A 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 A.1 to A.23. The model R^2s in those table for the HCLV circuitry are summarized as follows.

Circuit	Pre-test	DF	HF
HCLV PTH	28.5%	9.5%	3.0%
HCLV SMT	13.6%	9.1%	1.3%

These low values imply that the experimental parameters do 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 DF-HF exposure sequence have been created in Appendix B for each of the 23 electrical responses listed in Table 1.1. Figure B.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 B.2, B.3, and B.4 present 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. This behavior is consistent with the low model R^2s in the GLM analyses. The corresponding boxplots for HCLV SMT appear in Figures B.5 to B.8 and have a similar interpretation.

Comparison to JTP Acceptance Criterion. Only three HCLV PTH measurements exceeded the JTP acceptance criterion of $\Delta V < 0.50V$ after exposure to DF. All three were just above the criterion at 0.52V. None of the HCLV SMT measurements exceeded the JTP acceptance criterion after exposure to DF. Neither of the HCLV circuits exceeded the JTP acceptance criterion after exposure to HF.

2.4 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 (no comparisons are made to Pre-test for HVLC circuits). The mean current of the 40 urethane PWAs at Pre-test was close to that recorded for the other 120 PWAs (uncoated, parylene, and silicone), however, the standard deviations were considerably different. The means and standard deviations for these two groups are summarized as follows.

	Uncoated, Parylene, and Silicone (n=120)		**Urethane (n=40)**	
	Mean	St. Dev.	Mean	St. Dev.
HVLC PTH	5.04µA	.0288	5.02µA	.0048
HVLC SMT	4.95µA	.0104	5.01µA	.0374

Note that the standard deviation of the HVLC PTH current measurements for uncoated, parylene, and silicone (.0288) is six times that for urethane (.0048). On the other hand, the standard deviation of the HVLC SMT current measurements for uncoated, parylene, and silicone (.0104) is *less* than a third of that for urethane (.0374). The dotplots in Figure 2.1 clearly illustrate these differences. As explained in the opening remarks of this section, these differences could be due either to urethane or the fact that a second build was used to produce the urethane coated PWAs. As a check on the source of the variation, the means and standard deviations were computed for the HVLC circuits used in the accelerated life test sequence since these PWAs were manufactured at the same time as the urethane PWAs in the DF-HF test. HVLC PTH had a mean of 5.02µA and a standard deviation of 0.0068. HVLC SMT had a mean of 5.00µA and a standard deviation of 0.0459. These descriptive statistics are in excellent agreement with those recorded for the urethane coated PWAs in the DF-HF test sequence, so it is safe to conclude that the differences are due to the second build and not to urethane.

Results of the GLM analyses for HVLC PTH and HVLC SMT circuits are given in Tables A.3 and A.4, respectively. The model R^2s in those tables for the HVLC circuitry are summarized as follows.

Circuit	**Pre-test**	**DF**	**HF**
HVLC PTH	19.7%	53.5%	71.6%
HVLC SMT	55.4%	52.3%	57.9%

The model R^2 values at Pre-test are moderate to large except HVLC PTH at Pre-test. This indicates that surface finish, flux, and coating influence the Pre-test HVLC measurements. However, as can be seen in Tables A.3 and A.4, the coefficients in the GLM were too small (0.02µA to 0.06µA) to be of practical significance relative to the JTP acceptance criterion (current must be between 4µA and 6µA).

Displays. Figures B.9 to B.12 present boxplots for the HVLC PTH current measurements versus test time for HASL, benzimidazole, immersion Ag, and immersion Au/Pd, respectively. The corresponding boxplots for HVLC SMT appear in Figures B.13 to B.16. These boxplots show very little variability (a range of approximately 0.3µA) for all surface finishes at each test time. Note the small variability for urethane in the boxplots for HVLC PTH and its larger variability in HVLC SMT. These graphs are consistent with the comments above regarding the differences in standard deviations for the new build of PWAs.

Comparison to JTP Acceptance Criterion. HVLC PTH and HVLC SMT each had three anomalous measurements that did not meet the JTP acceptance criterion after exposure to DF. These six anomalies occurred on three PWAs. All six measurements returned to normal after exposure to HF, which implies that the measurements after DF were erroneous. The range of the 157 remaining HVLC PTH measurements after exposure to DF was 5.00µA to 5.11µA, all of which are well within the JTP acceptance criterion. The range of 156 of the remaining HVLC SMT measurements after exposure to DF was 4.92µA to 5.13µA with one measurement of 4.06µA. All 157 HVLC SMT measurements were well within the JTP acceptance criterion.

There were no anomalous HVLC PTH or HVLC SMT measurements after exposure to HF. The range of these measurements was 4.99µA to 5.19µA for HVLC PTH and 4.92µA to 5.07µA for HVLC SMT, all of which were well within the JTP acceptance criterion.

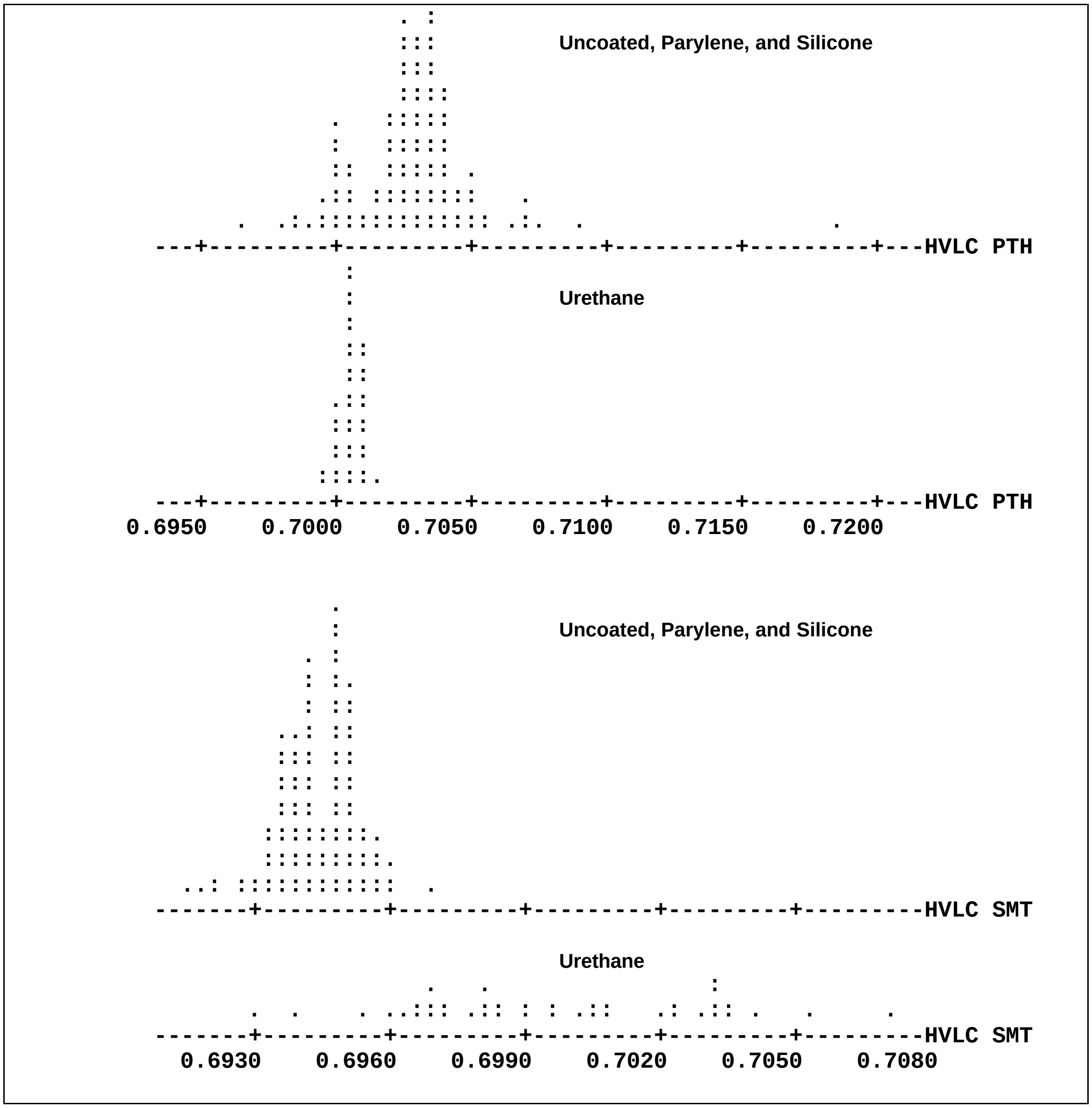

Figure 2.1 Dotplot Comparisons of the HVLC Measurements at Pre-Test

2.5 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 (TPD) in *nanoseconds* to be less than 20% from Pre-test measurements. Pre-test measurements for the 40 urethane PWAs showed their TPD to be longer than that recorded for the other 120 PWAs (see Figure 2.1). The mean TPDs for baseline testing are as follows.

	Average TPD (*ns*) for Uncoated, Parylene, and Silicone (n=120)	**Average TPD (*ns*) for Urethane (n=40)**
HSD PTH	13.03	17.03
HSD SMT	5.02	9.19

The explanation of this difference is related to the opening comments in this section about the 40 urethane coated PWAs coming from a second build of LRSTF PWAs. Components had to be reordered for the second build and the new HSD components used on the urethane coated PWAs had a longer TPD.

Figures 2.2 and 2.3 contain boxplot displays of the raw total propagation delay measurements (*ns*) for HSD PTH and HSD SMT at each test time for HASL. These figures clearly show the longer times associated with the urethane PWAs from the second build. This difference creates a higher model R^2 value at Pre-test as illustrated in the discussion below.

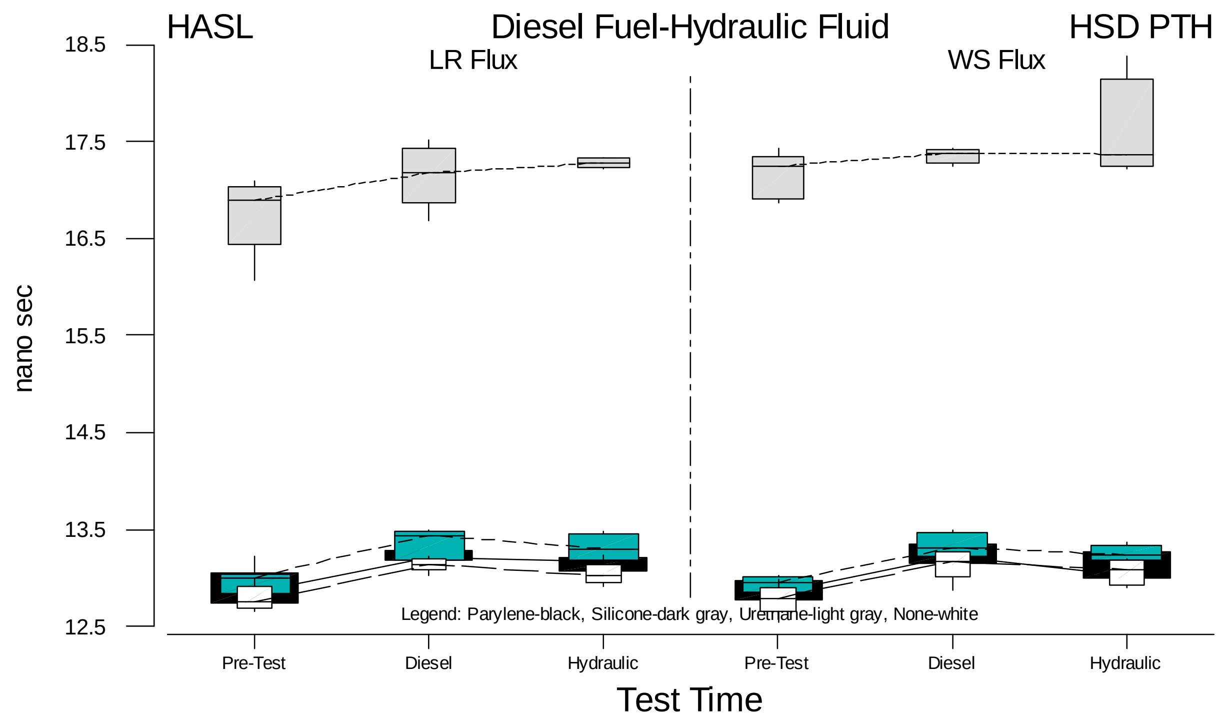

Figure 3.2 Boxplots of HSD PTH Propagation Delay Measurements for HASL versus Test Time

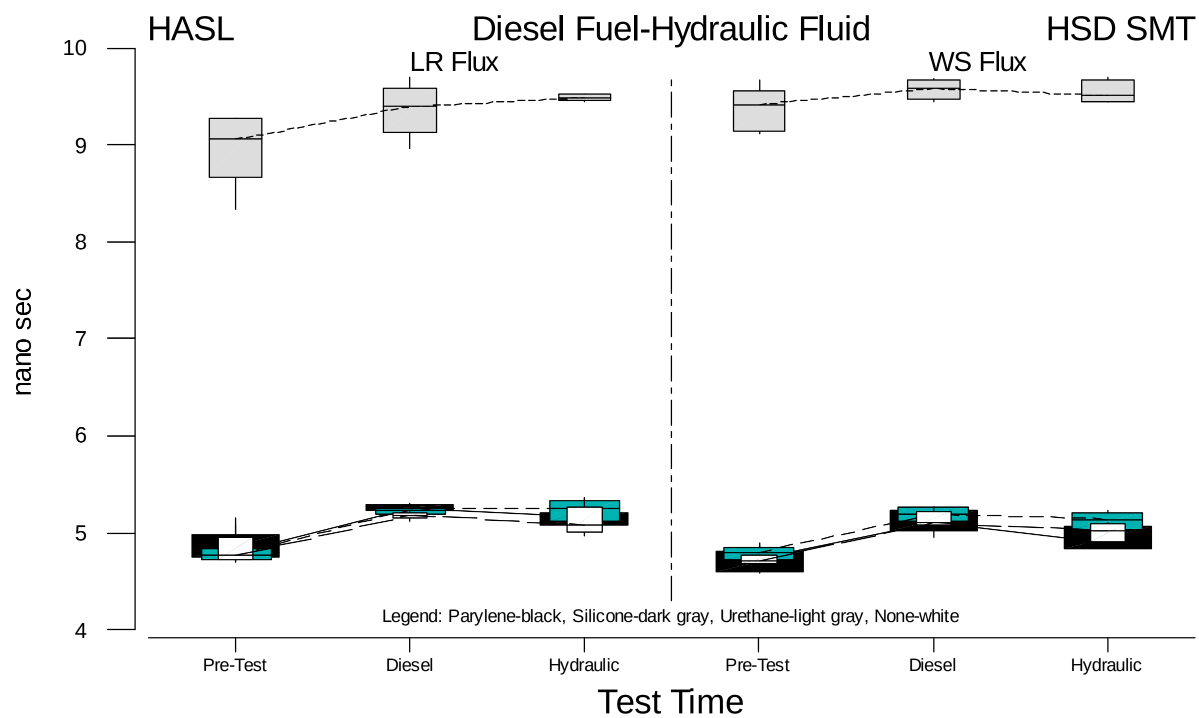

Figure 3.3 Boxplots of HSD SMT Propagation Delay Measurements for HASL versus Test Time

The difference in TPD for the two groups of PWAs requires careful interpretation of the GLM analyses at Pre-test for the HSD circuits. That is, the new HSD components are only used on the PWAs coated with urethane. Since there is a big difference in TPD as shown in Figures 2.2 and 2.3, the GLM analyses for HSD at Pre-test indicates that urethane is a significant effect. In reality, this effect is due to different HSD components. At subsequent test times, the test measurement is based on a percentage change in TPD from the respective Pre-test values, so the component effect will be greatly ameliorated. As previously pointed out, the HSD component difference at Pre-test is present in all environmental tests in the test matrix, except the accelerated life test sequence. This latter sequence is excluded because all 160 PWAs used in this test were part of the second build and all had the same HSD components as the urethane PWAs in the DF-HF test. Tables A.5 and A.6 present the results of the GLM analyses for the HSD circuits. The model R^2s from those tables for the HSD circuitry are summarized as follows.

Circuit	Pre-test	DF	HF
HSD PTH	98.9%	20.3%	14.2%
HSD SMT	99.2%	42.0%	35.9%

The high model R^2 values at Pre-test simply reflect the differences in components for the second build of PWAs that is illustrated in Figures 2.2 and 2.3. The model R^2s decrease at DF and HF because they are based on the percentage change in TPF rather than the raw TPF measurements. As evidenced by the coefficients for urethane in Tables A.5 and A.6, some of the second build difference carries over to Post DF and HF. However, the magnitude of these coefficients is too small to be of concern relative to the JTP acceptance criterion. The low R^2 values after DF and after HF imply that the experimental parameters do 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.

Displays. Figures B.17 to B.20 present boxplots for the HSD PTH total propagation delay measurements for HASL, benzimidazole, immersion Ag, and immersion Au/Pd, respectively. The corresponding boxplots for HSD SMT appear in Figures B.21 to B.24. These boxplots show very little variability within a given conformal coating for all surface finishes at each test time. However, they do reflect the difference in mean TPD for the components on the urethane coated PWAs.

Comparison to JTP Acceptance Criterion. Two HSD PTH circuits and one HSD SMT circuit did not give a response after exposure to DF. Six HSD PTH and seven HSD SMT circuits measurements did not produce a response after exposure to HF. All six HSD PTH anomalies occurred on PWAs also having HSD SMT anomalies. All other HSD circuits were well within the JTP acceptance criterion. Failure analysis results for non-responding HSD circuits are summarized by surface finish, coating status, and flux type in Table 2.3. This table shows that these anomalies were due to either a damaged component or trace and not related to surface finish, coating status, or flux type.

Table 2.3 Failure Analysis Results for HSD Circuits after Exposure to Hydraulic Fluid

MSN	Surface Finish	Coating	Flux	Propagation Delay	Failure Analysis Results
			HSD PTH		
314	HASL	None	WS	No response	Damaged component or trace
330	HASL	Parylene	WS	No response	Damaged component or trace
638	HASL	Urethane	LR	No response	Damaged component or trace
654	HASL	Urethane	WS	No response	Damaged component or trace
389	Benzimidazole	None	WS	No response	Damaged component or trace
889	Immersion Au/Pd	Urethane	WS	No response	Damaged component or trace
			HSD SMT		
314	HASL	None	WS	No response	Damaged component or trace
330	HASL	Parylene	WS	No response	Damaged component or trace
638	HASL	Urethane	LR	No response	Damaged component or trace
654	HASL	Urethane	WS	No response	Damaged component or trace
389	Benzimidazole	None	WS	No response	Damaged component or trace
232	Immersion Au/Pd	None	LR	No response	Damaged component or trace
889	Immersion Au/Pd	Urethane	WS	No response	Damaged component or trace

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

The JTP acceptance criterion 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) is also based on deviations from the average response of the five HASL PWAs at the current test time that are coated with parylene and processed with LR flux. Specifically, these deviations must be within ±50MHz of this average.

Pre-test measurements for all six HF LPF circuits were subjected to GLM analyses, as were the deltas after exposure to DF and HF. The results of the GLM analyses are given in Tables A.7 to A.12. The model R^2s from these tables are given below. These model R^2s range from quite small to close to 50%. However, the estimated coefficients in all models were too small to be of practical significance relative to the JTP acceptance criterion.

HF LPF Circuit	Pre-test	DF	HF
PTH 50MHz	18.6%	13.9%	26.2%
PTH f(-3dB)	20.7%	9.1%	9.1%
PTH f(-40dB)	16.9%	19.1%	16.7%
SMT 50MHz	21.0%	14.6%	25.2%
SMT f(-3dB)	25.7%	15.5%	20.8%
SMT f(-40dB)	39.9%	43.6%	49.0%

Displays. Figures B.25 to B.48 present boxplots for the HF LPF measurements for the HASL, benzimidazole, immersion Ag, and immersion Au/Pd surface finishes, respectively. These boxplots and show little variability relative to their respective JTP acceptance criterion.

Comparison to JTP Acceptance Criterion. There were no anomalies for HF PTH 50MHz or HF SMT 50MHz after exposure to DF. However, the remaining four HF LPF circuits had a total of eight anomalous measurements that did not meet the JTP acceptance criterion after exposure to DF and after exposure to HF. These eight anomalies occurred on six PWAs. Since the anomalies were just outside the JTP acceptance criterion, they did not warrant being subjected to failure analysis. A summary of the responses for these eight circuits is given in Table 2.4. The six unique MSNs listed in Table 2.4 include three of the four surface finishes, three of the four coating conditions, and both fluxes. There is no linkage between these experimental parameters and the anomalies.

Table 2.4 Summary of Anomalies for HF LPF Circuits after Exposure to Hydraulic Fluid

MSN	Surface Finish	Coating	Flux	Deviation	Failure Analysis Results
			HF LPF PTH f(-3dB)		
118	Benzimidazole	Parylene	LR	54.5 MHz	Failure analysis not required
330	HASL	Parylene	WS	55.7 MHz	Failure analysis not required
489	Immersion Ag	Parylene	WS	55.7 MHz	Failure analysis not required
			HF LPF PTH f(-40dB)		
118	Benzimidazole	Parylene	LR	65.2 MHz	Failure analysis not required
330	HASL	Parylene	WS	62.8 MHz	Failure analysis not required
489	Immersion Ag	Parylene	WS	62.8 MHz	Failure analysis not required
			HF LPF SMT f(-3dB)		
172	Immersion Ag	None	LR	55.3MHz	Failure analysis not required
			HF LPF SMT f(-40dB)		
144	Benzimidazole	Silicone	LR	54.0MHz	Failure analysis not required

2.7 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 RNF must be within

±50MHz. Finally, the increase in for the HF TLC RNR must be less than 5dB if the current response and the Pre-test response are both greater than -50dB, otherwise the increase must be less than 10dB.

Pre-test measurements for all five HF TLC circuits were subjected to GLM analyses, as were the deltas after exposure to DF and HF. The results of the GLM analyses are given in Tables A.13 to A.17. The model R^2s from those tables are summarized as follows.

HF LPF Circuit	Pre-test	DF	HF
50MHz	81.7%	49.3%	68.2%
500MHz	82.4%	5.4%	27.8%
1GHz	70.9%	5.9%	52.0%
RNF	82.0%	36.8%	69.3%
RNR	19.7%	11.3%	17.3%

The model R^2s at Pre-test are high for the first four HF TLC circuits at Pre-test. The magnitudes of these R^2s are primarily attributable to different electrical properties of conformal coatings as shown in Table 2.5. The coating effect is illustrated in Figure 2.4 for the HF TLC 50MHz circuit, where boxplots have been used to show the Pre-test measurements by coating and flux for each surface finish. This figure shows that uncoated boards have the highest response and the lowest variability for all surface finish/flux combinations. Also, silicone has the lowest response except for urethane with immersion Ag, which creates an interesting interaction in an otherwise regular pattern. The magnitudes of these responses do not necessarily mean that one is preferred over another since the JTP acceptance criterion is based on the changes from their respective Pre-test measurements. That is, the question of interest is how stable are the responses when exposed to different test environments such as DF and HF. Note that while these relationships hold for all surface finishes in Figure 2.4, there are differences due to surface finishes.

Table 2.5 Electrical Properties of Conformal Coatings

Electrical Property	Silicone	Parylene	Urethane
Dielectric strength short time, at 23°*C* (volts/mil @ 1 mil)	2000	5600	3500
Surface resistivity at 23°*C*, 50%RH (ohms-cm)	10^{13}	10^{14}	10^{14}
Dielectric constant at 23°*C*, 1 MHz	2.0 to 2.7	2.95	4.2 to 5.2

The difference in electrical properties affects the forward response function because the HF transmission lines on the underside of these PWAs are conformally coated. The magnitude of this effect can be seen in Figure 2.5, which shows HF TLC forward response functions at Pre-test for four PWAs representing each coating category. Curves in Figure 2.5 are separated across the spectrum of frequencies and this separation causes the coating parameters in the GLM analysis at Pre-test to show up as a significant.

The predicted changes from the base case value response of -38.2dB for HF TLC 50 MHz at Pre-test are summarized in Table 2.6. The predicted values in this table are in agreement with Figure 2.5 as they show that the responses for coated PWAs are up to 6dB below that of uncoated PWAs.

Table 2.6 Predicted Changes from the Base Case for HF TLC 50MHz at Pre-Test

		No Coating	Parylene	Silicone	Urethane
HASL	**LR**		-1.72	-6.37	-2.68
	WS		-1.72	-6.37	-2.68
Benzi	**LR**	1.64	-0.08	-2.60	-1.04
	WS	1.64	-0.08	-2.60	-1.04
Imm Ag	**LR**	2.11	0.39	-2.18	-4.07
	WS	2.11	0.39	-2.18	-4.07
Im Au/Pd	**LR**	1.24	-0.48	-2.24	-0.41
	WS	1.24	-0.48	-4.36	-0.41

The model R^2s for the HF TLC circuits all decrease after exposure to DF and HF. The reason for this decrease is that coating is no longer identified as significant in the GLM for Delta 1 and Delta 2 because these analyses are based on changes in the HF TLC measurements relative to their Pre-test measurements and not relative to other

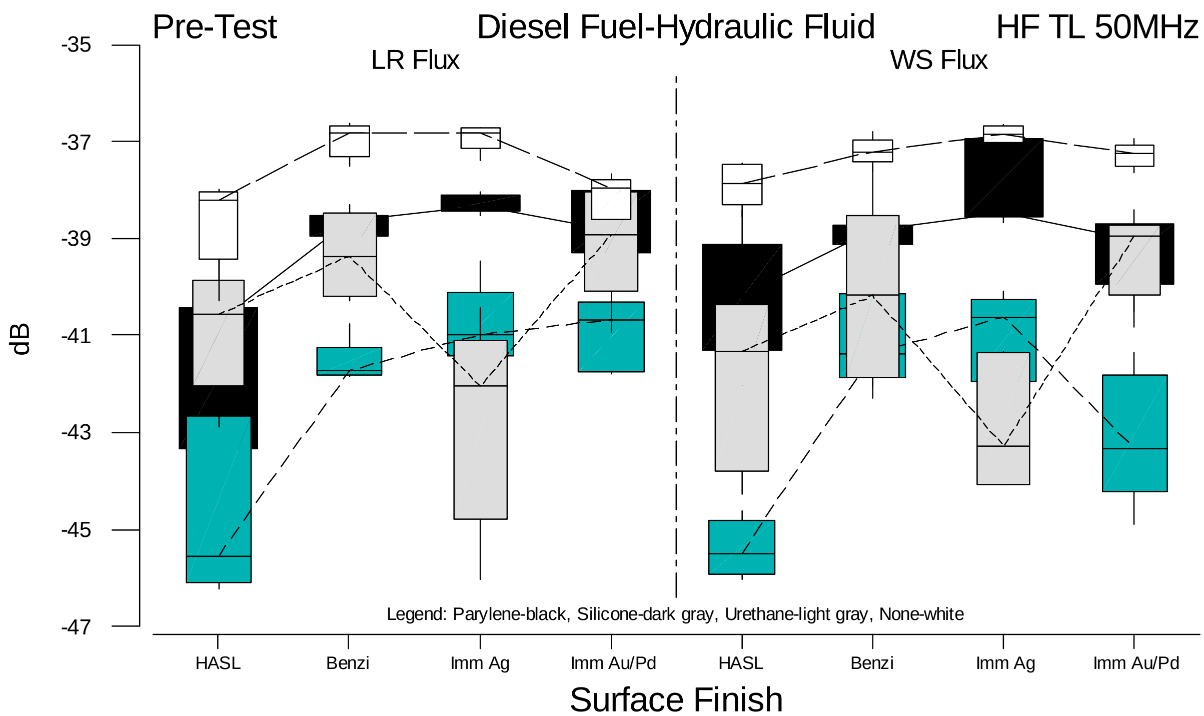

Figure 2.4 Boxplot Displays for Pre-test HF TLC 50MHz Measurements by Coating Status and Flux Type versus Surface Finish

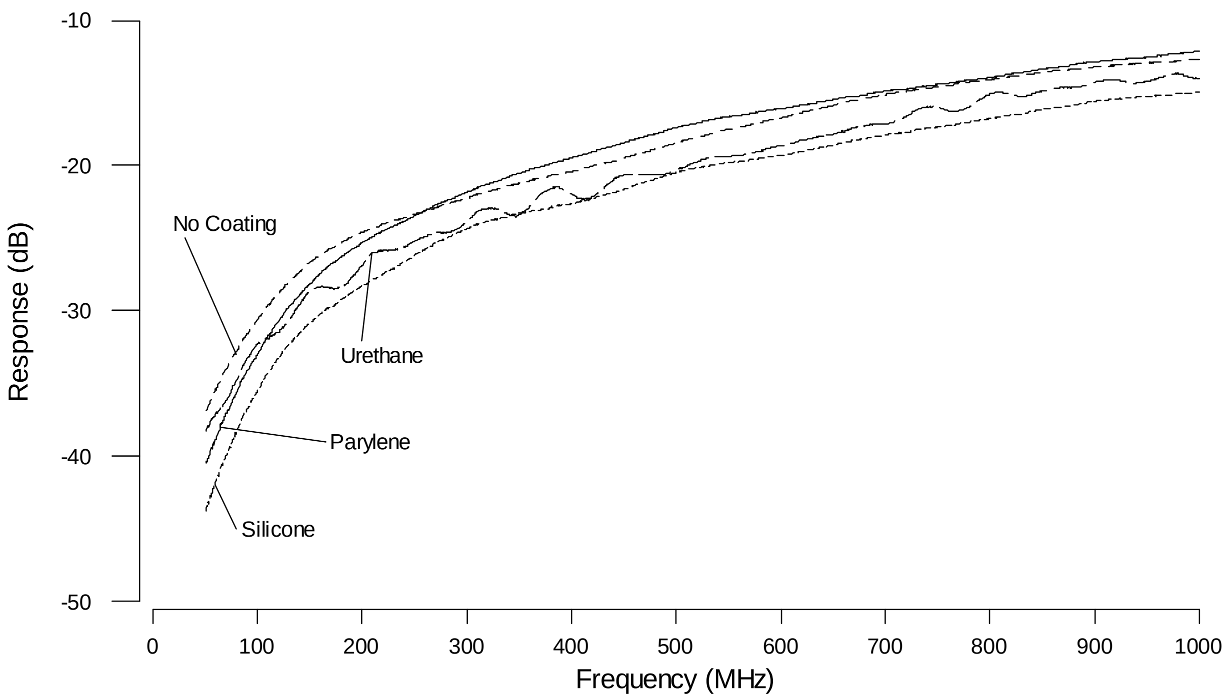

Figure 2.5 HF TLC Forward Response Functions for Uncoated, Parylene, and Silicone PWAs

coating categories at a given test time. All coefficients in these latter models were too small to be of concern relative to the JTP acceptance criterion.

Displays. Figures B.49 to B.68 present boxplots for the HF TLC measurements and deltas for HASL, benzimidazole, immersion Ag, and immersion Au/Pd, respectively. The boxplots for the Pre-test measurements are similar to Figure 2.4 and illustrate the effect of the electrical properties of conformal coating. The boxplots for the deltas are close to zero and show very little variability for all HF TLC circuits except HF TLC RNR. The boxplots for this latter circuit are generally within the JTP acceptance criteria, but show greater variability within those limits for all surface finishes and fluxes.

Comparison to JTP Acceptance Criterion. There were five anomalies for the HF TLC circuitry that did not meet the JTP acceptance criteria after exposure to DF. Three of these anomalies returned to normal after exposure to HF. There were three new anomalies after exposure to HF. Four of the six anomalies were just outside the JTP acceptance criteria and did not warrant being subjected to failure analysis. Failure analysis was not performed on the other two circuits, but a summary of their responses is given in Table 2.7.

Table 2.7 Summary of Anomalies for HF TLC Circuits after Exposure to Hydraulic Fluid

MSN	Surface Finish	Coating	Flux	Deviation	Failure Analysis Results
			HF TLC RNR		
274	Immersion Au/Pd	Parylene	WS	21.4dB	Failure analysis not performed
301	HASL	None	WS	22.6dB	Failure analysis not performed

The HF TLC RNR measurement is made in a vertical direction at the null point of the response function. The following points are important to keep in mind regarding measurements at the null point:

1. As shown in Figure 2.6, the null point is the region of steepest ascent and steepest descent and therefore has the greatest variability for the HF TLC reverse response. As such, the natural variability of measurements in this region can easily exceed the JTP acceptance criterion for HF RNR. This point is supported by baseline measurements (before coating was applied and before exposure to environmental conditions) on 393 LRSTF PWAs. These measurements had a standard deviation of 5.2dB and a range from -64.9dB to -34.9dB.
2. Responses < -50dB are beyond the resolution of the test equipment and the repeatability is poor in that region from one test time to the next.

2.8 Leakage Measurements. Four features were included in the design of the LRSTF PWA to specifically check for current leakage: 10-mil pads, 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 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.

The JTP acceptance criterion for the leakage measurements requires the resistance to be greater than 7.70 when expressed as $\log_{10}$ ohms. The leakage measurements were subjected to GLM analyses at Pre-test and after exposure to DF and HF. The results of the GLM analyses are given in Tables A.18 to A.21. The model R^2s from those tables are summarized as follows.

Leakage Circuit	Pre-test	DF	HF
10-Mil Pads	82.2%	73.6%	90.8%
PGA-A	49.8%	56.4%	85.7%
PGA-B	52.4%	49.6%	80.1%
Gull Wing	63.6%	61.2%	83.1%

10-Mil Pads. The predicted base case value at Pre-test is given in Table A.18 as 11.76, 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 obtained by substituting the values of the dummy variables defined in Section 1.9 for the GLM in Equation 1.1 into the estimated model given in Table A.18 *without using the intercept*. These predicted changes are given in Table 2.8, which shows that resistance for parylene coated PWAs is approximately two orders of magnitude higher than the base case for all surface finish/flux combinations. On the other hand, silicone does not increase

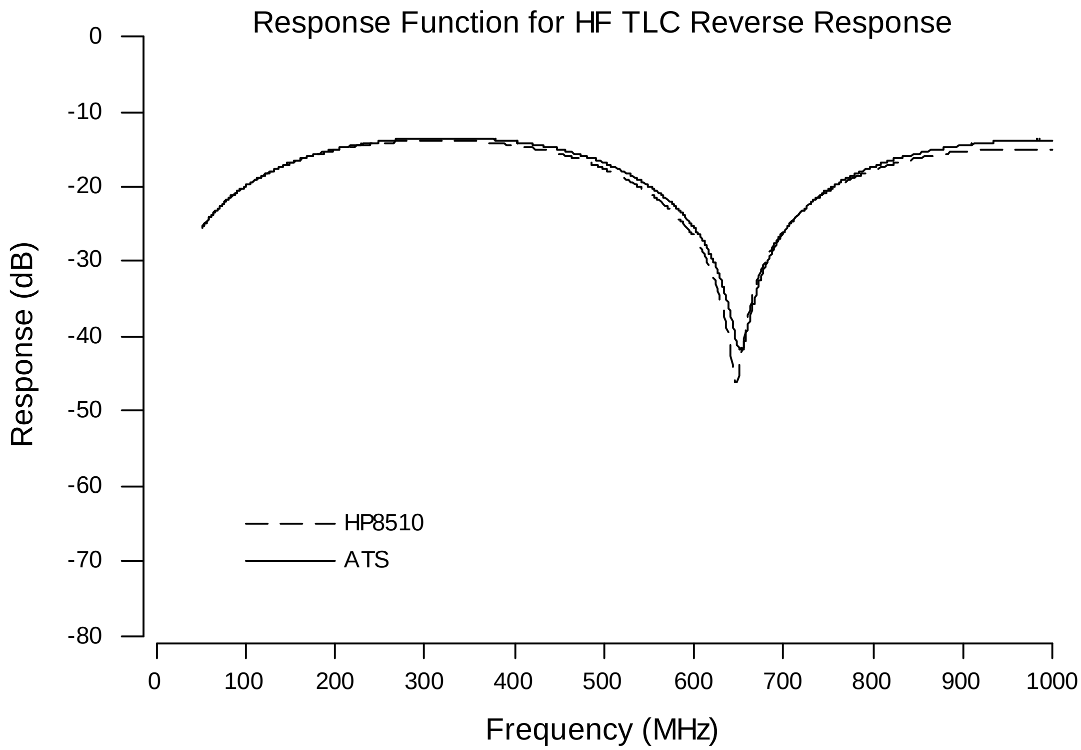

Figure 2.6 HF TLC Reverse Response Function for One PWA Measured On An HP8510 and Then With the CCAMTF ATS

resistance, and even lowers it slightly. The resistance for uncoated PWAs processed with WS flux is 1.6 orders of magnitude higher than those processed with LR flux. The resistance for urethane coated PWAs processed with WS flux is lower than uncoated PWAs, but slightly higher than uncoated PWAs when LR flux is used.

The predicted base case value in Table A.18 after exposure to DF is 13.32, which is approximately 1.5 orders of magnitude higher than at Pre-test and well above the JTP acceptance criterion. The predicted changes after exposure to DF are given in Table 2.9. These predictions show that uncoated PWAs give the best overall performance. Parylene coated PWAs had the same resistance as uncoated PWAs in all but two immersion Au/Pd cases, which are slightly lower. Silicone coated PWAs are approximately 2.7 orders of magnitude lower than the base case for all surface finish/flux combinations, but are still well above the JTP acceptance criterion. The resistance for urethane coated PWAs is approximately 0.5 orders of magnitude lower than uncoated PWAs for all cases.

The predicted base case value in Table A.18 after exposure to HF is 12.56, which is approximately 0.75 orders of magnitude higher than at Pre-test and well above the JTP acceptance criterion. The predicted changes after exposure to HF are given in Table 2.10. These predictions show that the resistance for silicone coated PWAs was approximately 2.6 orders of magnitude lower than the base case for all surface finish/flux combinations, but are still well above the JTP acceptance criterion. Parylene coated PWAs gave an increase of approximately 0.5 of an order of magnitude over the base case for all cases except immersion Ag with WS and immersion Au/Pd with LR, which are essentially the same as the base case. Uncoated PWAs gave the same resistance as the base case for all surface finish/flux combinations. The resistance for urethane coated PWAs is slightly higher than uncoated PWAs for all cases.

Displays. Figures 2.7 to 2.10 (also Figures B.69 to B.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.

- Resistance for all surface finish/coating/flux combinations was well above the JTP acceptance criterion after exposure to DF and HF

Table 2.8 Predicted Changes from the Base Case for 10-Mil Pads at Pre-test

		No Coating	Parylene	Silicone	Urethane
HASL	**LR**		1.86		0.69
	WS	1.63	2.26	-0.26	0.73
Benzimidazole	**LR**	0.28	2.14	0.28	0.97
	WS	1.91	2.54	-0.67	1.01
Immersion Ag	**LR**	0.38	2.24	-0.09	1.07
	WS	1.59	2.22	-0.77	0.69
Immersion Au/Pd	**LR**		1.86		0.69
	WS	1.63	2.26	-0.26	0.73

Table 2.9 Predicted Changes from the Base Case for 10-Mil Pads after Exposure to Diesel Fuel

		No Coating	Parylene	Silicone	Urethane
HASL	**LR**			-2.71	-0.55
	WS			-2.71	-0.55
Benzimidazole	**LR**			-2.71	-0.55
	WS			-2.71	-0.55
Immersion Ag	**LR**			-2.71	-0.55
	WS			-2.71	-0.55
Immersion Au/Pd	**LR**		-0.79	-2.71	-0.55
	WS		-0.79	-2.71	-0.55

Table 2.10 Predicted Changes from the Base Case for 10-Mil Pads after Exposure to Hydraulic Fluid

		No Coating	Parylene	Silicone	Urethane
HASL	**LR**		0.54	-2.56	0.28
	WS		0.54	-2.56	0.28
Benzimidazole	**LR**		0.54	-2.56	0.69
	WS		0.54	-2.56	0.69
Immersion Ag	**LR**		0.54	-2.56	0.28
	WS		0.05	-2.56	0.28
Immersion Au/Pd	**LR**		-0.09	-2.56	0.28
	WS		0.57	-2.56	0.28

- There was a slight decrease in resistance from Pre-test to DF to HF of approximately 0.5 to 2 orders of magnitude for most surface finish/coating/flux combinations
- Uncoated and parylene coated PWAs processed with either flux gave the best results throughout exposure to DF and HF
- Silicone coated PWAs had low variability, but also had the lowest resistance (undesirable) for all surface finish/coating/flux combinations—resistance was approximately three orders of magnitude lower than uncoated and parylene coated PWAs after exposure to HF
- Resistance measurements varied over approximately three orders of magnitude for immersion Au/Pd PWAs coated with parylene and processed with LR flux
- HF did not have the negative impact on resistance measurements as was the case in the CCAMTF screening study (Iman et al, 1998)

Comparison to JTP Acceptance Criterion. All 10-mil resistance measurements met the JTP acceptance criterion at Pre-test, after exposure to DF, and after exposure to HF.

PGA-A. The predicted base case value at Pre-test is given in Table A.19 as 11.38, 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 2.11. This table shows that resistance for parylene coated PWAs is approximately an order of magnitude higher than the base case. On the other hand, silicone gives a slight increase in resistance with LR flux and a slight decrease with WS flux. The resistance for uncoated PWAs processed with WS flux is

Table 2.11 Predicted Changes from the Base Case for PGA-A at Pre-test

		No Coating	Parylene	Silicone	Urethane
HASL	**LR**		0.96	0.38	
	WS	1.54	1.46	-0.35	0.17
Benzimidazole	**LR**	0.29	0.66	0.67	0.29
	WS	1.83	1.16	-0.06	0.46
Immersion Ag	**LR**		0.96	0.38	
	WS	1.54	1.46	-0.35	0.17
Immersion Au/Pd	**LR**		0.96	0.38	
	WS	1.54	1.46	-0.35	0.17

Table 2.12 Predicted Changes from the Base Case for PGA-A after Exposure to Diesel Fuel

		No Coating	Parylene	Silicone	Urethane
HASL	**LR**			-1.46	
	WS			-1.46	
Benzimidazole	**LR**		1.16	-1.46	
	WS		1.16	-1.46	
Immersion Ag	**LR**		0.85	-1.46	
	WS		0.85	-1.46	
Immersion Au/Pd	**LR**			-1.46	
	WS			-1.46	

Table 2.13 Predicted Changes from the Base Case for PGA-A after Exposure to Hydraulic Fluid

		No Coating	Parylene	Silicone	Urethane
HASL	**LR**		0.53	-1.20	1.09
	WS		0.53	-1.20	1.09
Benzimidazole	**LR**		0.53	-1.20	1.53
	WS		0.53	-1.20	1.53
Immersion Ag	**LR**		0.53	-1.20	1.09
	WS		0.53	-1.20	1.09
Immersion Au/Pd	**LR**		0.53	-1.20	1.09
	WS		0.53	-1.20	1.09

approximately 1.5 orders of magnitude higher than those processed with LR flux. Urethane coated PWAs are close to the base case throughout.

The predicted base case value in Table A.19 after exposure to DF is 11.56, which is approximately the same as that at Pre-test and well above the JTP acceptance criterion. The predicted changes after exposure to DF are given in Table 2.12. These predictions show that the resistance for silicone coated PWAs is approximately 1.5 orders of magnitude lower than the base case for all surface finish/flux combinations, but still well above the JTP acceptance criterion. Uncoated PWAs and parylene coated PWAs gave the same resistance for all surface finish/flux combinations except for benzimidazole and immersion Ag, where the resistance is approximately an order of magnitude higher for parylene case with either flux. Urethane coated PWAs had the same resistance as uncoated PWAs for all surface finish/flux combinations.

The predicted base case value in Table A.19 after exposure to HF is 10.69, which is approximately 0.7 orders of magnitude lower than at Pre-test, but still well above the JTP acceptance criterion. The predicted changes after exposure to HF are given in Table 2.13. These predictions show that the resistance for silicone coated PWAs is approximately 1.2 orders of magnitude lower than the base case for all surface finish/flux combinations, but still well above the JTP acceptance criterion. Parylene coated PWAs give an increase of approximately 0.5 of an order of magnitude over the base case for most cases. Urethane coated PWAs had the best overall performance with an increase of approximately an order of magnitude higher than the base case for all cases. Uncoated PWAs give the same resistance as the base case for all surface finish/flux combinations.

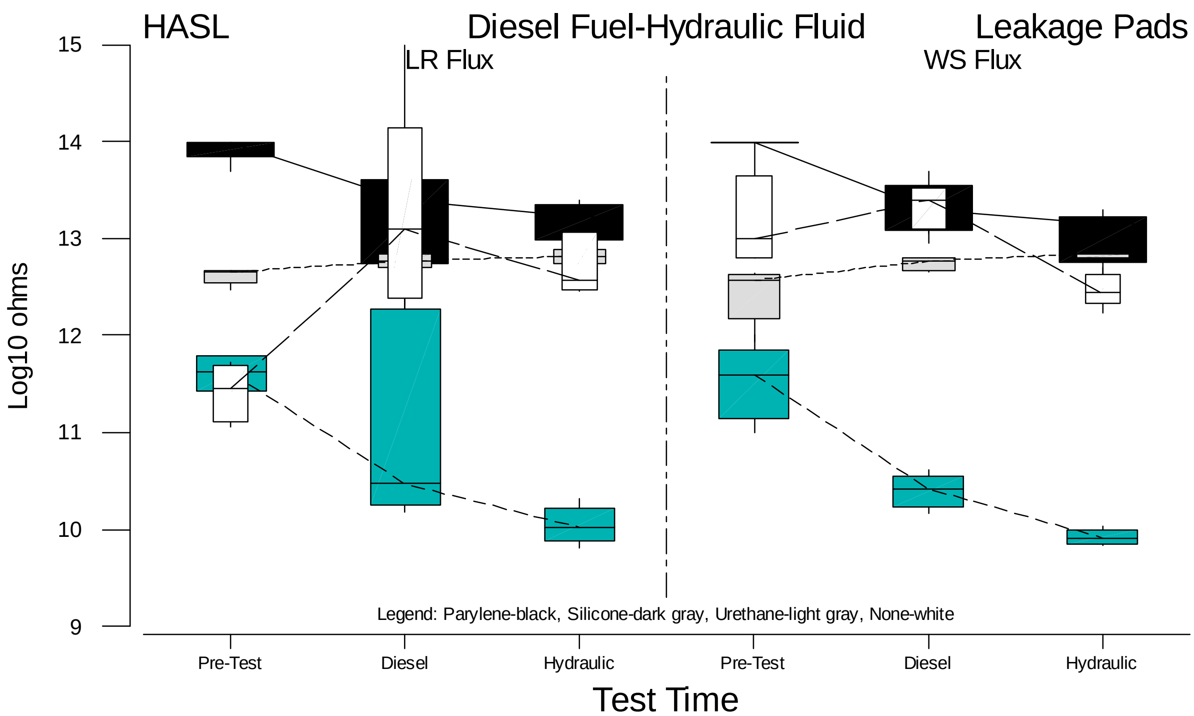

Figure 2.7 Boxplots of Leakage Measurements for 10-Mil Pads versus Test Time for HASL

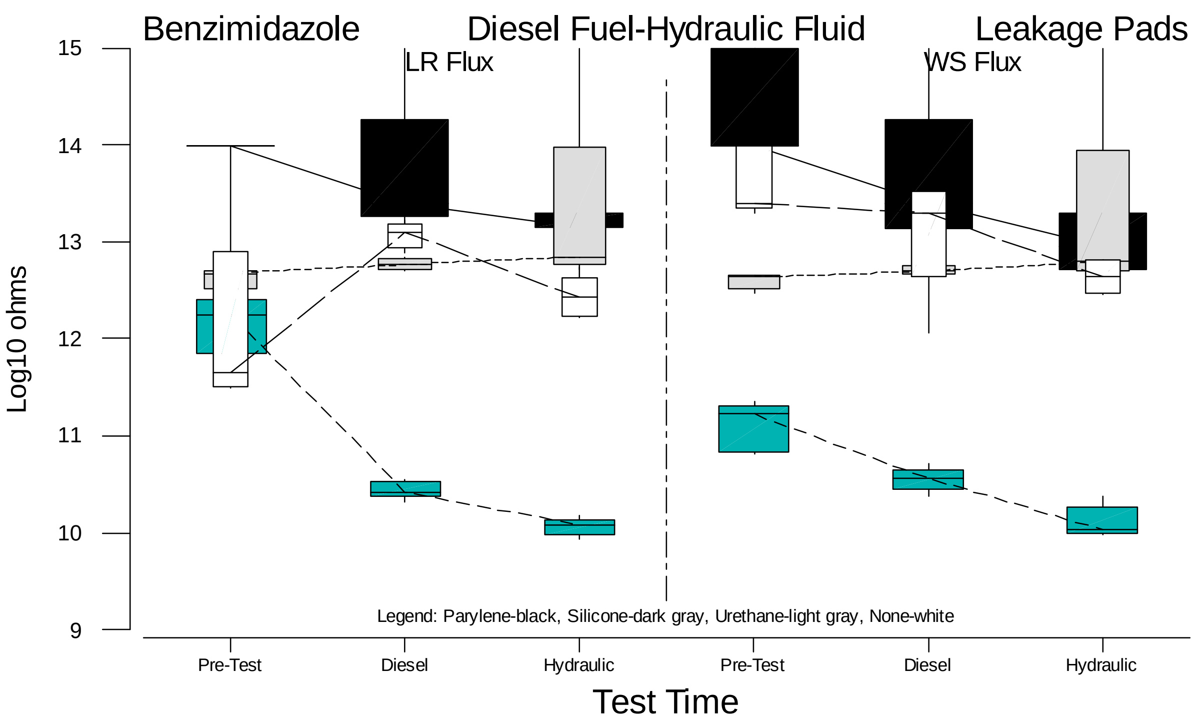

Figure 2.8 Boxplots of Leakage Measurements for 10-Mil Pads versus Test Time for Benzimidazole

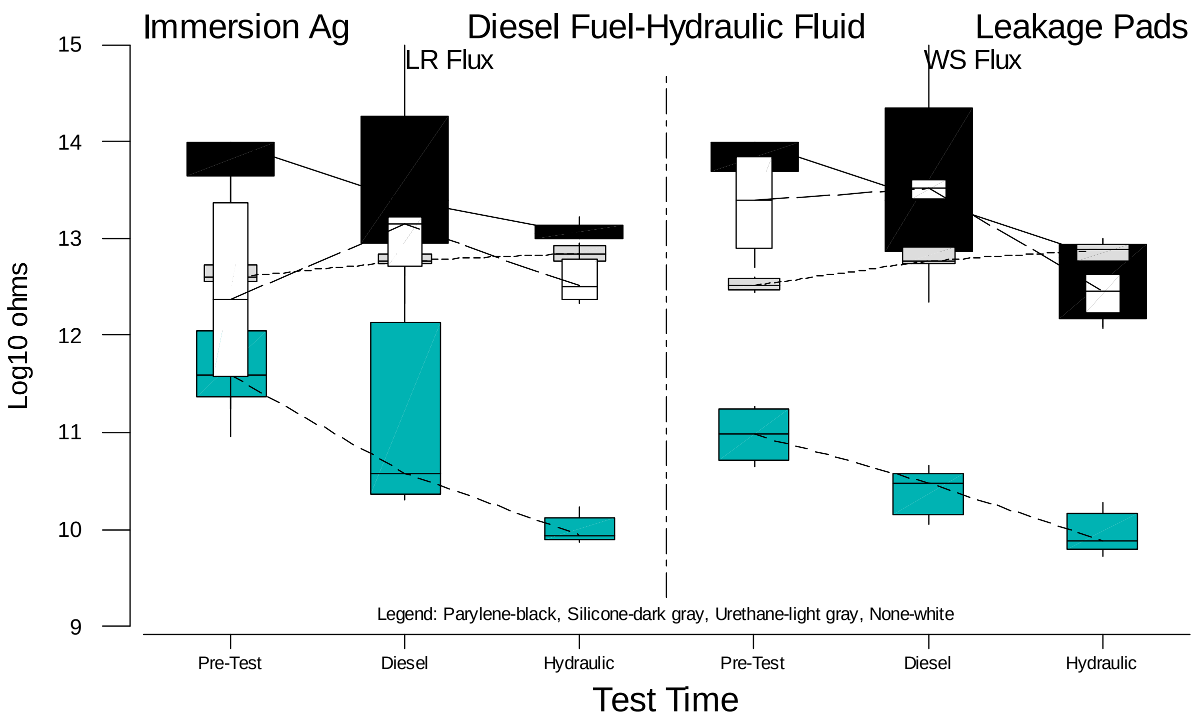

Figure 2.9 Boxplots of Leakage Measurements for 10-Mil Pads versus Test Time for Immersion Ag

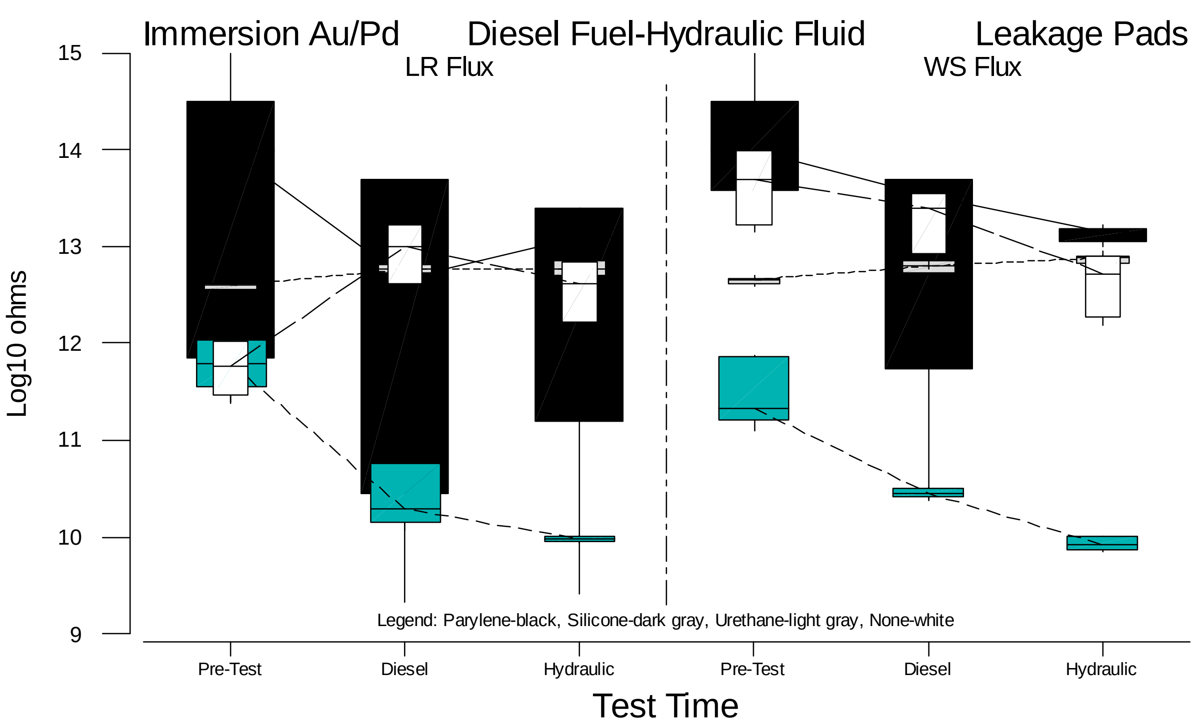

Figure 2. 10 Boxplots of Leakage Measurements for 10-Mil Pads versus Test Time for Immersion Au/Pd

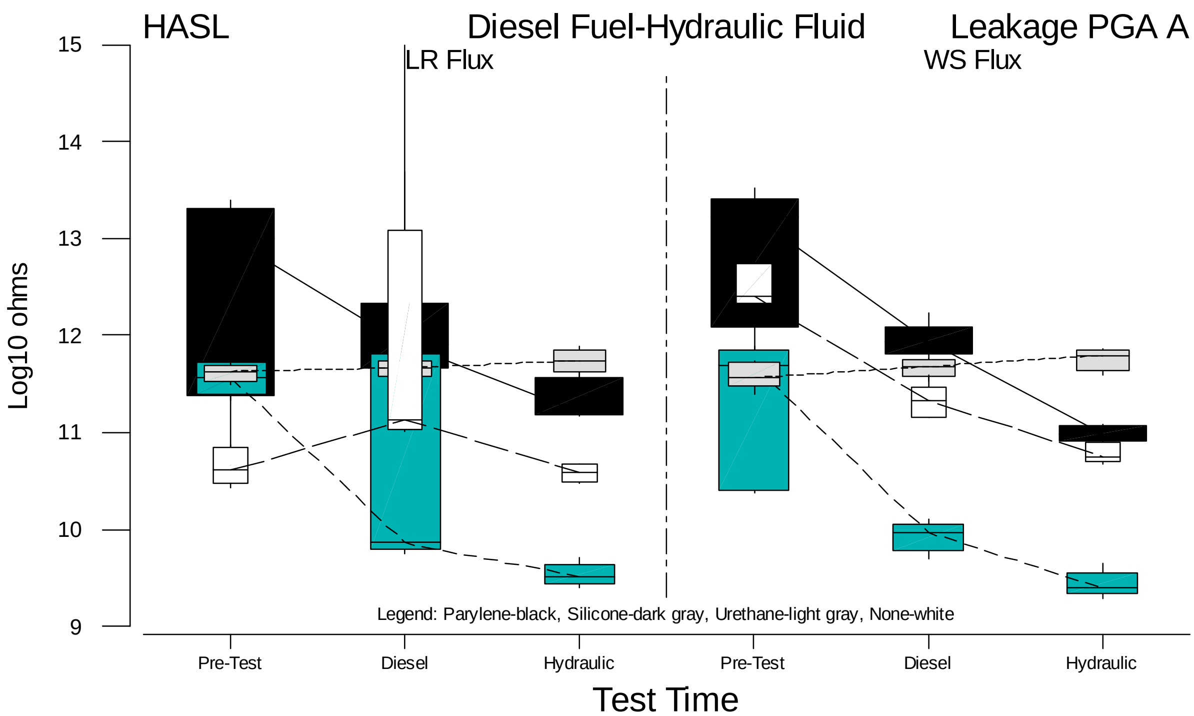

Figure 2.11 Boxplots of Leakage Measurements for PGA-A versus Test Time for HASL

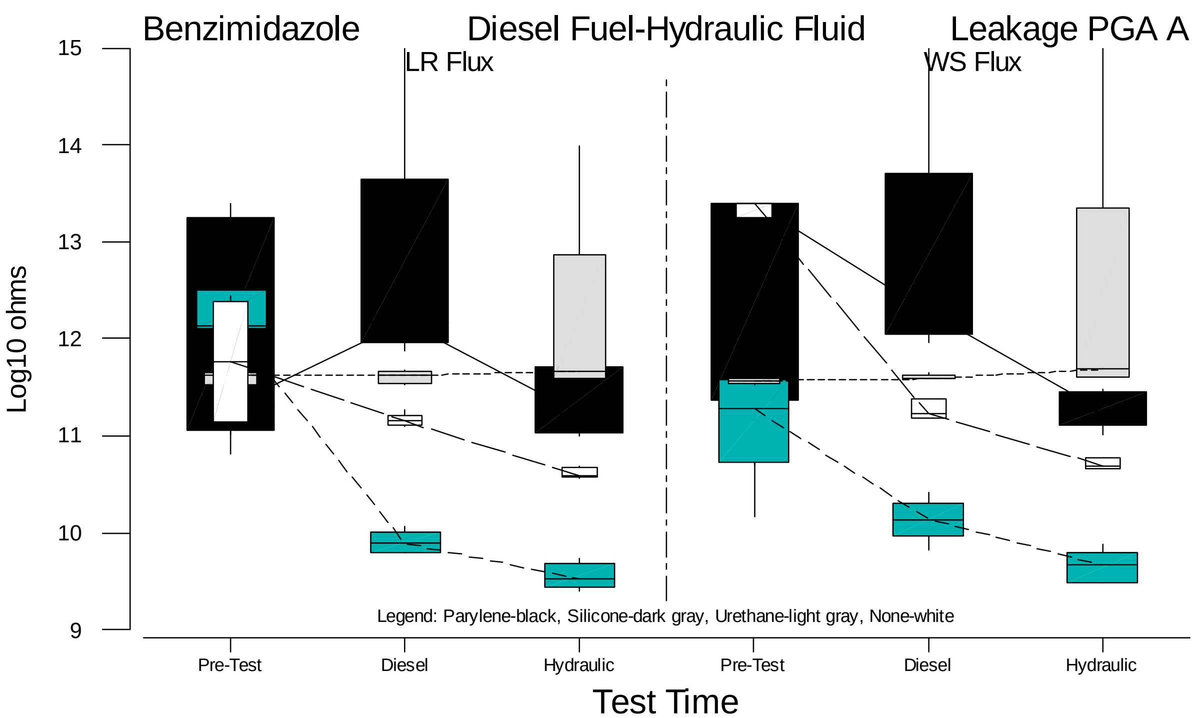

Figure 2.12 Boxplots of Leakage Measurements for PGA-A versus Test Time for Benzimidazole

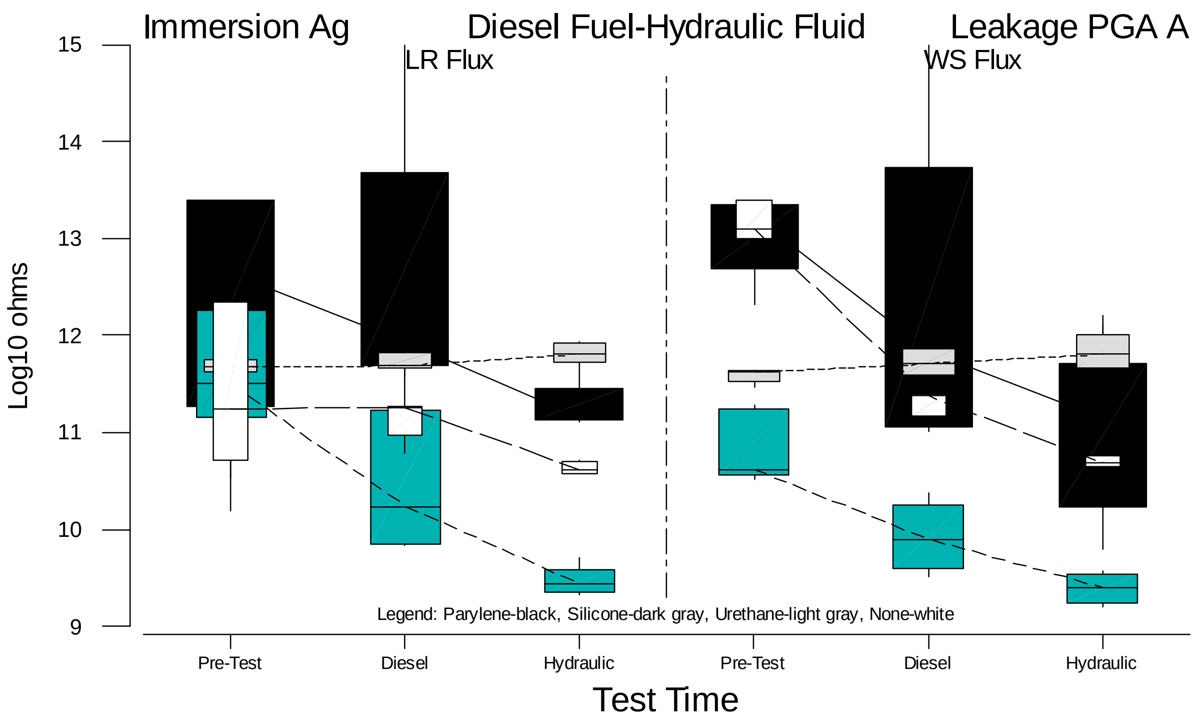

Figure 2.13 Boxplots of Leakage Measurements for PGA-A versus Test Time for Immersion Ag

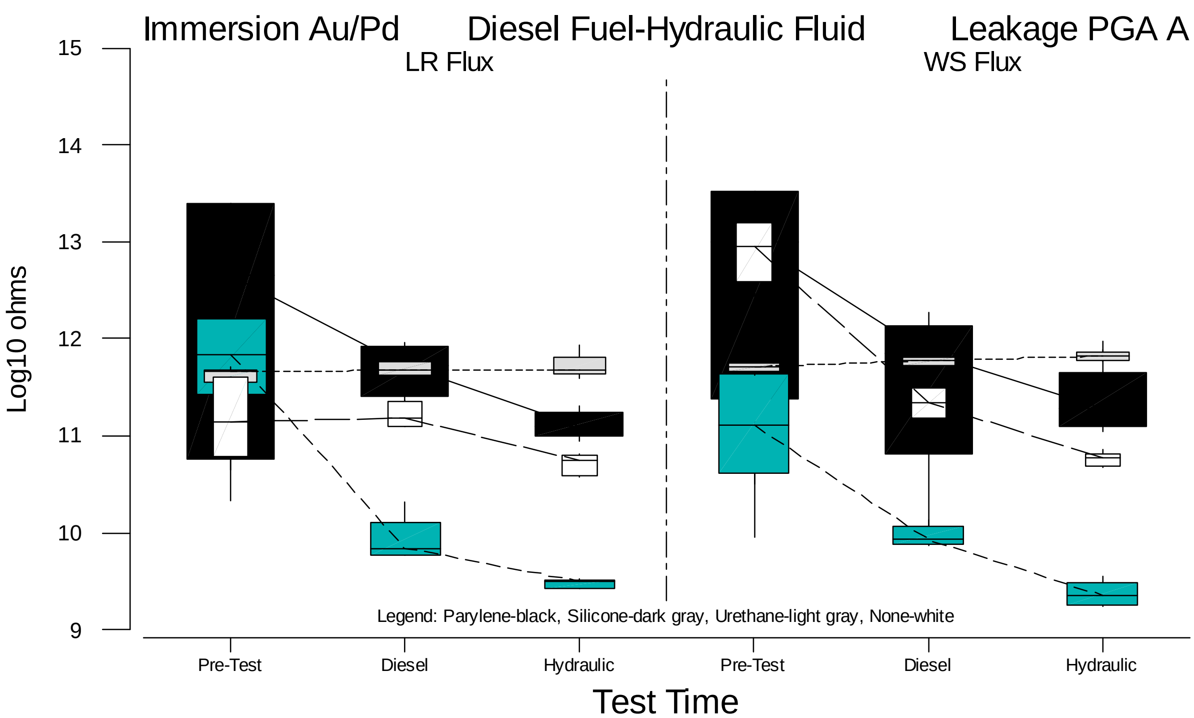

Figure 2.14 Boxplots of Leakage Measurements for PGA-A versus Test Time for Immersion Au/Pd

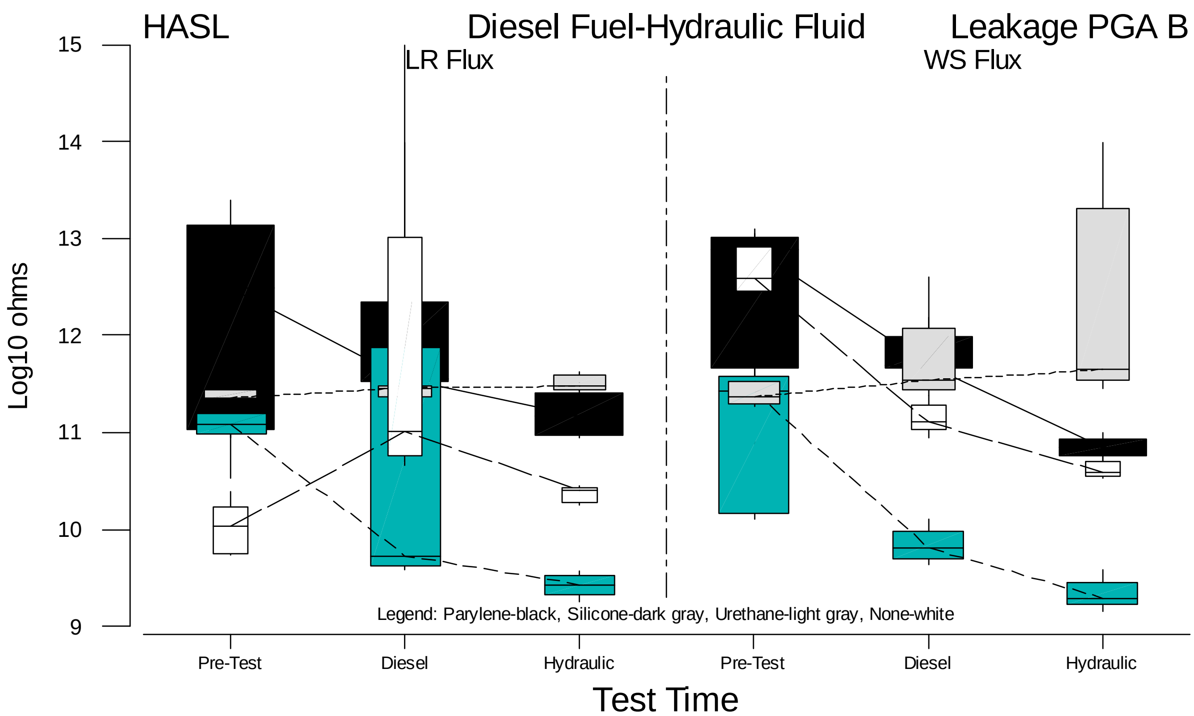

Figure 2.15 Boxplots of Leakage Measurements for PGA-B versus Test Time for HASL

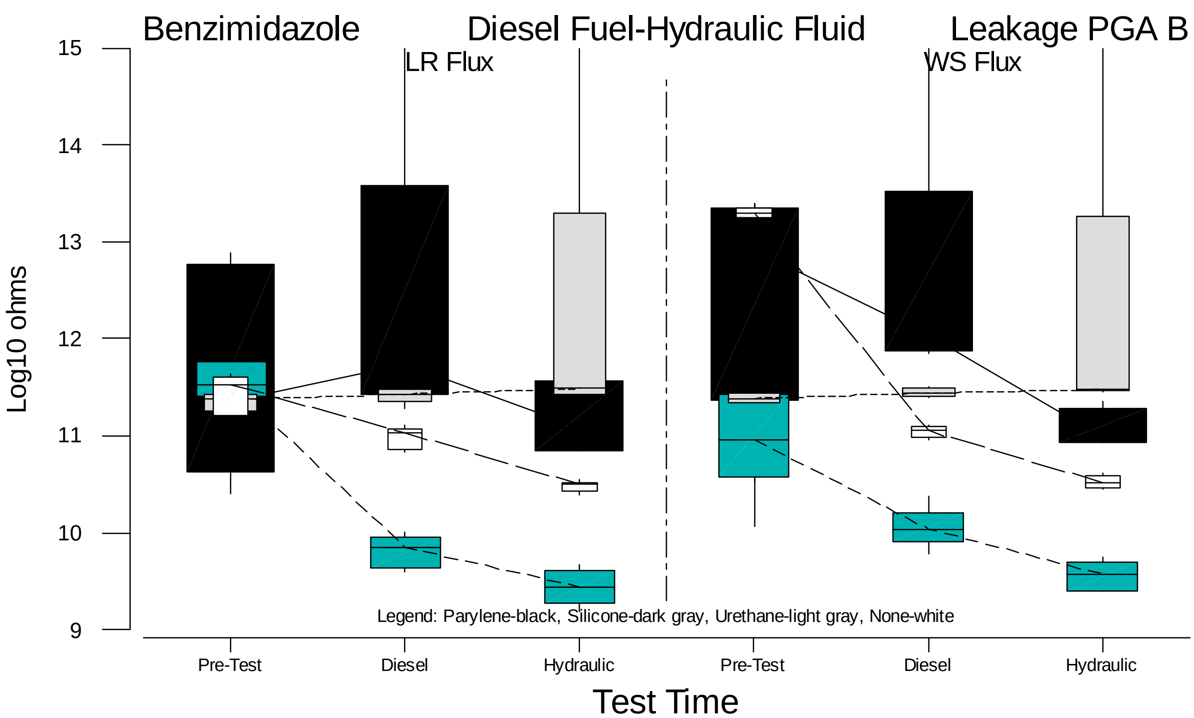

Figure 2.16 Boxplots of Leakage Measurements for PGA-B versus Test Time for Benzimidazole

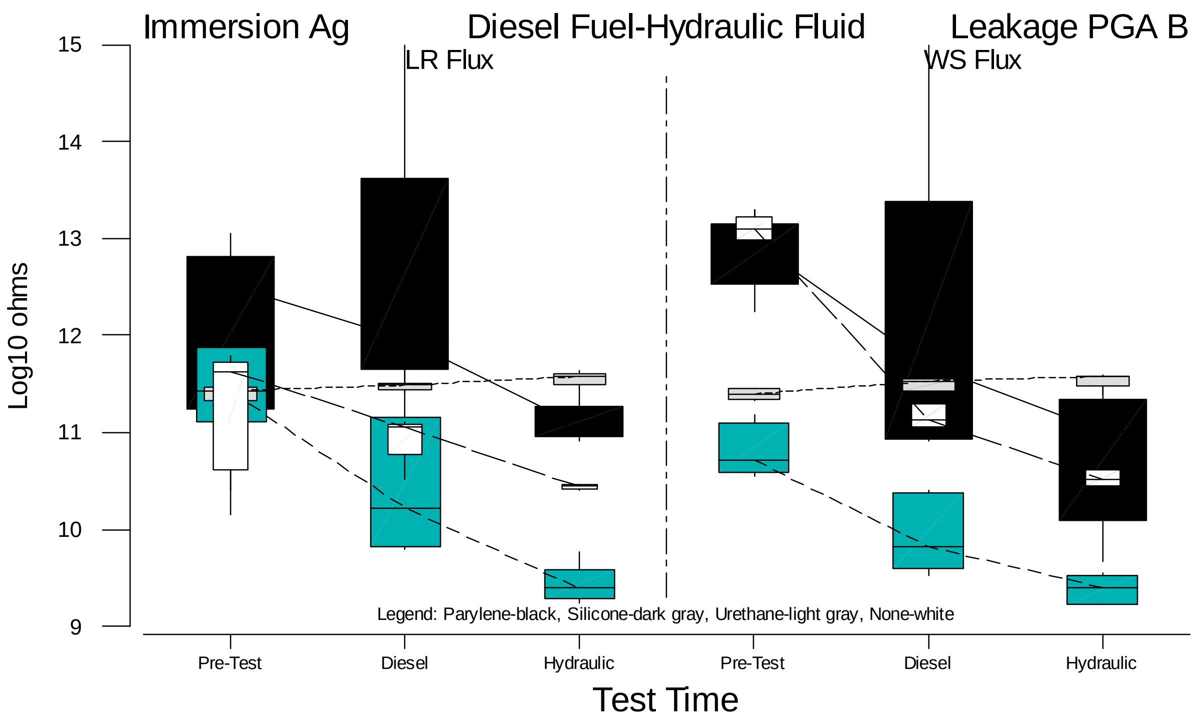

Figure 2.17 Boxplots of Leakage Measurements for PGA-B versus Test Time for Immersion Ag

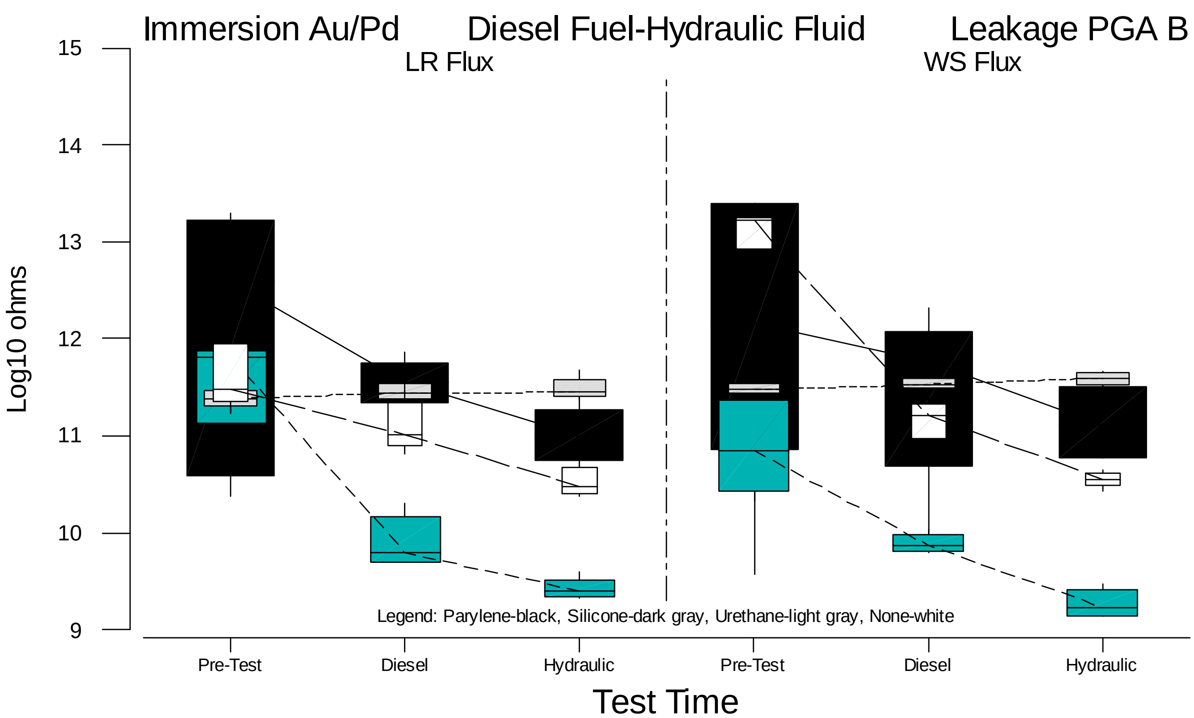

Figure 2.18 Boxplots of Leakage Measurements for PGA-B versus Test Time for Immersion Au/Pd

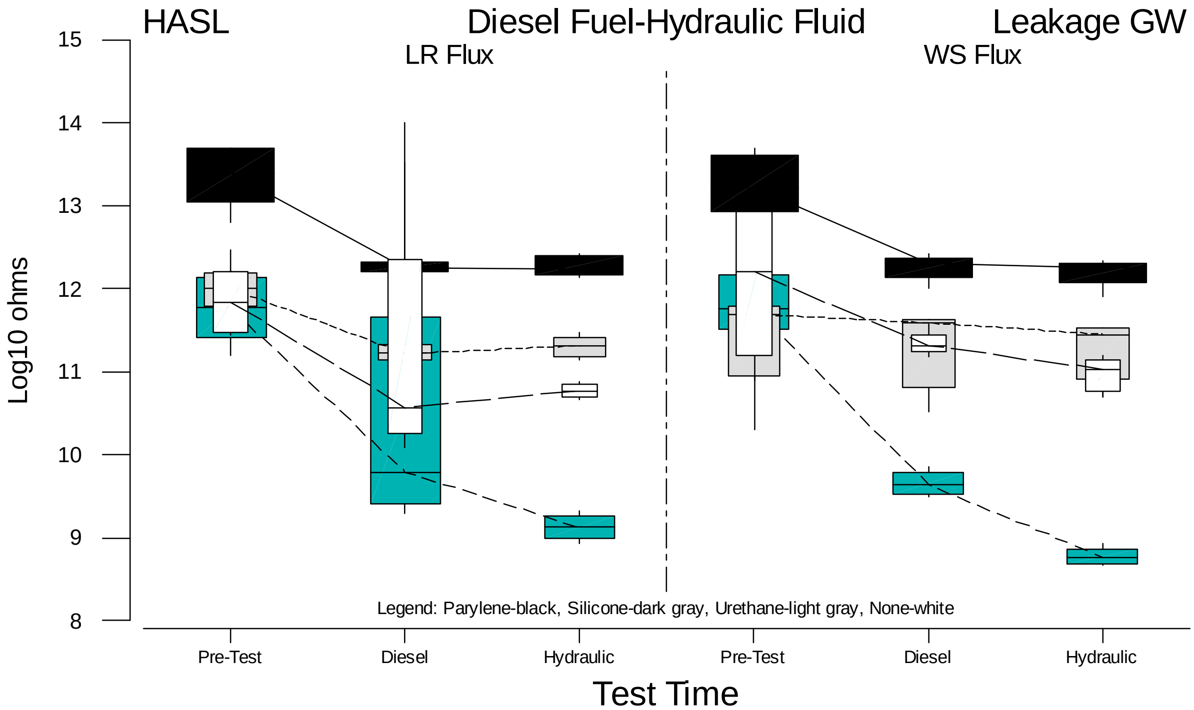

Figure 2.19 Boxplots of Leakage Measurements for the Gull Wing versus Test Time for HASL

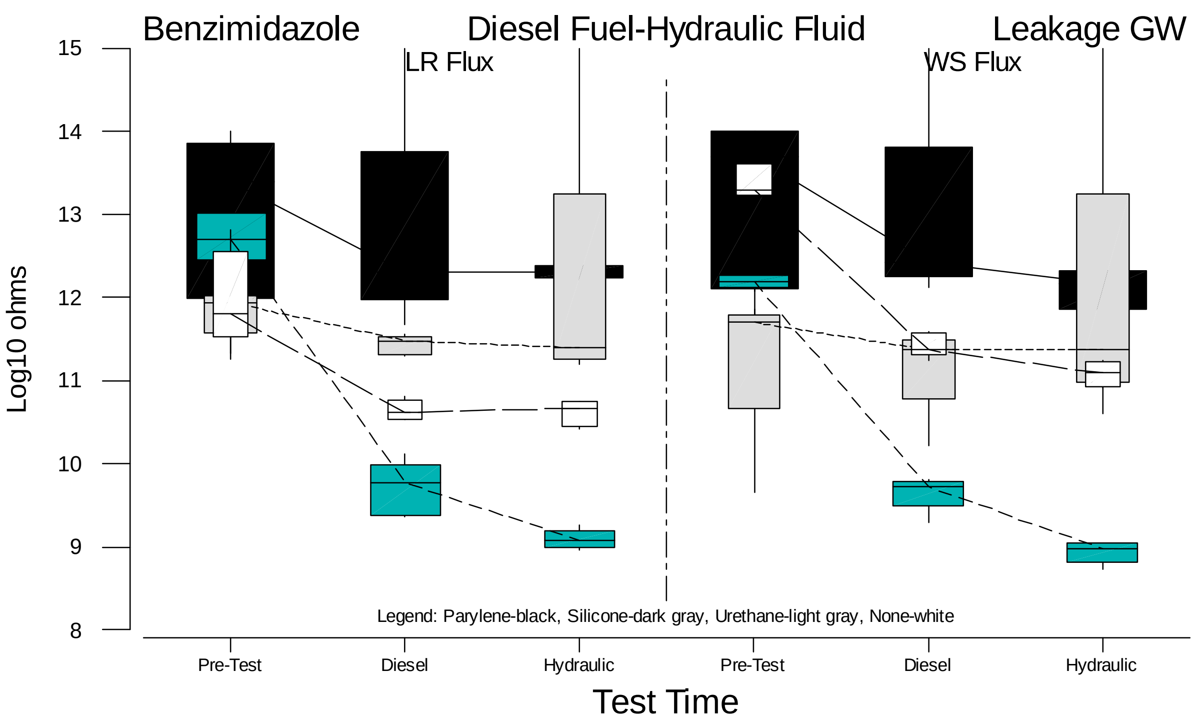

Figure 2.20 Boxplots of Leakage Measurements for the Gull Wing versus Test Time for Benzimidazole

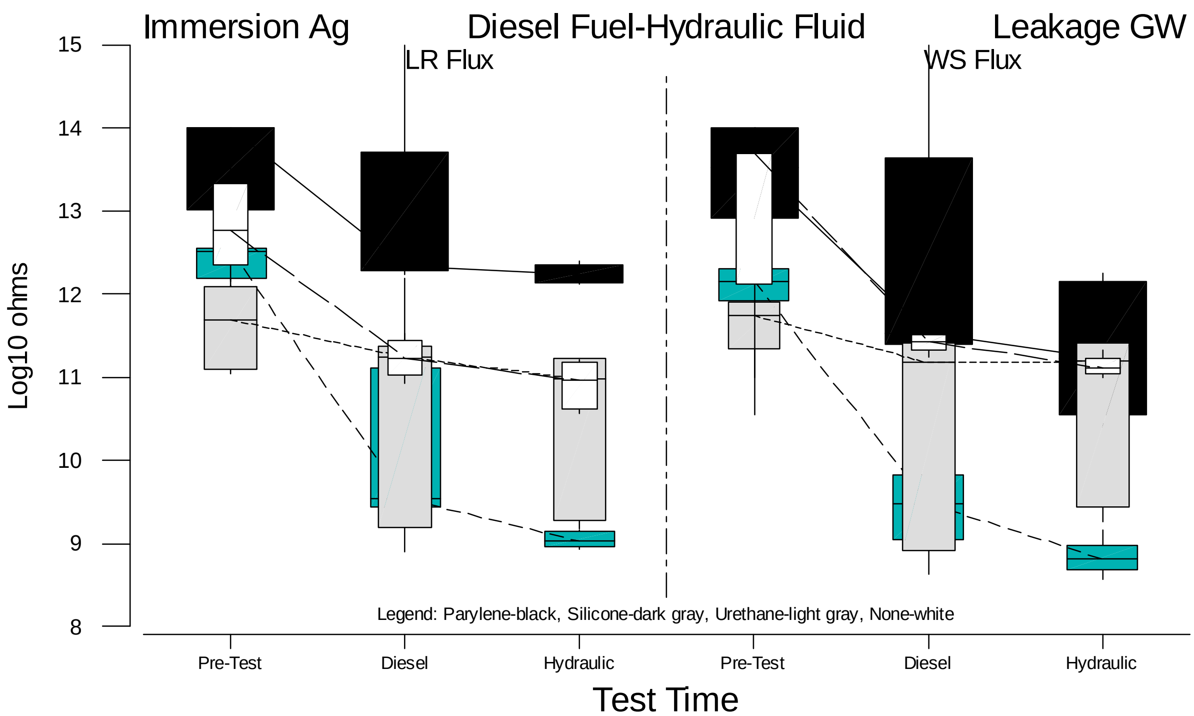

Figure 2.21 Boxplots of Leakage Measurements for the Gull Wing versus Test Time for Immersion Ag

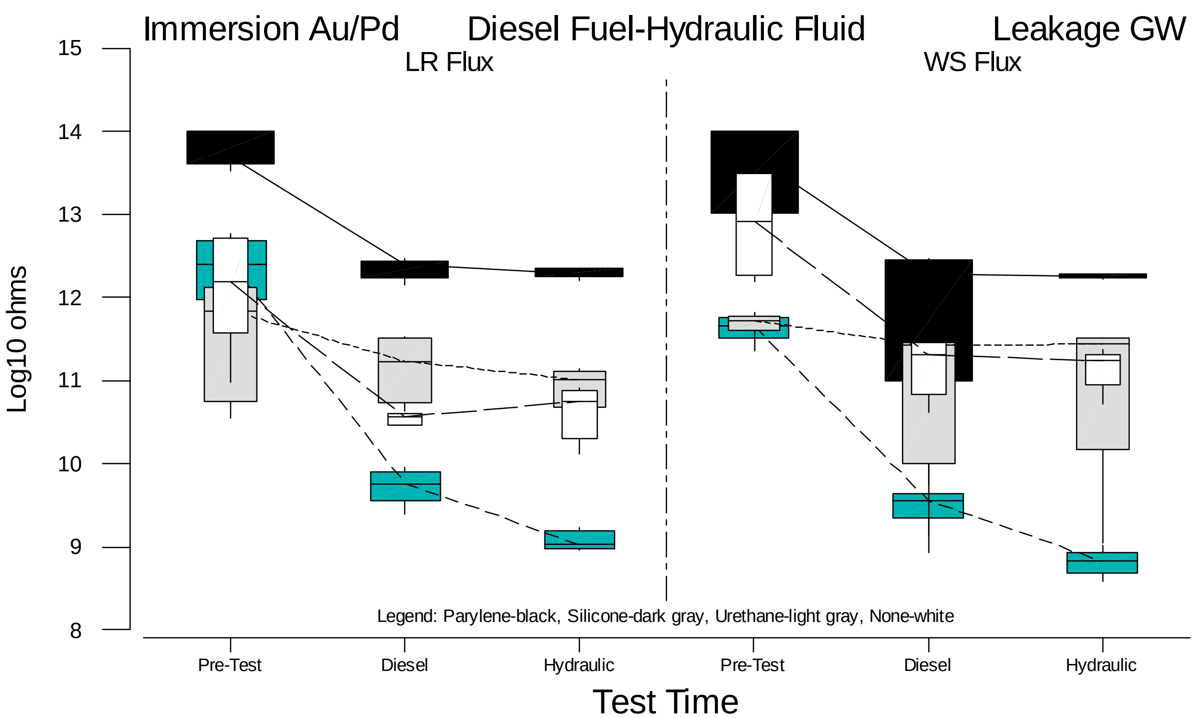

Figure 2.22 Boxplots of Leakage Measurements for the Gull Wing versus Test Time for Immersion Au/Pd

Displays. Figures 2.11 to 2.14 (also Figures B.73 to B.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.

- Resistance for all surface finish/coating/flux combinations was well above the JTP acceptance criterion after exposure to DF and HF
- There was a slight decrease in resistance from Pre-test to DF to HF of approximately 0.5 to 2 orders of magnitude for most surface finish/coating/flux combinations
- Uncoated and parylene coated PWAs processed with either flux gave the best results at Pre-test and after exposure to DF, but urethane coated PWAs gave the best results after HF
- Parylene coated PWAs generally had the greatest variability throughout the test sequene
- Silicone coated PWAs had the lowest resistance (undesirable) for all surface finish/coating/flux combinations—resistance is approximately 1 to 2 orders of magnitude lower than uncoated, parylene coated, and urethane coated PWAs after exposure to HF
- HF did not have the negative impact on resistance measurements as was the case in the CCAMTF screening study

Comparison to JTP Acceptance Criterion. All PGA-A resistance measurements met the JTP acceptance criterion at Pre-test, after exposure to DF, and after exposure to HF.

PGA-B. The predicted base case value at Pre-test is given in Table A.20 as 11.30, 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 2.14. This table shows that resistance for parylene coated PWAs is approximately an order of magnitude higher than the base case for all surface finish/flux combinations with WS being slightly higher. On the other hand, silicone gives a slight decrease in resistance when combined with WS flux. Urethane coated PWAs have essentially the same resistance as the base case throughout. The resistance for uncoated PWAs processed with WS flux is 1.75 orders of magnitude higher than those processed with LR flux.

Table 2.14 Predicted Changes from the Base Case for PGA-B at Pre-test

		No Coating	Parylene	Silicone	Urethane
HASL	**LR**		0.70		
	WS	1.75	1.18	-0.38	0.12
Benzimidazole	**LR**		0.70		
	WS	1.75	1.18	-0.38	0.12
Immersion Ag	**LR**		0.70		
	WS	1.75	1.18	-0.38	0.12
Immersion Au/Pd	**LR**		0.70		
	WS	1.75	1.18	-0.38	0.12

The predicted base case value in Table A.20 after exposure to DF is 11.40, which is nearly identical to that at Pre-test and well above the JTP acceptance criterion. The predicted changes after exposure to DF are given in Table 2.15. These predictions show the resistance for silicone coated PWAs is approximately 1.3 orders of magnitude lower than the base case for all surface finish/flux combinations, but still well above the JTP acceptance criterion. Uncoated PWAs and urethane coated PWAs give the same resistance for all surface finish/flux combinations as did parylene except for benzimidazole and immersion Ag, where the resistance is approximately an order of magnitude higher for parylene with either flux.

The predicted base case value in Table A.20 after exposure to HF is 10.50, which is 0.8 orders of magnitude lower than at Pre-test, but still well above the JTP acceptance criterion. The predicted changes after exposure to HF are given in Table 2.16. These predictions show that the resistance for silicone coated PWAs is approximately 1.1 orders of magnitude lower than the base case for all surface finish/flux combinations, but still well above the JTP acceptance criterion. Parylene coated PWAs gave an increase of approximately 0.5 of an order of magnitude over the base case for all cases. Urethane coated PWAs had the best overall performance with an increase of at least an order of magnitude over the base case for all surface finish/flux combinations. Uncoated PWAs give the same resistance as the base case for all surface finish/flux combinations.

Table 2.15 Predicted Changes from the Base Case for PGA-B after Exposure to Diesel Fuel

		No Coating	Parylene	Silicone	Urethane
HASL	**LR**			-1.34	
	WS			-1.34	
Benzimidazole	**LR**		1.06	-1.34	
	WS		1.06	-1.34	
Immersion Ag	**LR**		0.89	-1.34	
	WS		0.89	-1.34	
Immersion Au/Pd	**LR**			-1.34	
	WS			-1.34	

Table 2.16 Predicted Changes from the Base Case for PGA-B after Exposure to Hydraulic Fluid

		No Coating	Parylene	Silicone	Urethane
HASL	**LR**		0.54	-1.10	1.01
	WS		0.54	-1.10	1.76
Benzimidazole	**LR**		0.54	-1.10	1.68
	WS		0.54	-1.10	1.68
Immersion Ag	**LR**		0.54	-1.10	1.01
	WS		0.54	-1.10	1.03
Immersion Au/Pd	**LR**		0.54	-1.10	1.01
	WS		0.54	-1.10	1.08

Displays. Figures 2.15 to 2.18 (also Figures B.77 to B.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.

- Resistance for all surface finish/coating/flux combinations was well above the JTP acceptance criterion after exposure to DF and HF
- There was a slight decrease in resistance from Pre-test to DF to HF of approximately 0.5 to 2 orders of magnitude for most surface finish/coating/flux combinations
- Uncoated and parylene coated PWAs processed with either flux gave the best results at Pre-test and after exposure to DF, but urethane coated PWAs gave the best results after HF
- Parylene coated PWAs generally had the greatest variability
- Silicone coated PWAs had the lowest resistance (undesirable) for all surface finish/coating/flux combinations—resistance is approximately 1 to 1.5 orders of magnitude lower than uncoated, parylene, and urethane coated PWAs after exposure to HF
- HF did not have the negative impact on resistance measurements as was the case in the CCAMTF screening study

Comparison to JTP Acceptance Criterion. All PGA-B resistance measurements met the JTP acceptance criterion at Pre-test, after exposure to DF, and after exposure to HF.

Gull Wing. The predicted base case value at Pre-test is given in Table A.21 as 11.86, 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 2.17. This table shows that resistance for parylene coated PWAs is more than an order of magnitude higher than the base case for all surface finish/flux combinations. On the other hand, silicone and urethane show little change from the base case. The resistance for uncoated PWAs is higher than the base case for all but two surface finish/flux combinations.

The predicted base case value in Table A.21 after exposure to DF is 11.24, which is slightly lower than at Pre-test, but still well above the JTP acceptance criterion. The predicted changes after exposure to DF are given in Table 2.18. These predictions show the resistance for silicone coated PWAs is approximately 1.4 to 1.7 orders of magnitude lower than the base case for all surface finish/flux combinations, but still well above the JTP acceptance criterion. On the other hand, parylene coated PWAs gave approximately an order of magnitude

Table 2.17 Predicted Changes from the Base Case for the Gull Wing at Pre-test

		No Coating	Parylene	Silicone	Urethane
HASL	**LR**		1.31		
	WS		1.31		
Benzimidazole	**LR**		1.31	0.86	
	WS	1.53	1.32	0.33	-0.55
Immersion Ag	**LR**	1.09	1.68	0.40	-0.23
	WS	1.09	1.68	0.40	-0.23
Immersion Au/Pd	**LR**	0.56	1.87	0.56	-0.25
	WS	0.56	1.87	-0.23	-0.25

Table 2.18 Predicted Changes from the Base Case for the Gull Wing after Exposure to Diesel Fuel

		No Coating	Parylene	Silicone	Urethane
HASL	**LR**		1.29	-1.39	
	WS		1.29	-1.39	
Benzimidazole	**LR**		1.29	-1.39	
	WS		1.29	-1.39	
Immersion Ag	**LR**		1.29	-1.39	-0.82
	WS		1.29	-1.39	-0.82
Immersion Au/Pd	**LR**	-0.32	0.97	-1.71	-0.32
	WS	-0.32	0.97	-1.71	-0.32

Table 2.19 Predicted Changes from the Base Case for the Gull Wing after Exposure to Hydraulic Fluid

		No Coating	Parylene	Silicone	Urethane
HASL	**LR**		1.27	-2.02	
	WS		1.27	-2.02	
Benzimidazole	**LR**		1.27	-2.02	1.05
	WS		1.27	-2.02	1.05
Immersion Ag	**LR**		1.27	-2.02	-0.49
	WS		0.36	-2.02	-0.49
Immersion Au/Pd	**LR**		1.27	-2.02	
	WS		1.27	-2.02	

increase in resistance for all surface finish/flux combinations. Urethane coated PWAs were the same as the base case for HASL and benzimidazole, but they were slightly lower for immersion Ag and immersion Au/Pd. All uncoated PWAs are the same as the base except for immersion Au/Pd, which is only slightly lower with either flux.

The predicted base case value in Table A.21 after exposure to HF is 10.97, which is approximately an order of magnitude lower than at Pre-test, but still well above the JTP acceptance criterion. The predicted changes after exposure to HF are given in Table 2.19. These predictions show that the resistance for silicone coated PWAs is approximately two orders of magnitude lower than the base case for all surface finish/flux combinations, but still well above the JTP acceptance criterion. Parylene coated PWAs give an increase of approximately 1.3 orders of magnitude over the base case for all but immersion Ag processed with WS flux. Urethane coated PWAs have the same resistance as the base case, except for benzimidazole being an order of magnitude higher and immersion Ag being approximately 0.5 orders of magnitude lower. Uncoated PWAs give the same resistance as the base case for all surface finish/flux combinations.

Displays. Figures 2.19 to 2.22 (also Figures B.81 to B.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.

- Resistance for all surface finish/coating/flux combinations was well above the JTP acceptance criterion after exposure to DF and HF
- There was a slight decrease in resistance from Pre-test to DF to HF of approximately 1 to 3 orders of magnitude for all surface finish/coating/flux combinations
- Parylene coated PWAs processed with either flux gave the best results throughout exposure to DF and HF
- Uncoated and silicone coated PWAs generally had lower variability than parylene coated PWAs
- Silicone coated PWAs had the lowest resistance (undesirable) for all surface finish/coating/flux combinations—resistance is approximately 2 to 3 orders of magnitude lower than uncoated, parylene, and urethane coated PWAs after exposure to HF
- HF did not have the negative impact on resistance measurements as was the case in the CCAMTF screening study

Comparison to JTP Acceptance Criterion. All GW resistance measurements met the JTP acceptance criterion at Pre-test, after exposure to DF, and after exposure to HF.

2.9 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. There were no anomalous measurements for stranded wires after exposure to DF or HF.

Pre-test measurements for both stranded wires were subjected to GLM analyses, as were the deltas after exposure to DF and HF. The results of the GLM analyses are given in Tables A.22 and A.23. The model R^2s from those tables are summarized as follows.

Leakage Circuit	Pre-test	DF	HF
Stranded Wire 1	3.1%	3.6%	6.5%
Stranded Wire 2	34.3%	15.6%	8.0%

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 B.85 to B.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 B.89 to B.92. All boxplots show little variability throughout.

Comparison to JTP Acceptance Criterion. There were no anomalies for the stranded wire during exposure to DF and HF.

2.10 Summary and Conclusions. Detailed results of the electrical performance of 160 LRSTF PWAs after exposure to DF and HF have been presented in this section. These PWAs were each tested at Pre-test, after exposure to DF, and after exposure to HF. At each test time, 3680 electrical measurements were recorded and compared to the JTP acceptance criterion.

Summary of Yields by Circuit Type. Sixteen of the 23 circuits on the LRSTF PWA survived exposure to DF and HF with no anomalies while the remaining seven circuits had only 14 anomalies. Table 2.20 provides a summary of the yields relative to the JTP acceptance criteria by major circuit type after exposure to DF and HF. The yields are quite high for all circuits throughout the DF-HF test sequence.

There were 14 anomalies that did not meet the JTP acceptance criteria after exposure to HF. Of these, only two HF RNR circuits were of sufficient magnitude to be considered for failure analysis. In addition to these anomalies, there were 13 HSD circuits that did not respond. Failure analysis showed these anomalies were due to either a damaged trace or a damaged component and were not related to surface finish, coating status, or flux type.

Tabulation of Anomalies by Experimental Parameters. There were 22 anomalies that did not meet the JTP acceptance criteria after exposure to DF and 14 after exposure to HF. These anomalies are summarized by surface finishes, coating status, and flux type for each fluid exposure in Table 2.21.

Table 2.20 Summary of Yields for Circuits that Met the JTP Acceptance Criteria After Exposure to Diesel Fuel and Hydraulic Fluid

Circuitry	Diesel Fuel	Hydraulic Fluid
HCLV	317/320 = 99.1%	320/320 = 100.0%
HVLC	314/320 = 98.1%	320/320 = 100.0%
HSD	320/320 = 100.0%	320/320 = 100.0%
HF LPF	952/960 = 99.2%	952/960 = 98.2%
HF TLC	795/800 = 99.4%	794/800 = 99.3%
ON	640/640 = 100.0%	640/640 = 100.0%
SW	320/320 = 100.0%	320/320 = 100.0%
Totals	3658/3680 = 99.4%	3666/3680 = 99.6%

Table 2.21 Tabulation of Anomalies that did not Meet the JTP Acceptance Criteria by Fluid Type

Fluid	Surface Finish		Coating Status		Flux Type	
Diesel Fuel	HASL	2	None	2	LR	13
	Benzimidazole	5	Parylene	13	WS	9
	Immersion Ag	12	Silicone	3		
	Immersion Au/Pd	3	Urethane	4		
	Totals	22		22		22
Hydraulic Fluid	HASL	3	None	2	LR	7
	Benzimidazole	3	Parylene	7	WS	7
	Immersion Ag	4	Silicone	1		
	Immersion Au/Pd	4	Urethane	4		
	Totals	14		14		14

Tabulation of the Anomalies by PWA. One hundred and fifty of the 160 PWAs survived exposure to HF without any anomalies. The remaining 10 PWAs each had either one or two anomalies. Eleven of the 14 anomalies after HF carried over from DF, so exposure to HF did not have an adverse affect on the PWAs. The complete frequency distribution of the anomalies per PWA for each fluid is given in Table 2.22.

Table 2.22 Number of Anomalies per PWA by Fluid Type

Anomalies per PWA	DF	HF
0	146	150
1	7	6
2	6	4
3	1	0
Totals	160	160

Chi-Square Tests of Independence. Fourteen PWAs had at least one anomaly after exposure to DF and 10 PWAs had at least one anomaly after exposure to HF. 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 2.23 presents the PWA anomaly frequencies by surface finish at each test time. The chi-square analysis of the frequencies in Table 2.23 after DF shows that the number of anomalies has a slight dependence on surface finish (p-value = 0.028). However, the number of anomalies is independent of surface finish after HF (p-value = 0.935). Thus, there is no relationship between the number of anomalies and surface finish.

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 2.24 presents the anomaly frequencies by coating status at each test time. The chi-square analysis of the frequencies in Table 2.24 indicates that number of anomalies is independent of coating status after both DF (p-value = 0.421) and HF (p-value = 0.545). Thus, coating was not beneficial relative to the JTP acceptance criteria taken over all 23 circuits. This is not to say that coating would not be beneficial to some

Table 2.23 Summary of Anomalies by Surface Finish and Fluid Type

Fluid	Anomalies	HASL	Benzi	Imm Ag	Imm Au/Pd	Totals
Diesel Fuel	At least 1	1	3	8	2	14
	None	39	37	32	38	146
	Totals	40	40	40	40	160
Hydraulic Fluid	At least 1	2	2	3	3	10
	None	38	38	37	37	150
	Totals	40	40	40	40	160

Table 2.24 Summary of Anomalies by Coating Status and Fluid Type

Fluid	Anomalies	None	Parylene	Silicone	Urethane	Totals
Diesel Fuel	At least 1	2	6	3	3	14
	None	38	34	37	37	146
	Totals	40	40	40	40	160
Hydraulic Fluid	At least 1	2	4	1	3	10
	None	38	36	39	37	150
	Totals	40	40	40	40	160

Table 2.25 Summary of Anomalies by Flux Type and Fluid Type

Fluid	Anomalies	LR	WS	Totals
Diesel Fuel	At least 1	9	5	14
	None	71	75	146
	Totals	80	80	160
Hydraulic Fluid	At least 1	6	4	10
	None	74	76	150
	Totals	80	80	160

circuits in some instances, but rather coating is not an important factor in determining the number of anomalies that fail to meet the JTP acceptance criteria in the DF-HF test sequence.

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 2.25 presents the anomaly frequencies by flux type at each test time. The chi-square analysis of the frequencies in Table 2.24 indicates that number of anomalies is independent of coating status after both DF (p-value = 0.263) and HF (p-value = 0.499). Thus, flux type was not an important factor relative to the number of anomalies not meeting the JTP acceptance criteria.

References

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