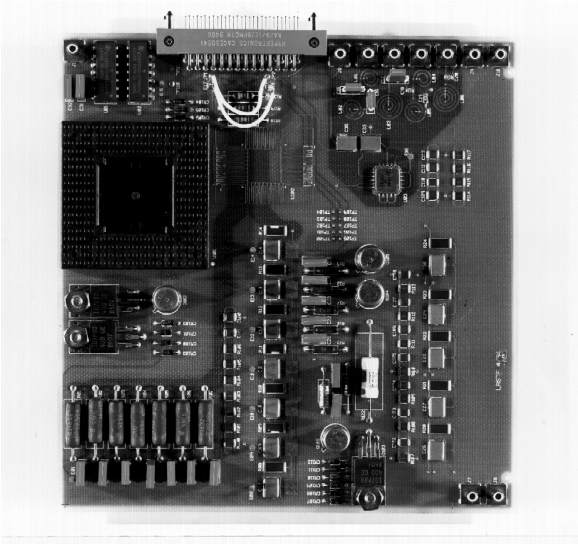
Printed Wiring Board
Surface Finishes



Cleaner Technologies Substitutes Assessment

VOLUME 2: Appendices

Jack R. Geibig, Senior Research Associate
Mary B. Swanson, Research Scientist
and the
PWB Engineering Support Team

This document was produced by the University of Tennessee Center for Clean Products and Clean Technologies under grant #X825373 from EPA's Design for the Environment Branch, Economics, Exposure, & Technology Division, Office of Pollution Prevention and Toxics.

Appendix A

Data Collection Sheets

Contents

Design for the Environment

Printed Wiring Board Project
Workplace Practices Questionnaire

Please complete this questionnaire, make a copy for your records, and send the original to:

Jack Geibig
UT Center for Clean Products
311 Conference Center Building
Knoxville TN 37996
Phone: (423) 974-6513
Fax: (423) 974-1838

FACILITY AND CONTACT INFORMATION

Facility Identification

Company Name:					
Site Name:					
Street Address:					
City:		State:		Zip:	

Contact Identification Enter the names of the persons who can be contacted regarding this survey.

Name:		
Title:		
Phone:		
Fax:		
E-Mail:		

—INSTRUCTION SHEET—

FOR THE DESIGN FOR THE ENVIRONMENT (DFE) ALTERNATIVE SURFACE FINISHES (ASF) PROJECT

WORKPLACE PRACTICES QUESTIONNAIRE

INTRODUCTION

This questionnaire was prepared by the University of Tennessee Center for Clean Products and Clean Technologies in partnership with The US EPA Design for the Environment (DfE) Printed Wiring Board (PWB) Program, IPC, and other members of the DfE PWB Industry Project Work Groups.

The purpose of this questionnaire is to collect data that will be used in preparation of a Design for the Environment (DfE) Alterative Surface Technologies report. This report will present an analysis and evaluation of the risk, performance, and costs associated with operating each of the alternative surface finish processes. Much of this report will be based on data submitted by PWB manufacturing facilities. You can obtain more information about this project and other DfE PWB projects from the US EPA's website at http://www.epa.gov/opptintr/dfe/pwb/pwb.html).

CONFIDENTIALITY

All information and data that is entered into this questionnaire is confidential. The sources of responses are only known to the IPC and have been coded by the IPC for industry research purposes. Any use or publication of the data will not identify the names or locations of the respondent companies or the individuals completing the forms.

INSTRUCTIONS

Respondents must complete Sections 1 (Facility Characterization) and Section 2 (HASL Process) of this questionnaire.

Section 3 is divided into five processes (3A through 3E) as shown below:

3A. Organic Solder Preservative (OSP) Process
3B. Immersion Silver Process
3C. Immersion Tin Process
3D. Electroless Nickel/Immersion Gold Process
3E. Electroless Nickel/Electroless Palladium/Immersion Gold Process

Of these five subsections, 3A-3E, please fill out only the top two alternative processes, based on PWB through-put, that are currently being implemented at your facility.

If your responses do not fit in the spaces provided, please photocopy the section to provide more space or use ordinary paper and mark the response with the section number to which it applies.

Please make a copy of the completed sections and retain them for your records.

If you have questions regarding the survey, please contact Jack Geibig of the University of Tennessee Center for Clean Products and Clean Technologies at (telephone 423/975-6513; fax 423/974-1838; email jgeibig@utk.edu) or Star Summerfield at IPC (telephone 847/790-5347; fax 847/509-9798; email summst@ipc.org).

Please return the completed questionnaire by January 8, 1999 to:
Star Summerfield, IPC
2215 Sanders Road, Northbrook, IL 60062-6135
Phone: 847/790-5347, FAX 847/509-9798, email summst@ipc.org

A RETURN LABEL TO IPC IS ENCLOSED FOR YOUR CONVENIENCE.

Section 1. Facility Characterization

This section focuses on general information specific to the facility. This information is not process-specific. Please estimate manufacturing data for the previous 12 month period, or other convenient time period of 12 consecutive months (e.g., FY97). Only consider the portion of the facility dedicated to PWB manufacturing when entering employee and facility size data.

1.1 General Information

Size of portion of facility used for manufacturing PWBs:	sq. ft.	Overall amount of PWB produced in surface square feet (ssf):	ssf/yr

1.2 Process Type

Estimate the percentage of PWBs manufactured at your facility using the following methods for surface finishing (SF). Specify "other" entry.

Surface Finish Process	Percent of Total	Surface Finish Process	Percent of Total
HASL	%	Electroless Nickel/ Immersion Gold	%
OSP-Thick	%	Electroless Nickel/Electroless Palladium/ Immersion Gold	%
OSP-Thin (benzotriazole-based)	%	Other:	%
Immersion Tin	%	Other:	%
Electroless Palladium	%	Other:	%
Immersion Silver	%	**Total**	100%

1.3 Wastewater Discharge and Sludge Data

Wastewater discharge method (circle one):	Direct (to stream) Indirect (to POTW) Zero
Throughput of facility wastewater treatment system:	gals/day
Annual weight of sludge generated:	lbs
Is sludge dewatered prior to disposal (circle one)?	Yes No
Water content **prior** to dewatering:	%
Water content **after** dewatering:	%

Section 2. HASL Process

2.1 Process Schematic: HASL

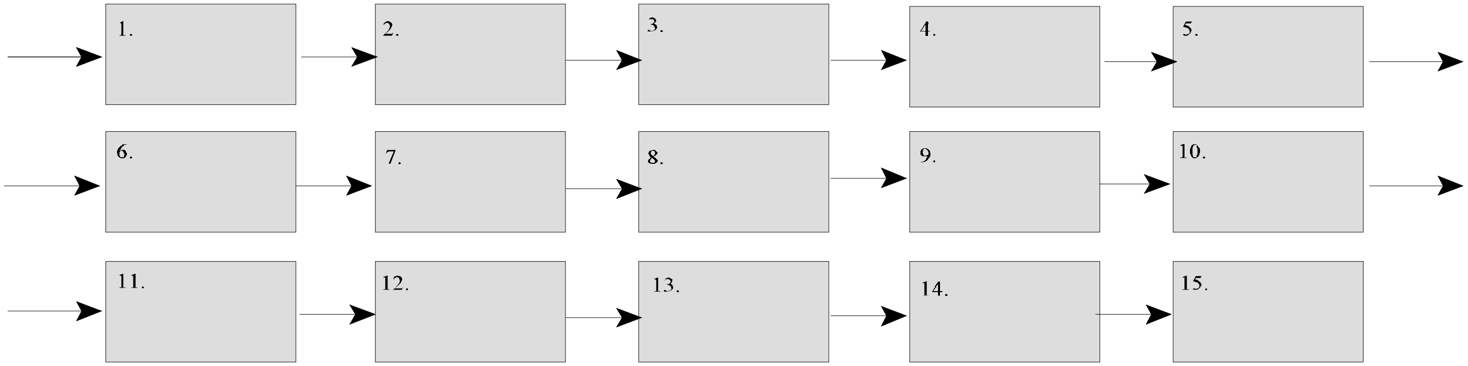
Fill in the figure below for your HASL surface finishing processses. Using the key at the bottom of the page, identify which letter corresponds w the first step in your HASL process and write that letter in the first box (see example). Continue using the key to fill in boxes for each step intil y entire HASL process is represented. If your particular process step is not represented by the key below, complete the figure by writing in the na of the process step in your particular surface finishing line in the corresponding box(es). Finish by responding to the questions at the bottom of page.

Type of Process

Process Step Letter (see key below) → Ex. **A**

Chemical Supplier: ______________________

Process Line Installation Date:______________



Is the entire HASL process, as described in the chart above, co-located in the same room: Yes ________ No ___________

* If no (process steps performed in more than one room), please circle the steps above that are in a separate room.

Type of Process Automation for the HASL line: (circle one)

Conveyorized   Automated non-conveyorized   Manually-controlled hoist

Manual (no automation)   Other (specify):________________________

HASL Process Step Key

[A] - Cleaner
[B] - Microetch
[C] - Flux
[D] - Solder
[E] - Air Cool
[G] - Post-cleaner
[H] - Dryer
[I] - Water Rinse
[J] - Air Knife
[K] - Other (Specify in the appropriate box)

2.2 General Data--HASL

Number of days HASL line is in operation:	days/yr	Number of hours per day the HASL line is in operation:	hrs/day
Estimated scrap rate (% of defective product) for HASL process:	%	Total of PWB surface square feet processed by HASL line per year:	ssf/yr

2.3 Process Area Employees--HASL

Complete the following table by indicating the number of employees of each type that perform work duties in the same process room as the HASL line, and for what length of time. Consider only workers who have regularly scheduled responsibilities that require them to be physically within the process room. Specify "other" entry. Enter "N/A" in any category that is not applicable.

Type of HASL Area Worker	**Number of Employees in HASL Process Area**	**Average Hours per Week per Employee in HASL Process Area**
Line Operators		hrs
Lab Technicians		hrs
Maintenance Workers		hrs
Wastewater Treatment Operators		hrs
Supervisory Personnel		hrs
Other (specify):		hrs

2.4 Physical Settings--HASL

Size of the room containing the HASL process:	sq. ft.	Height of room:	ft.
Are the overall process areas/rooms ventilated (circle one)?	Yes No	Air flow rate:	cu. ft./min.
Do you have local vents (circle one)?	Yes No	Local vent air flow rate:	cu. ft./min.
Overall surface finishing process line dimensions Length (ft.): Width (ft.): Height (ft.):			

2.5 Rack Dimensions--HASL

Average number of panels per rack:		Average space between panels in rack:	in.
Average size of panel in rack:	Length (in.):	Width (in.):	
Do you purposely slow the withdraw rate of your panels from process baths to reduce drag-out? (Circle one)			Yes No

2.6 Rinse Bath Water Usage--HASL

Consult the process schematic in section 2.1 to obtain the process step numbers associated with each of the water rinse baths present in your HASL process. Enter, in the table below, the process step number along with the flow control method and flow rate data requested for each water rinse bath. **If the water rinse bath is part of a cascade, you need only report the daily water flow rate of one bath in the cascade.**

Total volume of water used by the HASL line when operating:	gal./day

Process Step Number [a]	**Flow Control** [b]	**Daily Water Flow Rate** [c]	**Cascade Water Process Steps** [d]
Example: 8	**R**	**2,400 gal./day**	**8→6**
		gal./day	
		gal./day	
		gal./day	
		gal./day	
		gal./day	
		gal./day	

[a] **Process step number** - Consult the process schematic in question 2.1 and enter the process step number of the specific water rinse tank.
[b] **Flow control** - Consult key at right and enter the letter for the flow control method used for that specific rinse bath.
[c] **Daily water flow rate** - Enter the average daily flow rate for the specific water rinse tank.
[d] **Cascade water process steps** - Use the step numbers for rinses that are cascaded together.

Flow Control Methods Key
[C] - Conductivity Meter
[P] - pH Meter
[V] - Operator Control Valve
[R] - Flow Restricter
[N] - None (continuous flow)
[O] - Other (explain)

2.7 Filter Replacement--HASL

Not Applicable ☐

Bath(s) filtered (enter process step # from flow diagram in 2.1)					
Frequency of replacement:					
Duration of replacement process:					
Personal protective equipment (see key):					

Personal Protective Equipment Key:
[E] - Eye Protection
[L] - Lab coat/Sleeved garment
[R] - Respiratory Protection
[A] - Apron
[B] - Boots
[G] - Gloves
[N] - None
[Z] - All except Respiratory Protection

2.8 Rack or Conveyor Cleaning--HASL

Not Applicable	☐
Rack Cleaning Method (see key): **OR**	
Conveyor Cleaning Method (see key):	
Frequency of rack or conveyor cleaning:	
Number of personnel involved:	
Personal protective equipment (see key):	
Average time required to clean:	min.

Rack Cleaning Method:
[C]-Chemical bath on SF process line
[D]-Chemical bath on another line
[T]-Temporary chemical bath
[S]-Manual scrubbing with chemical
[M]-Non-chemical cleaning
[N]-None
[O]-Continuous cleaning

Conveyor Cleaning Method:
[C]-Chemical rinsing or soaking
[S]-Manual scrubbing with chemical
[M]-Non-chemical cleaning
[N]-None
[O]-Continuous cleaning

Personal Protective Equipment:
[E]-Eye Protection [G]-Gloves
[L]-Lab coat/Sleeved garment [A]-Apron
[R]-Respiratory Protection [B]-Boots
[O]-Continuous Cleaning [N]-None
[Z]-All except Respiratory Protection

2.9 Solder Unit Maintenance and Waste disposal

Complete the following maintenance and waste disposal questions for only the unit of the process that performs the hot air solder leveling

Frequency of maintenance:		Method of dross removal:	
Duration of maintenance :	min.	Frequency of dross removal:	
Personal protective equipment (see key):		Quantity of solder waste disposed (per day):	
Number of personnel involved:		Method of solder waste disposal (see key):	

[d] **Personal Protective Equipment** - Enter the letters of **all** the protective equipment used by the workers who physically replace the spent bath.
[E] - Eye protection [B] - Boots
[A] - Apron [G] - Gloves
[L] - Lab coat/Sleeved garment
[R] - Respiratory protection
[Z] - All except Respiratory Protection
[N] - None

Method Of Solder Waste Disposal - Indicate method of solder waste disposal from key below:
[M] - Metals reclaimed off-site
[R] - Recycled on-site
[RO] - Recycled off-site
[D] - Drummed and treated as hazardous waste
[O] - Other (specify)

2.10 Physical Data and Operating Conditions--HASL

Complete the tables below by entering the data requested for each specific type of chemical bath listed. If two tanks of the same type are used within the process, list the data for each tank separately.

Average cycle time for a panel to complete entire HASL process (includes cleaning and post cleaning steps, if any):	**min.**

Bath	**Physical Data**			**Process Data**		**Operating Conditions**		
	Length (inches)	**Width (inches)**	**Nominal Volume (gal)**	**Immersion Time[a] (seconds)**	**Drip Time[b] (seconds)**	**Temp (ºF)**	**Agitation (see key)**	**Vapor Control (see key)**
Cleaner	**in.**	**in.**	**gal.**	**sec.**	**sec.**	**ºF**		
Microetch	**in.**	**in.**	**gal.**	**sec.**	**sec.**	**ºF**		
Flux	**in.**	**in.**	**gal.**	**sec.**	**sec.**	**ºF**		
Solder	**in.**	**in.**	**gal.**	**sec.**	**sec.**	**ºF**		
Post-Clean	**in.**	**in.**	**gal.**	**sec.**	**sec.**	**ºF**		
Other (specify)								

[a] **Immersion Time -** Enter the average elapsed time a rack of panels is immersed in the specific process bath.

[b] **Drip Time -** Enter the average elapsed time that a rack of panels is allowed to hang above the specific process bath to allow drainage from panels.

Agitation Methods Key:
[PA]- Panel agitation
[CP]- Circulation pump
[AS]- Air sparge
[O]- Other (explain)

Vapor Control Methods Key:
[BC]- Bath cover
[FE]- Fully enclosed
[VO]- Vent to outside
[VC]- Vent to control
[PP]- Push pull
[O]- Other (explain)

2.11 Initial Chemical Bath Make-Up Composition--HASL

Complete the chart below for each chemical component of the bath type listed. Provide the manufacturer name if the chemical used is known only by trade name. If more room is needed, please attach another sheet with the additional information. If two tanks of the same type are used within the process, list the data for a single tank only.

Bath		**Chemical Product Name**	**Manufacturer (if applicable)**	**Annual Quantity Used[a] (gallons)**
Cleaner	**1.**			
	2.			
	3.			
	4.			
Microetch	**1.**			
	2.			
	3.			
	4.			
Flux	**1.**			
	2.			
	3.			
	4.			
Solder	**1.**			
	2.			
	3.			
	4.			
Post-Clean	**1.**			
	2.			
	3.			
	4.			
Other (specify)	**1.**			
	2.			
	3.			
	4.			

[a] **Annual Quantity Used -** If the amount of a particular chemical used is measured by weight (i.e., crystalline chemicals) instead of volume, enter the weight in pounds and clearly specify the units (lbs).

2.12 Chemical Bath Bailout and Additions--HASL

Complete the following chart detailing the typical bath bailout and chemical additions that are made to maintain the chemical balance of each specific process bath. If more than three chemicals are added to a specific bath, attach another sheet with the additional information. If chemical additions to a bath are made automatically, do not complete the last three columns for that bath. If two tanks of the same type are used within the process, list the data for a single tank only.

Bath Type	Bailout Frequency	Bailout Duration [c] (minutes)	Bailout Quantity	Personal Protective Equipment [d]	Chemical Products Added		Criteria for Addition[a]	Method of Chemical Addition to Tank[b]	Duration of Addition[c] (minutes)
Cleaner		min.			1				min.
					2				
					3				
Microetch		min.			1				min.
					2				
					3				
Flux		min.			1				min.
					2				
					3				
Solder		min.			1				min.
					2				
					3				
Post-Clean		min.			1				min.
					2				
					3				
Other (specify)		min.			1				min.
					2				
					3				

[a] **Criteria for Additions** - Enter the letter for the criteria typically used to determine when bath additions are necessary.
[S] - Statistical process control
[P] - Panel square feet processed
[C] - Chemical testing
[T] - Time
[O] - Other

[b] **Method of Chemical Addition to Tank** - Enter the letter for the method typically used to add chemicals to the tanks.
[PR] - Poured
[P] - Pumped manually [O] - Other
[S] - Scooped

[c] **Duration of Bailout or Addition** - Enter the elapsed time from the retrieval of the chemical stock through the completion of the addition of all chemicals. For bailout, enter the time required to bailout the bath prior to making additions.

[d] **Personal Protective Equipment** - Enter the letters of all the protective equipment used by the workers who physically replace the spent bath.
[E] - Eye protection
[A] - Apron
[L] - Lab coat/Sleeved garment
[B] - Boots
[R] - Respiratory protection
[Z] - All except Respiratory Protection
[N] - None
[G] - Gloves

2.13 Chemical Bath Replacement -- HASL

Complete the chart below by providing information on the process of replacing, treating, and disposing of a spent chemical bath.

Bath Type	Criteria for Replacement[a]	Replacement Frequency[b]	Method of Spent Bath Removal [c]	Tank Cleaning Method[d]	Duration of Replacement Procedure[e]	Personal Protective Equipment[f]
Cleaner					**min.**	
Microetch					**min.**	
Flux					**min.**	
Solder					**min.**	
Post-Clean					**min.**	
Other (specify)					**min.**	

[a] **Criteria for Replacement -**
[S] - Statistical process control
[P] - Panel square feet processed
[C] - Chemical testing
[T] - Time
[O] - Other (specify)

[b] **Frequency -** Enter the average amount of time elapsed, or number of square feet processed, between bath replacements. Clearly specify units (e.g., hours, sq.ft.).

[c] **Methods of Spent Bath Removal-**
[P] - Pump spent bath from tank
[S] - Siphon spent bath from tank
[D] - Drain spent bath from tank
[O] - Other (specify)

[d] **Tank Cleaning Method -**
[C] - Chemical flush
[W] - Water rinse
[H] - Hand scrub
[O] - Other (specify)

[e] **Duration of Replacement -** Enter the elapsed time from the beginning of bath removal until the replacement bath is finished.

[F] **Personal Protective Equip. -** Enter the letters of all the protective equipment used by the workers who physically replace the spent bath.

[E] - Eye protection
[G] - Gloves
[L] - Lab coat/sleeved garment
[A] - Apron
[R] - Respiratory protection
[B] - Boots
[Z] - All except respiratory protection
[N] - None

2.14 Chemical Bath Sampling--HASL

Bath Type	Type of Sampling [a]	Frequency [b]	Duration of Sampling [c]	Protective Equipment [d]	Method of Sampling [e]
Example:	**A**	**3 per day**	**5 min**	**E, G, A**	**P**
Cleaner					
Microetch					
Other (specify):					

[a] **Type of Sampling**
[A] - Automated
[M] - Manual
[N] - None

[b] **Frequency:** Enter the average time elapsed or number of panel sq. ft. processed between samples. Clearly specify units (e.g., hours, sq.ft.)

[c] **Duration of Sampling**: Enter the average time required to manually take a sample from the tank.

[d] **Protective Equipment:** Consult the key for the above table and enter the letters for all protective equipment used by the person performing the chemical sampling.

[e] **Method of Sampling:**
[D] - Drain or spigot
[P] - Pipette
[L] - Ladle
[O] - Other (specify)

2.15 Process Waste Disposal -- HASL

Bath Type	Annual Volume Treated or Disposed [a]	Method of Treatment or Disposal [b]	RCRA Waste Code (if applicable)	Container Type
Cleaner				
Microetch				
Flux				
Solder				
Post-Clean				
Other (specify):				

[a] **Annual Volume Treated or Disposed -** Enter the yearly amount of the specific bath treated or disposed. ***Be sure to consider the volume treated from both bath change outs and bailout before entering the total.***

[B] **Methods of Treatment or Disposal -**
[P] - Precipitation pretreatment on-site
[N] - pH neutralization pretreatment on-site
[S] - Disposed directly to sewer with no treatment
[D] - Drummed for off-site treatment or disposal
[RN] - Recycled on-site
[RF] - Recycled off-site
[O] - Other (specify)

Container Type - Indicate the type of container used for disposal of bath wastes
[OH]- Open-head drum
[CH]- Closed-head drum
[T]- Chemical tote
[O]- Other (specify)

Section 3. Electroless Nickel/Immersion Gold Process

3.1 Process Schematic: Nickel/Gold

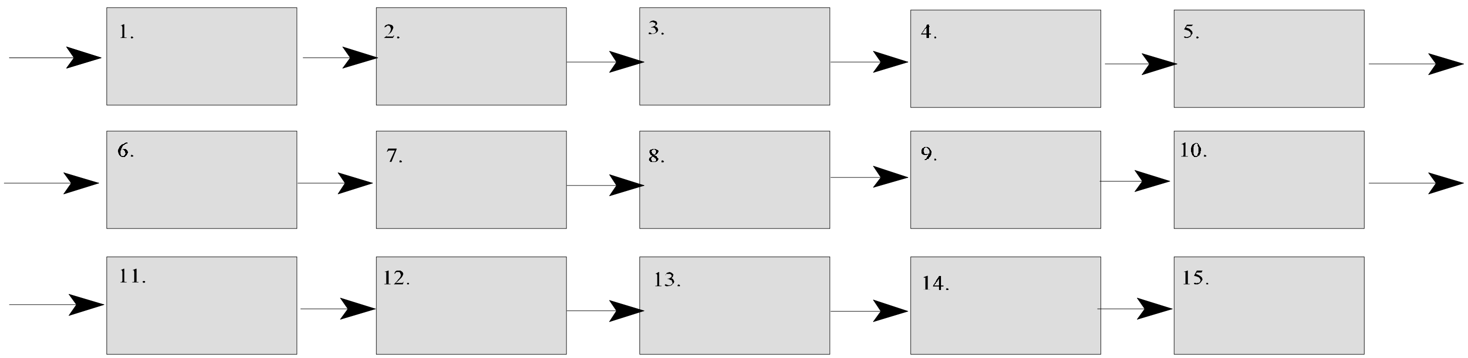
Fill in the figure below for your electroless nickel/immersion gold surface finishing processses. Using the key at the bottom of the page, iedntify which letter corresponds with the first step in your process and write that letter in the first box (see example). Continue using the key to fill in bo for each step until your entire electroless nickel/immersion gold process is represented. If a particular process step is not represented by the key below, complete the figure by writing in the name of the process step in your particular surface finishing line in the corresponding box(es). Finis by responding to the questions at the bottom of the page.

Type of Process

Process Step Letter (see key below) → Ex. **A**

Chemical Supplier: ______________________

Process Line Installation Date:______________



Is the entire electroless nickel/immersion gold, as described in the chart above, co-located in the same room:
Yes ________ No __________

* If no (process steps performed in more than one room), please circle the steps above that are in a separate room.

Type of Process Automation for the nickel/gold line: (circle one)

Conveyorized   Automated non-conveyorized   Manually-controlled hoist

Manual (no automation)   Other (specify):________________________

Electroless Nickel/Immersion Gold Process Step Key

[A] - Conditioner/Cleaner
[B] - Microetch
[C] - Catalyst
[D] - Acid Dip
[E] - Activator
[F] - Predip
[G] - Electroless Nickel
[H] - Immersion Gold
[I] - Water Rinse
[J] - Other (Specify in the appropriate box)

3.2 General Data--Nickel/Gold

Number of days the nickel/gold line is in operation:	days/yr	Number of hours per day the nickel/gold line is in operation:	hrs/day
Estimated scrap rate (% of defective product) for the nickel/gold process:	%	Total of PWB surface square feet processed by the nickel/gold line per year:	ssf/yr

3.3 Process Area Employees--Nickel/Gold

Complete the following table by indicating the number of employees of each type that perform work duties in the same process room as the nickel/gold line, and for what length of time. Consider only workers who have regularly scheduled responsibilities that require them to be physically within the process room. Specify "other" entry. Enter "N/A" in any category that is not applicable.

Type of Surface Finish Area Worker	**Number of Employees in Surface Finish Process Area**	**Average Hours per Week per Employee in Surface Finish Process Area**
Line Operators		hrs
Lab Technicians		hrs
Maintenance Workers		hrs
Wastewater Treatment Operators		hrs
Supervisory Personnel		hrs
Other (specify):		hrs

3.4 Physical Settings--Nickel/Gold

Size of the room containing the surface finish process:	sq. ft.	Height of room:	ft.
Are the overall process areas/rooms ventilated (circle one)?	Yes No	Air flow rate:	cu. ft./min.
Do you have local vents (circle one)?	Yes No	Local vent air flow rate:	cu. ft./min.

Overall surface finishing process line dimensions
Length (ft.): Width (ft.): Height (ft.):

3.5 Rack Dimensions--Nickel/Gold

Average number of panels per rack:		Average space between panels in rack:	in.
Average size of panel in rack:	Length (in.):	Width (in.):	
Do you purposely slow the withdraw rate of your panels from process baths to reduce drag-out? (Circle one)			Yes No

3.6 Rinse Bath Water Usage--Nickel/Gold

Consult the process schematic in section 2.1 to obtain the process step numbers associated with each of the water rinse baths present in your nickel/gold process. Enter, in the table below, the process step number along with the flow control method and flow rate data requested for each water rinse bath. **If the water rinse bath is part of a cascade, you need only report the daily water flow rate of one bath in the cascade.**

Total volume of water used by the surface finish line when operating: gal./day

Process Step Number [a]	Flow Control [b]	Daily Water Flow Rate [c]	Cascade Water Process Steps [d]
Example: 8	**R**	**2,400 gal./day**	**8 -> 6**
		gal./day	
		gal./day	
		gal./day	
		gal./day	
		gal./day	
		gal./day	

[a] **Process step number** - Consult the process schematic in question 2.1 and enter the process step number of the specific water rinse tank.
[b] **Flow control** - Consult key at right and enter the letter for the flow control method used for that specific rinse bath.
[c] **Daily water flow rate** - Enter the average daily flow rate for the specific water rinse tank.
[d] **Cascade water process steps** - Use the step numbers for rinses that are cascaded together.

Flow Control Methods Key
[C] - Conductivity Meter
[P] - pH Meter
[V] - Operator Control Valve
[R] - Flow Restricter
[N] - None (continuous flow)
[O] - Other (explain)

3.7 Filter Replacement--Nickel/Gold

Not Applicable ☐

Bath(s) filtered (enter process step # from flow diagram in 2.1)					
Frequency of replacement:					
Duration of replacement process:					
Personal protective equipment (see key):					

Personal Protective Equipment Key:
[E] - Eye Protection
[G] - Gloves
[Z] - All except Respiratory Protection
[L] - Lab coat/Sleeved garment
[A] - Apron
[N] - None
[R] - Respiratory Protection
[B] - Boots

3.8 Rack or Conveyor Cleaning--Nickel/Gold

Not Applicable	☐
Rack Cleaning Method (see key): **OR**	
Conveyor Cleaning Method (see key):	
Frequency of rack or conveyor cleaning:	
Number of personnel involved:	
Personal protective equipment (see key):	
Average time required to clean:	min.

Rack Cleaning Method:
[C]-Chemical bath on SF process line
[D]-Chemical bath on another line
[T]-Temporary chemical bath
[S]-Manual scrubbing with chemical
[M]-Non-chemical cleaning
[N]-None
[O]-Continuous cleaning

Conveyor Cleaning Method:
[C]-Chemical rinsing or soaking
[S]-Manual scrubbing with chemical
[M]-Non-chemical cleaning
[N]-None
[O]-Continuous cleaning

Personal Protective Equipment:
[E]-Eye Protection
[L]-Lab coat/Sleeved garment
[R]-Respiratory Protection
[O]-Continuous Cleaning
[Z]-All except Respiratory Protection
[G]-Gloves
[A]-Apron
[B]-Boots
[N]-None

3.9 Chemical Bath Sampling --Nickel/Gold

Bath Type	Type of Sampling [a]	Frequency [b]	Duration of Sampling [c]	Protective Equipment [d]	Method of Sampling [e]
Example:	**A**	**3 per day**	**5 min**	**E, G, A**	**P**
Cleaner/ Conditioner					
Microetch					
Catalyst					
Acid Dip					
Acivator					
Electroless Nickel					
Immersion Gold					
Other (specify):					

[a] **Type of Sampling**
[A] - Automated
[M] - Manual
[N] - None

[b] **Frequency:** Enter the average time elapsed or number of panel sq. ft. processed between samples. Clearly specify units (e.g., hours, sq. ft.).

[c] **Duration of Sampling:** Enter the a verage time required to manually take a sample from the tank.

[d] **Protective Equipment:** Consult the key for the above table and enter the letters for all protective equipment used by the person performing the chemical sampling.

[e] **Method of Sampling:**
[D] - Drain or spigot
[P] - Pipette
{L] - Ladle
[O] - Other (specify)

3.10 Physical Data and Operating Conditions--Nickel/Gold

Complete the tables below by entering the data requested for each specific type of chemical bath listed. If two tanks of the same type are used within the process, list the data for each tank separately.

Average cycle time for a panel to complete entire nickel/gold process (includes cleaning and post cleaning steps, if any):	**min.**

Bath	**Physical Data**			**Process Data**		**Operating Conditions**		
	Length (inches)	**Width (inches)**	**Nominal Volume (gal)**	**Immersion Time [a] (seconds)**	**Drip [b] Time (seconds)**	**Temp (ºF)**	**Agitation (see key)**	**Vapor Control (see key)**
Cleaner/ Conditioner	**in.**	**in.**	**gal.**	**sec.**	**sec.**	**ºF**		
Microetch	**in.**	**in.**	**gal.**	**sec.**	**sec.**	**ºF**		
Catalyst	**in.**	**in.**	**gal.**	**sec.**	**sec.**	**ºF**		
Acid Dip	**in.**	**in.**	**gal.**	**sec.**	**sec.**	**ºF**		
Activator	**in.**	**in.**	**gal.**	**sec.**	**sec.**	**ºF**		
Electroless Nickel	**in.**	**in.**	**gal.**	**sec.**	**sec.**	**ºF**		
Immersion Gold	**in.**	**in.**	**gal.**	**sec.**	**sec.**	**ºF**		
Other (specify);	**in.**	**in.**	**gal.**	**sec.**	**sec.**	**ºF**		

[a] **Immersion Time -** Enter the average elapsed time a rack of panels is immersed in the specific process bath.

[b] **Drip Time -** Enter the average elapsed time that a rack of panels is allowed to hang above the specific process bath to allow drainage from panels.

<u>Agitation Methods Key:</u>
[PA] - Panel agitation
[CP] - Circulation pump
[AS] - Air sparge
[O] - Other (explain)

<u>Vapor Control Methods Key:</u>
[BC] - Bath cover
[FE] - Fully enclosed
[VO] - Vent to outside
[VC] - Vent to control
[PP] - Push pull
[O] - Other (explain)

3.11 Initial Chemical Bath Make-Up Composition --Nickel/Gold

Complete the chart below for each chemical component of the bath type listed. Provide the manufacturer name if the chemical used is known only by trade name. If more room is needed, please attach another sheet with the additional information. If two tanks of the same type are used within the process, list the data for a single tank only.

Bath		**Chemical Product Name**	**Manufacturer (if applicable)**	**Annual Quantity Used [a] (gallons)**
Cleaner	**1.**			
	2.			
	3.			
	4.			
Microetch	**1.**			
	2.			
	3.			
	4.			
Catalyst	**1.**			
	2.			
	3.			
	4.			
Acid Dip	**1.**			
	2.			
	3.			
	4.			
Activator	**1.**			
	2.			
	3.			
	4.			
Electroless Nickel	**1.**			
	2.			
	3.			
	4.			
Immersion Gold	**1.**			
	2.			
	3.			
	4.			
Other (specify)	**1.**			
	2.			
	3.			
	4.			

[a] **Annual Quantity Used -** If the amount of a particular chemical used is measured by weight (i.e., crystalline chemicals) instead of volume, enter the weight in pounds and clearly specify the units (lbs).

3.12 Chemical Bath Bailout and Additions--Nickel/Gold

Complete the following chart detailing the typical bath bailout and chemical additions that are made to maintain the chemical balance of each specific process bath. If more than three chemicals are added to a specific bath, attach another sheet with the additional information. If chemical additions to a bath are made automatically, do not complete the last three columns for that bath. If two tanks of the same type are used within the process, list the data for a single tank only.

Bath Type	**Bailout Frequency**	**Bailout Duration [c] (minutes)**	**Bailout Quantity**	**Personal Protective Equipment [d]**		**Chemical Products Added**	**Criteria for Addition[a]**	**Method of Chemical Addition to Tank[b]**	**Duration of Addition[c] (minutes)**
Cleaner/ Conditioner		**min.**			**1**				**min.**
					2				
					3				
Microetch		**min.**			**1**				**min.**
					2				
					3				
Catalyst		**min.**			**1**				**min.**
					2				
					3				
Acid Dip		**min.**			**1**				**min.**
					2				
					3				
Activator		**min.**			**1**				**min.**
					2				
					3				
Electroless Nickel		**min.**			**1**				**min.**
					2				
					3				
Immersion Gold		**min.**			**1**				**min.**
					2				
					3				
Other (specify)		**min.**			**1**				**min.**
					2				
					3				

[a] **Criteria for Additions** - Enter the letter for the criteria typically used to determine when bath additions are necessary.
[S] - Statistical process control
[P] - Panel square feet processed
[C] - Chemical testing
[T] - Time
[O] - Other

[b] **Method of Chemical Addition to Tank** - Enter the letter for the method typically used to add chemicals to the tanks.
[PR] - Poured
[P] - Pumped manually [O] - Other
[S] - Scooped

[c] **Duration of Bailout or Addition - Enter the elapsed time from the retrieval of the chemical stock** through the completion of the addition of all chemicals. For bailout, enter the time required to bailout the bath prior to making additions.

[d] **Personal Protective Equipment** - Enter the letters of all the protective equipment used by the workers who physically replace the spent bath.
[E] - Eye protection
[A] - Apron
[L] - Lab coat/Sleeved garment
[B] - Boots
[R] - Respiratory protection
[Z] - All except Respiratory Protection
[N] - None
[G] - Gloves

3.13 Chemical Bath Replacement -- Nickel/Gold

Complete the chart below by providing information on the process of replacing, treating, and disposing of a spent chemical bath.

Bath Type	Criteria for Replacement [a]	Replacement Frequency [b]	Method of Spent Bath Removal [c]	Tank Cleaning Method [d]	Duration of Replacement Procedure [e]	Personal Protective Equipment [f]
Cleaner/Conditioner					**min.**	
Microetch					**min.**	
Catalyst					**min.**	
Acid Dip					**min.**	
Activator					**min.**	
Electroles Nickel					**min.**	
Immersion Gold					**min.**	
Other (specify)					**min.**	

[a] **Criteria for Replacement -**
[S] - Statistical process control
[P] - Panel square feet processed
[C] - Chemical testing
[T] - Time
[O] - Other (specify)

[b] **Frequency -** Enter the average amount of time elapsed, or number of square feet processed, between bath replacements. Clearly specify units (e.g., hours, sq.ft.).

[c] **Methods of Spent Bath Removal-**
[P] - Pump spent bath from tank
[S] - Siphon spent bath from tank
[D] - Drain spent bath from tank
[O] - Other (specify)

[d] **Tank Cleaning Method -**
[C] - Chemical flush
[W] - Water rinse
[H] - Hand scrub
[O] - Other (specify)

[e] **Duration of Replacement -** Enter the elapsed time from the beginning of bath removal until the replacement bath is finished.

[f] **Personal Protective Equip. -** Enter the letters of all the protective equipment used by the workers who physically replace the spent bath.

[E] - Eye protection
[G] - Gloves
[L] - Lab coat/sleeved garment
[A] - Apron
[R] - Respiratory protection
[B] - Boots
[Z] - All except respiratory protection
[N] - None

3.14 Process Waste Disposal -- Nickel/Gold

Bath Type	**Annual Volume Treated or Disposed** [a]	**Method of Treatment or Disposal** [b]	**RCRA Waste Code (if applicable)**	**Container Type**
Cleaner/Conditioner				
Microetch				
Catalyst				
Acid Dip				
Activator				
Electroless Nickel				
Immersion Gold				
Other (specify):				

[a] **Annual Volume Treated or Disposed** - Enter the yearly amount of the specific bath treated or disposed. ***Be sure to consider the volume treated from both bath change outs and bailout before entering the total.***	[b] **Methods of Treatment or Disposal -** [P] - Precipitation pretreatment on-site [N] - pH neutralization pretreatment on-site [S] - Disposed directly to sewer with no treatment [D] - Drummed for off-site treatment or disposal [RN] - Recycled on-site [RF] - Recycled off-site [O] - Other (specify)	**Container Type -** Indicate the type of container used for disposal of bath wastes [OH]- Open-head drum [CH]- Closed-head drum [T]- Chemical tote [O]- Other (specify)

Section 4. Electroless Nickel/Electroless Palladium/Immersion Gold Process

4.1 Process Schematic: Nickel/Palladium/Gold

Fill in the figure below for your electroless nickel/ electroless palladium/immersion gold surface finishing processses. Using the key at the botto of the page, identify which letter corresponds with the first step in your process and write that letter in the first box (see example). Continue usin the key to fill in boxes for each step until your entire nickel/palladium/gold process is represented. If a particular process step is not represente the key below, complete the figure by writing in the name of the process step in your particular surface finishing line in the corresponding boxe(Finish by responding to the questions at the bottom of the page.

Type of Process

Process Step Letter (see key below) → Ex. **A**

Chemical Supplier: ______________________

Process Line Installation Date:______________

1.	2.	3.	4.	5.
6.	7.	8.	9.	10.
11.	12.	13.	14.	15.

Is the entire nickel/palladium/gold, as described in the chart above, co-located in the same room:
Yes ________ **No** __________

*** If no (process steps performed in more than one room), please circle the steps above that are in a separate room.**

Type of Process Automation for the nickel/palladium/gold line: (circle one)

Conveyorized Automated non-conveyorized Manually-controlled hoist

Manual (no automation) Other (specify):_________________________

Nickel/Palladium/Gold Process Step Key

[A] - Conditioner/Cleaner
[B] - Microetch
[C] - Catalyst
[D] - Acid Dip
[E] - Activator
[F] - Electroless Nicke.
[G] - Electroless Palladium
[H] - Immersion Gold
[I] - Water Rinse
[J] - Other (Specify in the appropriate box)

4.2 General Data--Nickel/Palladium/Gold

Number of days the nickel/palladium/gold line is in operation:	days/yr	Number of hours per day the nickel/palladium/gold line is in operation:	hrs/day
Estimated scrap rate (% of defective product) for the nickel/palladium/gold process:	%	Total of PWB surface square feet processed by the nickel/palladium/gold line per year:	ssf/yr

4.3 Process Area Employees--Nickel/Palladium/Gold

Complete the following table by indicating the number of employees of each type that perform work duties in the same process room as the nickel/palladium/gold line, and for what length of time. Consider only workers who have regularly scheduled responsibilities that require them to be physically within the process room. Specify "other" entry. Enter "N/A" in any category that is not applicable.

Type of Surface Finish Area Worker	Number of Employees in Surface Finish Process Area	Average Hours per Week per Employee in Surface Finish Process Area
Line Operators		hrs
Lab Technicians		hrs
Maintenance Workers		hrs
Wastewater Treatment Operators		hrs
Supervisory Personnel		hrs
Other (specify):		hrs

4.4 Physical Settings--Nickel/Palladium/Gold

Size of the room containing the surface finish process:	sq. ft.	Height of room:	ft.
Are the overall process areas/rooms ventilated (circle one)?	Yes No	Air flow rate:	cu. ft./min.
Do you have local vents (circle one)?	Yes No	Local vent air flow rate:	cu. ft./min.

Overall surface finishing process line dimensions
Length (ft.): Width (ft.): Height (ft.):

4.5 Rack Dimensions--Nickel/Palladium/Gold

Average number of panels per rack:		Average space between panels in rack:	in.
Average size of panel in rack:	Length (in.):	Width (in.):	
Do you purposely slow the withdraw rate of your panels from process baths to reduce drag-out? (Circle one)			Yes No

4.6 Rinse Bath Water Usage--Nickel/Palladium/Gold

Consult the process schematic in section 2.1 to obtain the process step numbers associated with each of the water rinse baths present in your nickel/palladium/gold process. Enter, in the table below, the process step number along with the flow control method and flow rate data requested for each water rinse bath. **If the water rinse bath is part of a cascade, you need only report the daily water flow rate of one bath in the cascade.**

Total volume of water used by the surface finish line when operating:	gal./day

Process Step Number [a]	**Flow Control [b]**	**Daily Water Flow Rate [c]**	**Cascade Water Process Steps [d]**
Example: 8	**R**	**2,400 gal./day**	**8→6**
		gal./day	
		gal./day	
		gal./day	
		gal./day	
		gal./day	
		gal./day	
[a] **Process step number** - Consult the process schematic in question 2.1 and enter the process step number of the specific water rinse tank. [b] **Flow control** - Consult key at right and enter the letter for the flow control method used for that specific rinse bath. [c] **Daily water flow rate** - Enter the average daily flow rate for the specific water rinse tank. [d] **Cascade water process steps** - Use the step numbers for rinses that are cascaded together.			**Flow Control Methods Key** [C] - Conductivity Meter [P] - pH Meter [V] - Operator Control Valve [R] - Flow Restricter [N] - None (continuous flow) [O] - Other (explain)

4.7 Filter Replacement--Nickel/Palladium/Gold

Not Applicable ☐					
Bath(s) filtered (enter process step # from flow diagram in 2.1)					
Frequency of replacement:					
Duration of replacement process:					
Personal protective equipment (see key):					

Personal Protective Equipment Key:

[E] - Eye Protection	[G] - Gloves	[Z] - All except Respiratory Protection
[L] - Lab coat/Sleeved garment	[A] - Apron	[N] - None
[R] - Respiratory Protection	[B] - Boots	

4.8 Rack or Conveyor Cleaning--Nickel/Palladium/Gold

Not Applicable	☐
Rack Cleaning Method (see key): **OR**	
Conveyor Cleaning Method (see key):	
Frequency of rack or conveyor cleaning:	
Number of personnel involved:	
Personal protective equipment (see key):	
Average time required to clean:	min.

Rack Cleaning Method:
[C]-Chemical bath on SF process line
[D]-Chemical bath on another line
[T]-Temporary chemical bath
[S]-Manual scrubbing with chemical
[M]-Non-chemical cleaning
[N]-None
[O]-Continuous cleaning

Conveyor Cleaning Method:
[C]-Chemical rinsing or soaking
[S]-Manual scrubbing with chemical
[M]-Non-chemical cleaning
[N]-None
[O]-Continuous cleaning

Personal Protective Equipment:
[E]-Eye Protection
[L]-Lab coat/Sleeved garment
[R]-Respiratory Protection
[O]-Continuous Cleaning
[G]-Gloves
[A]-Apron
[B]-Boots
[N]-None
[Z]-All except Respiratory Protection

4.9 Chemical Bath Sampling --Nickel/Palladium/Gold

Bath Type	**Type of Sampling [a]**	**Frequency [b]**	**Duration of Sampling [c]**	**Protective Equipment [d]**	**Method of Sampling [e]**
Example:	**A**	**3 per day**	**5 min**	**E, G, A**	**P**
Cleaner/ Conditioner					
Microetch					
Catalyst					
Acid Dip					
Acivator					
Electroless Nickel					
Electroless Palladium					
Immersion Gold					
Other (specify):					

[a] **Type of Sampling**
[A] - Automated
[M] - Manual
[N] - None

[b] **Frequency:** Enter the average time elapsed or number of panel sq. ft. processed between samples. Clearly specify units (e.g., hours, sq. ft.).

[c] **Duration of Sampling:** Enter the average time required to manually take a sample from the tank.

[d] **Protective Equipment:** Consult the key for the above table and enter the letters for all protective equipment used by the person performing the chemical sampling.

[e] **Method of Sampling:**
[D] - Drain or spigot
[P] - Pipette
{L] - Ladle
[O] - Other (specify)

4.10 Physical Data and Operating Conditions--Nickel/Palladium/Gold

Complete the tables below by entering the data requested for each specific type of chemical bath listed. If two tanks of the same type are used within the process, list the data for each tank separately.

Average cycle time for a panel to complete entire surface finish process (includes cleaning and post cleaning steps, if any):	**min.**

Bath	**Physical Data**			**Process Data**		**Operating Conditions**		
	Length (inches)	**Width (inches)**	**Nominal Volume (gal)**	**Immersion Time [a] (seconds)**	**Drip [b] Time (seconds)**	**Temp (ºF)**	**Agitation (see key)**	**Vapor Control (see key)**
Cleaner/Conditioner	**in.**	**in.**	**gal.**	**sec.**	**sec.**	**ºF**		
Microetch	**in.**	**in.**	**gal.**	**sec.**	**sec.**	**ºF**		
Catalyst	**in.**	**in.**	**gal.**	**sec.**	**sec.**	**ºF**		
Acid Dip	**in.**	**in.**	**gal.**	**sec.**	**sec.**	**ºF**		
Activator	**in.**	**in.**	**gal.**	**sec.**	**sec.**	**ºF**		
Electroless Nickel	**in.**	**in.**	**gal.**	**sec.**	**sec.**	**ºF**		
Electroless Palladium	**in.**	**in.**	**gal.**	**sec.**	**sec.**	**ºF**		
Immersion Gold	**in.**	**in.**	**gal.**	**sec.**	**sec.**	**ºF**		
Other (specify);	**in.**	**in.**	**gal.**	**sec.**	**sec.**	**ºF**		

[a] **Immersion Time -** Enter the average elapsed time a rack of panels is immersed in the specific process bath.

[b] **Drip Time -** Enter the average elapsed time that a rack of panels is allowed to hang above the specific process bath to allow drainage from panels.

Agitation Methods Key:
[PA] - Panel agitation
[CP] - Circulation pump
[AS] - Air sparge
[O] - Other (explain)

Vapor Control Methods Key:
[BC] - Bath cover
[FE] - Fully enclosed
[VO] - Vent to outside
[VC] - Vent to control
[PP] - Push pull
[O] - Other (explain)

4.11 Initial Chemical Bath Make-Up Composition --Nickel/Palladium/Gold

Complete the chart below for each chemical component of the bath type listed. Provide the manufacturer name if the chemical used is known only by trade name. If more room is needed, please attach another sheet with the additional information. If two tanks of the same type are used within the process, list the data for a single tank only.

Bath		Chemical Product Name	Manufacturer (if applicable)	Annual Quantity Used [a] (gallons)
Cleaner	**1.**			
	2.			
	3.			
	4.			
Microetch	**1.**			
	2.			
	3.			
	4.			
Catalyst	**1.**			
	2.			
	3.			
	4.			
Acid Dip	**1.**			
	2.			
	3.			
	4.			
Activator	**1.**			
	2.			
	3.			
	4.			
Electroless Nickel	**1.**			
	2.			
	3.			
	4.			
Electroless Palladium	**1.**			
	2.			
	3.			
	4.			
Immersion Gold	**1.**			
	2.			
	3.			
	4.			
Other (specify)	**1.**			
	2.			
	3.			
	4.			

[a] **Annual Quantity Used -** If the amount of a particular chemical used is measured by weight (i.e., crystalline chemicals) instead of volume, enter the weight in pounds and clearly specify the units (lbs).

4.12 Chemical Bath Bailout and Additions--Nickel/Palladium/Gold

Complete the following chart detailing the typical bath bailout and chemical additions that are made to maintain the chemical balance of each specific process bath. If more than three chemicals are added to a specific bath, attach another sheet with the additional information. If chemical additions to a bath are made <u>automatically</u>, do not complete the last three columns for that bath. If two tanks of the same type are used within the process, list the data for a single tank only.

Bath Type	Bailout Frequency	Bailout Duration [c] (minutes)	Bailout Quantity	Personal Protective Equipment [d]	Chemical Products Added		Criteria for Addition[a]	Method of Chemical Addition to Tank[b]	Duration of Addition[c] (minutes)
Cleaner/ Conditioner		min.			1				min.
					2				
					3				
Microetch		min.			1				min.
					2				
					3				
Catalyst		min.			1				min.
					2				
					3				
Acid Dip		min.			1				min.
					2				
					3				
Activator		min.			1				min.
					2				
					3				
Electroless Nickel		min.			1				min.
					2				
					3				
Electroless Palladium		min.			1				
					2				
					3				
Immersion Gold		min.			1				min.
					2				
					3				
Other (specify)		min.			1				min.
					2				
					3				

[a] **Criteria for Additions** - Enter the letter for the criteria typically used to determine when bath additions are necessary.
[S] - Statistical process control
[P] - Panel square feet processed
[C] - Chemical testing
[T] - Time
[O] - Other

[b] **Method of Chemical Addition to Tank** - Enter the letter for the method typically used to add chemicals to the tanks.
[PR] - Poured
[P] - Pumped manually [O] - Other
[S] - Scooped

[c] **Duration of Bailout or Addition** - Enter the elapsed time from the retrieval of the chemical stock through the completion of the addition of all chemicals. For bailout, enter the time required to bailout the bath prior to making additions.

[d] **Personal Protective Equipment** - Enter the letters of <u>all</u> the protective equipment used by the workers who physically replace the spent bath.
[E] - Eye protection
[A] - Apron
[L] - Lab coat/Sleeved garment
[B] - Boots
[R] - Respiratory protection
[Z] - All except Respiratory Protection
[N] - None
[G] - Gloves

4.13 Chemical Bath Replacement -- Nickel/Palladium/Gold

Complete the chart below by providing information on the process of replacing, treating, and disposing of a spent chemical bath.

Bath Type	Criteria for Replacement [a]	Replacement Frequency [b]	Method of Spent Bath Removal [c]	Tank Cleaning Method [d]	Duration of Replacement Procedure [e]	Personal Protective Equipment [f]
Cleaner/Conditioner					**min.**	
Microetch					**min.**	
Catalyst					**min.**	
Acid Dip					**min.**	
Activator					**min.**	
Electroless Nickel					**min.**	
Electroless Palladium					**min.**	
Immersion Gold					**min.**	
Other (specify)					**min.**	

[a] **Criteria for Replacement -**
[S] - Statistical process control
[P] - Panel square feet processed
[C] - Chemical testing
[T] - Time
[O] - Other (specify)

[b] **Frequency -** Enter the average amount of time elapsed, or number of square feet processed, between bath replacements. Clearly specify units (e.g., hours, sq.ft.).

[c] **Methods of Spent Bath Removal-**
[P] - Pump spent bath from tank
[S] - Siphon spent bath from tank
[D] - Drain spent bath from tank
[O] - Other (specify)

[d] **Tank Cleaning Method -**
[C] - Chemical flush
[W] - Water rinse
[H] - Hand scrub
[O] - Other (specify)

[e] **Duration of Replacement -** Enter the elapsed time from the beginning of bath removal until the replacement bath is finished.

[f] **Personal Protective Equip. -** Enter the letters of all the protective equipment used by the workers who physically replace the spent bath.

[E] - Eye protection
[G] - Gloves
[L] - Lab coat/sleeved garment
[A] - Apron
[R] - Respiratory protection
[B] - Boots
[Z] - All except respiratory protection
[N] - None

4.14 Process Waste Disposal -- Nickel/Palladium/Gold

Bath Type	**Annual Volume Treated or Disposed [a]**	**Method of Treatment or Disposal [b]**	**RCRA Waste Code (if applicable)**	**Container Type**
Cleaner/ Conditioner				
Microetch				
Catalyst				
Acid Dip				
Activator				
Electroless Nickel				
Electroless Palladium				
Immersion Gold				
Other (specify):				

[a] **Annual Volume Treated or Disposed** - Enter the yearly amount of the specific bath treated or disposed. ***Be sure to consider the volume treated from both bath change outs and bailout before entering the total.***

[b] **Methods of Treatment or Disposal -**
[P] - Precipitation pretreatment on-site
[N] - pH neutralization pretreatment on-site
[S] - Disposed directly to sewer with no treatment
[D] - Drummed for off-site treatment or disposal
[RN] - Recycled on-site
[RF] - Recycled off-site
[O] - Other (specify)

Container Type - Indicate the type of container used for disposal of bath wastes
[OH]- Open-head drum
[CH]- Closed-head drum
[T]- Chemical tote
[O]- Other (specify)

Section 5. Organic Solder Preservative (OSP) Process

5.1 Process Schematic: OSP

Fill in the figure below for your OSP surface finishing process. Using the key at the bottom of the page, identify which letter corresponds with t first step in your process and write that letter in the first box (see example). Continue using the key to fill in boxes for each step until your entir process is represented. If a particular step is not represented by the key below, complete the figure by writing in the name of the process step in your particular surface finishing line in the corresponding box(es). Finish by responding to the questions at the bottom of the page.

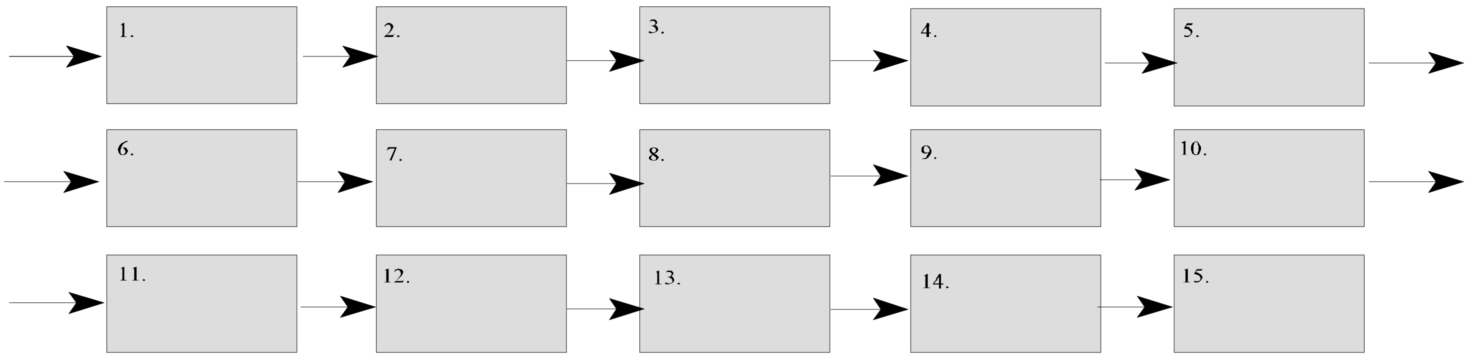
Type of Process

Process Step Letter
(see key below)

Ex.
A

Chemical Supplier: ________________________

Process Line Installation Date:________________



Is the entire OSP process, as described in the chart above, co-located in the same room:
Yes _________ **No** ___________

*** If no (process steps performed in more than one room), please circle the steps above that are in a separate room.**

Type of Process Automation for the OSP line: (circle one)

Conveyorized Automated non-conveyorized Manually-controlled hoist

Manual (no automation) Other (specify):_________________________

OSP Process Step Key

[A] - Cleaner
[B] - Microetch
[C] - Predip
[D] - OSP
[E] - Water Rinse
[F] - Air Knife
[G] - Other (Specify in the appropriate box)

5.2 General Data--OSP

Number of days the OSP line is in operation:	days/yr	Number of hours per day the OSP line is in operation:	hrs/day
Estimated scrap rate (% of defective product) for the OSP process:	%	Total of PWB surface square feet processed by the OSP line per year:	ssf/yr

5.3 Process Area Employees--OSP

Complete the following table by indicating the number of employees of each type that perform work duties in the same process room as the OSP line, and for what length of time. Consider only workers who have regularly scheduled responsibilities that require them to be physically within the process room. Specify "other" entry. Enter "N/A" in any category that is not applicable.

Type of Surface Finish Area Worker	**Number of Employees in Surface Finish Process Area**	**Average Hours per Week per Employee in Surface Finish Process Area**
Line Operators		hrs
Lab Technicians		hrs
Maintenance Workers		hrs
Wastewater Treatment Operators		hrs
Supervisory Personnel		hrs
Other (specify):		hrs

5.4 Physical Settings--OSP

Size of the room containing the surface finish process:	sq. ft.	Height of room:	ft.
Are the overall process areas/rooms ventilated (circle one)?	Yes No	Air flow rate:	cu. ft./min.
Do you have local vents (circle one)?	Yes No	Local vent air flow rate:	cu. ft./min.

Overall surface finishing process line dimensions
Length (ft.): Width (ft.): Height (ft.):

5.5 Rack Dimensions--OSP

Average number of panels per rack:		Average space between panels in rack:	in.
Average size of panel in rack:	Length (in.):	Width (in.):	
Do you purposely slow the withdraw rate of your panels from process baths to reduce drag-out? (Circle one)			Yes No

5.6 Rinse Bath Water Usage--OSP

Consult the process schematic in section 2.1 to obtain the process step numbers associated with each of the water rinse baths present in your OSP process. Enter, in the table below, the process step number along with the flow control method and flow rate data requested for each water rinse bath. **If the water rinse bath is part of a cascade, you need only report the daily water flow rate of one bath in the cascade.**

Total volume of water used by the surface finish line when operating:	gal./day

Process Step Number [a]	Flow Control [b]	Daily Water Flow Rate [c]	Cascade Water Process Steps [d]
Example: 8	**R**	**2,400 gal./day**	**8→6**
		gal./day	
		gal./day	
		gal./day	
		gal./day	
		gal./day	
		gal./day	

[a] **Process step number** - Consult the process schematic in question 2.1 and enter the process step number of the specific water rinse tank.
[b] **Flow control** - Consult key at right and enter the letter for the flow control method used for that specific rinse bath.
[c] **Daily water flow rate** - Enter the average daily flow rate for the specific water rinse tank.
[d] **Cascade water process steps** - Use the step numbers for rinses that are cascaded together.

Flow Control Methods Key
[C] - Conductivity Meter
[P] - pH Meter
[V] - Operator Control Valve
[R] - Flow Restricter
[N] - None (continuous flow)
[O] - Other (explain)

5.7 Filter Replacement--OSP

Not Applicable ☐

Bath(s) filtered (enter process step # from flow diagram in 2.1)					
Frequency of replacement:					
Duration of replacement process:					
Personal protective equipment (see key):					

Personal Protective Equipment Key:
[E] - Eye Protection
[L] - Lab coat/Sleeved garment
[R] - Respiratory Protection
[G] - Gloves
[A] - Apron
[B] - Boots
[Z] - All except Respiratory Protection
[N] - None

5.8 Rack or Conveyor Cleaning--OSP

Not Applicable	☐
Rack Cleaning Method (see key): **OR**	
Conveyor Cleaning Method (see key):	
Frequency of rack or conveyor cleaning:	
Number of personnel involved:	
Personal protective equipment (see key):	
Average time required to clean:	min.

Rack Cleaning Method:
[C]-Chemical bath on SF process line
[D]-Chemical bath on another line
[T]-Temporary chemical bath
[S]-Manual scrubbing with chemical
[M]-Non-chemical cleaning
[N]-None
[O]-Continuous cleaning

Conveyor Cleaning Method:
[C]-Chemical rinsing or soaking
[S]-Manual scrubbing with chemical
[M]-Non-chemical cleaning
[N]-None
[O]-Continuous cleaning

Personal Protective Equipment:

[E]-Eye Protection	[G]-Gloves
[L]-Lab coat/Sleeved garment	[A]-Apron
[R]-Respiratory Protection	[B]-Boots
[O]-Continuous Cleaning	[N]-None
[Z]-All except Respiratory Protection	

5.9 Chemical Bath Sampling --OSP

Bath Type	**Type of Sampling [a]**	**Frequency [b]**	**Duration of Sampling [c]**	**Protective Equipment [d]**	**Method of Sampling [e]**
Example:	**A**	**3 per day**	**5 min**	**E, G, A**	**P**
Cleaner					
Microetch					
Other (specify):					

[a] **Type of Sampling**
[A] - Automated
[M] - Manual
[N] - None

[b] **Frequency:** Enter the average time elapsed or number of panel sq. ft. processed between samples. Clearly specify units (e.g., hours, sq. ft.).

[c] **Duration of Sampling:** Enter the average time required to manually take a sample from the tank.

[d] **Protective Equipment:** Consult the key for the above table and enter the letters for all protective equipment used by the person performing the chemical sampling.

[e] **Method of Sampling:**
[D] - Drain or spigot
[P] - Pipette
{L] - Ladle
[O] - Other (specify)

5.10 Physical Data and Operating Conditions--OSP

Complete the tables below by entering the data requested for each specific type of chemical bath listed. If two tanks of the same type are used within the process, list the data for each tank separately.

Average cycle time for a panel to complete entire OSP process (includes cleaning and post cleaning steps, if any):	**min.**

Bath	**Physical Data**			**Process Data**		**Operating Conditions**		
	Length (inches)	**Width (inches)**	**Nominal Volume (gal)**	**Immersion Time [a] (seconds)**	**Drip [b] Time (seconds)**	**Temp (ºF)**	**Agitation (see key)**	**Vapor Control (see key)**
Cleaner	**in.**	**in.**	**gal.**	**sec.**	**sec.**	**ºF**		
Microetch	**in.**	**in.**	**gal.**	**sec.**	**sec.**	**ºF**		
Flux	**in.**	**in.**	**gal.**	**sec.**	**sec.**	**ºF**		
Solder	**in.**	**in.**	**gal.**	**sec.**	**sec.**	**ºF**		
Post-Clean	**in.**	**in.**	**gal.**	**sec.**	**sec.**	**ºF**		
Other (specify);	**in.**	**in.**	**gal.**	**sec.**	**sec.**	**ºF**		

[a] **Immersion Time -** Enter the average elapsed time a rack of panels is immersed in the specific process bath.

[b] **Drip Time -** Enter the average elapsed time that a rack of panels is allowed to hang above the specific process bath to allow drainage from panels.

Agitation Methods Key:
[PA] - Panel agitation
[CP] - Circulation pump
[AS] - Air sparge
[O] - Other (explain)

Vapor Control Methods Key:
[BC] - Bath cover
[FE] - Fully enclosed
[VO] - Vent to outside
[VC] - Vent to control
[PP] - Push pull
[O] - Other (explain)

5.11 Initial Chemical Bath Make-Up Composition -OSP

Complete the chart below for each chemical component of the bath type listed. Provide the manufacturer name if the chemical used is known only by trade name. If more room is needed, please attach another sheet with the additional information. If two tanks of the same type are used within the process, list the data for a single tank only.

Bath		Chemical Product Name	Manufacturer (if applicable)	Annual Quantity Used [a] (gallons)
Cleaner	**1.**			
	2.			
	3.			
	4.			
Microetch	**1.**			
	2.			
	3.			
	4.			
Flux	**1.**			
	2.			
	3.			
	4.			
Solder	**1.**			
	2.			
	3.			
	4.			
Post-Clean	**1.**			
	2.			
	3.			
	4.			
Other (specify)	**1.**			
	2.			
	3.			
	4.			

[a] **Annual Quantity Used -** If the amount of a particular chemical used is measured by weight (i.e., crystalline chemicals) instead of volume, enter the weight in pounds and clearly specify the units (lbs).

5.12 Chemical Bath Bailout and Additions--OSP

Complete the following chart detailing the typical bath bailout and chemical additions that are made to maintain the chemical balance of each specific process bath. If more than three chemicals are added to a specific bath, attach another sheet with the additional information. If chemical additions to a bath are made automatically, do not complete the last three columns for that bath. If two tanks of the same type are used within the process, list the data for a single tank only.

Bath Type	Bailout Frequency	Bailout Duration [c] (minutes)	Bailout Quantity	Personal Protective Equipment [d]	Chemical Products Added		Criteria for Addition[a]	Method of Chemical Addition to Tank[b]	Duration of Addition[c] (minutes)
Cleaner		**min.**			**1**				**min.**
					2				
					3				
Microetch		**min.**			**1**				**min.**
					2				
					3				
Flux		**min.**			**1**				**min.**
					2				
					3				
Solder		**min.**			**1**				**min.**
					2				
					3				
Post-Clean		**min.**			**1**				**min.**
					2				
					3				
Other (specify)		**min.**			**1**				**min.**
					2				
					3				

[a] **Criteria for Additions** - Enter the letter for the criteria typically used to determine when bath additions are necessary.
[S] - Statistical process control
[P] - Panel square feet processed
[C] - Chemical testing
[T] - Time
[O] - Other

[b] **Method of Chemical Addition to Tank -** Enter the letter for the method typically used to add chemicals to the tanks.
[PR] - Poured
[P] - Pumped manually [O] - Other
[S] - Scooped

[c] **Duration of Bailout or Addition -** Enter the elapsed time from the retrieval of the chemical stock through the completion of the addition of all chemicals. For bailout, enter the time required to bailout the bath prior to making additions.

[d] **Personal Protective Equipment -** Enter the letters of all the protective equipment used by the workers who physically replace the spent bath.
[E] - Eye protection
[A] - Apron
[L] - Lab coat/Sleeved garment
$[B] - Boots
[R] - Respiratory protection
[Z] - All except Respiratory Protection
[N] - None
[G] - Gloves

5.13 Chemical Bath Replacement -- OSP

Complete the chart below by providing information on the process of replacing, treating, and disposing of a spent chemical bath.

Bath Type	Criteria for Replacement [a]	Replacement Frequency [b]	Method of Spent Bath Removal [c]	Tank Cleaning Method [d]	Duration of Replacement Procedure [e]	Personal Protective Equipment [f]
Cleaner					**min.**	
Microetch					**min.**	
Flux					**min.**	
Solder					**min.**	
Post-Clean					**min.**	
Other (specify)					**min.**	

[a] **Criteria for Replacement -**
[S] - Statistical process control
[P] - Panel square feet processed
[C] - Chemical testing
[T] - Time
[O] - Other (specify)

[b] **Frequency -** Enter the average amount of time elapsed, or number of square feet processed, between bath replacements. Clearly specify units (e.g., hours, sq.ft.).

[c] **Methods of Spent Bath Removal-**
[P] - Pump spent bath from tank
[S] - Siphon spent bath from tank
[D] - Drain spent bath from tank
[O] - Other (specify)

[d] **Tank Cleaning Method -**
[C] - Chemical flush
[W] - Water rinse
[H] - Hand scrub
[O] - Other (specify)

[e] **Duration of Replacement -** Enter the elapsed time from the beginning of bath removal until the replacement bath is finished.

[f] **Personal Protective Equip. -** Enter the letters of all the protective equipment used by the workers who physically replace the spent bath.

[E] - Eye protection
[G] - Gloves
[L] - Lab coat/sleeved garment
[A] - Apron
[R] - Respiratory protection
[B] - Boots
[Z] - All except respiratory protection
[N] - None

5.14 Process Waste Disposal -- OSP

Bath Type	Annual Volume Treated or Disposed [a]	Method of Treatment or Disposal [b]	RCRA Waste Code (if applicable)	Container Type
Cleaner				
Microetch				
Flux				
Solder				
Post-Clean				
Other (specify):				

[a] **Annual Volume Treated or Disposed** - Enter the yearly amount of the specific bath treated or disposed. ***Be sure to consider the volume treated from both bath change outs and bailout before entering the total.***	[b] **Methods of Treatment or Disposal -** [P] - Precipitation pretreatment on-site [N] - pH neutralization pretreatment on-site [S] - Disposed directly to sewer with no treatment [D] - Drummed for off-site treatment or disposal [RN] - Recycled on-site [RF] - Recycled off-site [O] - Other (specify)	**Container Type -** Indicate the type of container used for disposal of bath wastes [OH]- Open-head drum [CH]- Closed-head drum [T]- Chemical tote [O]- Other (specify)

Section 6. Immersion Silver Process

6.1 Process Schematic: Immersion Silver

Fill in the figure below for your immersion silver surface finishing process. Using the key at the bottom of the page, dentify which letter corresponds with the first step in your process and write that letter in the first box (see example). Continue using the key to fill in boxes for each step until your entire immersion silver process is represented. If a particular process step is not represented by the key below, complete the figu by writing in the name of the process step in your particular surface finishing line in the corresponding bbox(es) . Finish by responding to the questions at the bottom of the page.

Type of Process

Process Step Letter (see key below) → Ex. **A**

Chemical Supplier: ________________________

Process Line Installation Date:________________

1.	2.	3.	4.	5.
6.	7.	8.	9.	10.
11.	12.	13.	14.	15.

Is the entire immersion silver process, as described in the chart above, co-located in the same room:
Yes _________ No ___________

*** If no (process steps performed in more than one room), please circle the steps above that are in a separate room.**

Type of Process Automation for the immersion silver line: (circle one)

Conveyorized Automated non-conveyorized Manually-controlled hoist

Manual (no automation) Other (specify):__________________________

Immersion Silver Process Step Key

[A] - Pre-Cleaner
[B] - Microetch
[C] - Pre-Conditioner
[D] - Immersion Silver
[E] - Water Rinse
[F] - Other (Specify in the appropriate box)

6.2 General Data--Immersion Silver

Number of days the immersion silver line is in operation:	days/yr	Number of hours per day the immersion silver line is in operation:	hrs/day
Estimated scrap rate (% of defective product) for the immersion silver process:	%	Total of PWB surface square feet processed by the immersion silver line per year:	ssf/yr

6.3 Process Area Employees--Immersion Silver

Complete the following table by indicating the number of employees of each type that perform work duties in the same process room as the immersion silver line, and for what length of time. Consider only workers who have regularly scheduled responsibilities that require them to be physically within the process room. Specify "other" entry. Enter "N/A" in any category that is not applicable.

Type of Surface Finish Area Worker	**Number of Employees in Surface Finish Process Area**	**Average Hours per Week per Employee in Surface Finish Process Area**
Line Operators		hrs
Lab Technicians		hrs
Maintenance Workers		hrs
Wastewater Treatment Operators		hrs
Supervisory Personnel		hrs
Other (specify):		hrs

6.4 Physical Settings--Immersion Silver

Size of the room containing the surface finish process:	sq. ft.	Height of room:	ft.
Are the overall process areas/rooms ventilated (circle one)?	Yes No	Air flow rate:	cu. ft./min.
Do you have local vents (circle one)?	Yes No	Local vent air flow rate:	cu. ft./min.
Overall surface finishing process line dimensions Length (ft.): Width (ft.): Height (ft.):			

6.5 Rack Dimensions--Immersion Silver

Average number of panels per rack:		Average space between panels in rack:	in.
Average size of panel in rack:	Length (in.):	Width (in.):	
Do you purposely slow the withdraw rate of your panels from process baths to reduce drag-out? (Circle one)			Yes No

6.6 Rinse Bath Water Usage--Immersion Silver

Consult the process schematic in section 2.1 to obtain the process step numbers associated with each of the water rinse baths present in your nickel/gold process. Enter, in the table below, the process step number along with the flow control method and flow rate data requested for each water rinse bath. **If the water rinse bath is part of a cascade, you need only report the daily water flow rate of one bath in the cascade.**

Total volume of water used by the surface finish line when operating:	gal./day

Process Step Number [a]	**Flow Control [b]**	**Daily Water Flow Rate [c]**	**Cascade Water Process Steps [d]**
Example: 8	**R**	**2,400 gal./day**	**8→6**
		gal./day	
		gal./day	
		gal./day	
		gal./day	
		gal./day	
		gal./day	

[a] **Process step number** - Consult the process schematic in question 2.1 and enter the process step number of the specific water rinse tank.
[b] **Flow control** - Consult key at right and enter the letter for the flow control method used for that specific rinse bath.
[c] **Daily water flow rate** - Enter the average daily flow rate for the specific water rinse tank.
[d] **Cascade water process steps** - Use the step numbers for rinses that are cascaded together.

Flow Control Methods Key
[C] - Conductivity Meter
[P] - pH Meter
[V] - Operator Control Valve
[R] - Flow Restricter
[N] - None (continuous flow)
[O] - Other (explain)

6.7 Filter Replacement--Immersion Silver

Not Applicable ☐

Bath(s) filtered (enter process step # from flow diagram in 2.1)					
Frequency of replacement:					
Duration of replacement process:					
Personal protective equipment (see key):					

Personal Protective Equipment Key:

[E] - Eye Protection	[G] - Gloves	[Z] - All except Respiratory Protection
[L] - Lab coat/Sleeved garment	[A] - Apron	[N] - None
[R] - Respiratory Protection	[B] - Boots	

6.8 Rack or Conveyor Cleaning--Immersion Silver

Not Applicable ☐	
Rack Cleaning Method (see key): **OR**	
Conveyor Cleaning Method (see key):	
Frequency of rack or conveyor cleaning:	
Number of personnel involved:	
Personal protective equipment (see key):	
Average time required to clean:	min.

Rack Cleaning Method:
[C]-Chemical bath on SF process line
[D]-Chemical bath on another line
[T]-Temporary chemical bath
[S]-Manual scrubbing with chemical
[M]-Non-chemical cleaning
[N]-None
[O]-Continuous cleaning

Conveyor Cleaning Method:
[C]-Chemical rinsing or soaking
[S]-Manual scrubbing with chemical
[M]-Non-chemical cleaning
[N]-None
[O]-Continuous cleaning

Personal Protective Equipment:

[E]-Eye Protection	[G]-Gloves
[L]-Lab coat/Sleeved garment	[A]-Apron
[R]-Respiratory Protection	[B]-Boots
[O]-Continuous Cleaning	[N]-None

[Z]-All except Respiratory Protection

6.9 Chemical Bath Sampling --Immersion Silver

Bath Type	**Type of Sampling [a]**	**Frequency [b]**	**Duration of Sampling [c]**	**Protective Equipment [d]**	**Method of Sampling [e]**
Example:	**A**	**3 per day**	**5 min**	**E, G, A**	**P**
Pre-Cleaner					
Microetch					
Pre-Conditioner					
Immersion Silver					
Other (specify):					

[a] **Type of Sampling**
[A] - Automated
[M] - Manual
[N] - None

[b] **Frequency:** Enter the average time elapsed or number of panel sq. ft. processed between samples. Clearly specify units (e.g., hours, sq. ft.).

[c] **Duration of Sampling:** Enter the a verage time required to manually take a sample from the tank.

[d] **Protective Equipment:** Consult the key for the above table and enter the letters for all protective equipment used by the person performing the chemical sampling.

[e] **Method of Sampling:**
[D] - Drain or spigot
[P] - Pipette
{L] - Ladle
[O] - Other (specify)

6.10 Physical Data and Operating Conditions--Immersion Silver

Complete the tables below by entering the data requested for each specific type of chemical bath listed. If two tanks of the same type are used within the process, list the data for each tank separately.

Average cycle time for a panel to complete entire immersion silver process (includes cleaning and post cleaning steps, if any):	**min.**

Bath	**Physical Data**			**Process Data**		**Operating Conditions**		
	Length (inches)	**Width (inches)**	**Nominal Volume (gal)**	**Immersion Time [a] (seconds)**	**Drip [b] Time (seconds)**	**Temp (ºF)**	**Agitation (see key)**	**Vapor Control (see key)**
Pre-Cleaner	**in.**	**in.**	**gal.**	**sec.**	**sec.**	**ºF**		
Microetch	**in.**	**in.**	**gal.**	**sec.**	**sec.**	**ºF**		
Pre-Conditioner	**in.**	**in.**	**gal.**	**sec.**	**sec.**	**ºF**		
Immersion Silver	**in.**	**in.**	**gal.**	**sec.**	**sec.**	**ºF**		
Other (specify):	**in.**	**in.**	**gal.**	**sec.**	**sec.**	**ºF**		

[a] **Immersion Time -** Enter the average elapsed time a rack of panels is immersed in the specific process bath.

[b] **Drip Time -** Enter the average elapsed time that a rack of panels is allowed to hang above the specific process bath to allow drainage from panels.

Agitation Methods Key:
[PA] - Panel agitation
[CP] - Circulation pump
[AS] - Air sparge
[O] - Other (explain)

Vapor Control Methods Key:
[BC] - Bath cover
[FE] - Fully enclosed
[VO] - Vent to outside
[VC] - Vent to control
[PP] - Push pull
[O] - Other (explain)

6.11 Initial Chemical Bath Make-Up Composition --Immersion Silver

Complete the chart below for each chemical component of the bath type listed. Provide the manufacturer name if the chemical used is known only by trade name. If more room is needed, please attach another sheet with the additional information. If two tanks of the same type are used within the process, list the data for a single tank only.

Bath		Chemical Product Name	Manufacturer (if applicable)	Annual Quantity Used [a] (gallons)
Pre-Cleaner	**1.**			
	2.			
	3.			
	4.			
Microetch	**1.**			
	2.			
	3.			
	4.			
Pre-Conditioner	**1.**			
	2.			
	3.			
	4.			
Immersion Silver	**1.**			
	2.			
	3.			
	4.			
Other (specify)	**1.**			
	2.			
	3.			
	4.			

[a] **Annual Quantity Used -** If the amount of a particular chemical used is measured by weight (i.e., crystalline chemicals) instead of volume, enter the weight in pounds and clearly specify the units (lbs).

6.12 Chemical Bath Bailout and Additions--Immersion Silver

Complete the following chart detailing the typical bath bailout and chemical additions that are made to maintain the chemical balance of each specific process bath. If more than three chemicals are added to a specific bath, attach another sheet with the additional information. If chemical additions to a bath are made automatically, do not complete the last three columns for that bath. If two tanks of the same type are used within the process, list the data for a single tank only.

Bath Type	Bailout Frequency	Bailout Duration [c] (minutes)	Bailout Quantity	Personal Protective Equipment [d]	Chemical Products Added		Criteria for Addition[a]	Method of Chemical Addition to Tank[b]	Duration of Addition[c] (minutes)
Pre-Cleaner		**min.**			**1**				**min.**
					2				
					3				
Microetch		**min.**			**1**				**min.**
					2				
					3				
Pre-Conditioner		**min.**			**1**				**min.**
					2				
					3				
Immersion Silver		**min.**			**1**				**min.**
					2				
					3				
Other (specify)		**min.**			**1**				**min.**
					2				
					3				
		min.			**1**				**min.**
					2				
					3				

[a] **Criteria for Additions** - Enter the letter for the criteria typically used to determine when bath additions are necessary.
[S] - Statistical process control
[P] - Panel square feet processed
[C] - Chemical testing
[T] - Time
[O] - Other

[b] **Method of Chemical Addition to Tank -** Enter the letter for the method typically used to add chemicals to the tanks.
[PR] - Poured
[P] - Pumped manually [O] - Other
[S] - Scooped

[c] **Duration of Bailout or Addition -** Enter the elapsed time from the retrieval of the chemical stock through the completion of the addition of all chemicals. For bailout, enter the time required to bailout the bath prior to making additions.

[d] **Personal Protective Equipment -** Enter the letters of all the protective equipment used by the workers who physically replace the spent bath.
[E] - Eye protection
[A] - Apron
[L] - Lab coat/Sleeved garment
[B] - Boots
[R] - Respiratory protection
[Z] - All except Respiratory Protection
[N] - None
[G] - Gloves

6.13 Chemical Bath Replacement --Immersion Silver

Complete the chart below by providing information on the process of replacing, treating, and disposing of a spent chemical bath.

Bath Type	Criteria for Replacement [a]	Replacement Frequency [b]	Method of Spent Bath Removal [c]	Tank Cleaning Method [d]	Duration of Replacement Procedure [e]	Personal Protective Equipment [f]
Pre-Cleaner					**min.**	
Microetch					**min.**	
Pre-Conditioner					**min.**	
Immersion Silver					**min.**	
Other (specify)					**min.**	

[a] **Criteria for Replacement -**
[S] - Statistical process control
[P] - Panel square feet processed
[C] - Chemical testing
[T] - Time
[O] - Other (specify)

[b] **Frequency -** Enter the average amount of time elapsed, or number of square feet processed, between bath replacements. Clearly specify units (e.g., hours, sq.ft.).

[c] **Methods of Spent Bath Removal-**
[P] - Pump spent bath from tank
[S] - Siphon spent bath from tank
[D] - Drain spent bath from tank
[O] - Other (specify)

[d] **Tank Cleaning Method -**
[C] - Chemical flush
[W] - Water rinse
[H] - Hand scrub
[O] - Other (specify)

[e] **Duration of Replacement -** Enter the elapsed time from the beginning of bath removal until the replacement bath is finished.

[f] **Personal Protective Equip. -** Enter the letters of all the protective equipment used by the workers who physically replace the spent bath.

[E] - Eye protection
[G] - Gloves
[L] - Lab coat/sleeved garment
[A] - Apron
[R] - Respiratory protection
[B] - Boots
[Z] - All except respiratory protection
[N] - None

6.14 Process Waste Disposal -- Immersion Silver

Bath Type	Annual Volume Treated or Disposed [a]	Method of Treatment or Disposal [b]	RCRA Waste Code (if applicable)	Container Type
Pre-Cleaner				
Microetch				
Pre-Conditioner				
Immersion Silver				
Other (specify):				

[a] **Annual Volume Treated or Disposed** - Enter the yearly amount of the specific bath treated or disposed. ***Be sure to consider the volume treated from both bath change outs and bailout before entering the total.***	[b] **Methods of Treatment or Disposal -** [P] - Precipitation pretreatment on-site [N] - pH neutralization pretreatment on-site [S] - Disposed directly to sewer with no treatment [D] - Drummed for off-site treatment or disposal [RN] - Recycled on-site [RF] - Recycled off-site [O] - Other (specify)	**Container Type -** Indicate the type of container used for disposal of bath wastes [OH]- Open-head drum [CH]- Closed-head drum [T]- Chemical tote [O]- Other (specify)

Section 7. Immersion Tin Process

7.1   Process Schematic: Immersion Tin

Fill in the figure below for your immersion tin surface finishing processses. Using the key at the bottom of the page, dentify which letter corresponds with the first step in your process and write that letter in the first box (see example). Continue using the key to fill in boxes for each step intil your entire immersion tin process is represented. If a particular process step is not represented by the key below, complete the figure b writing in the name of the process step in your particular surface finishing line in the corresponding boxe(s). Finish by responding to the questions at the bottom of the page.

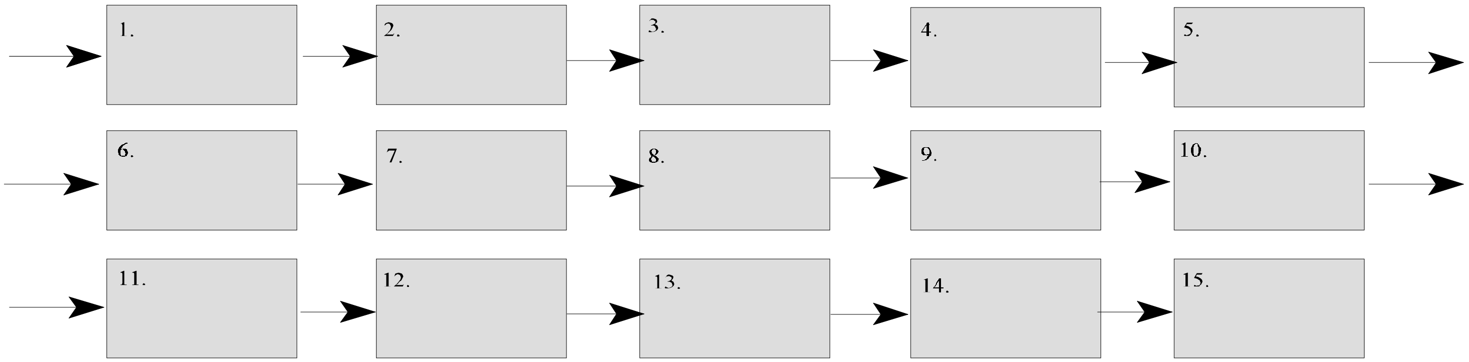
Type of Process

Process Step Letter
(see key below)

Ex.
A

Chemical Supplier: ________________________

Process Line Installation Date:________________



Is the entire immersion tin process, as described in the chart above, co-located in the same room:
Yes _________   **No** ___________

*** If no (process steps performed in more than one room), please circle the steps above that are in a separate room.**

Type of Process Automation for the immersion tin line: (circle one)

Conveyorized   Automated non-conveyorized   Manually-controlled hoist

Manual (no automation)   Other (specify):__________________________

Immersion Tin Process Step Key

[A] - Cleaner
[B] - Microetch
[C] - Predip
[D] - Immersion Tin
[E] - Water Rinse
[F] - Dry
[G] - Other (Specify in the appropriate box)

7.2 General Data--Immersion Tin

Number of days the immersion tin line is in operation:	days/yr	Number of hours per day the immersion tin line is in operation:	hrs/day
Estimated scrap rate (% of defective product) for the immersion tin process:	%	Total of PWB surface square feet processed by the immersion tin line per year:	ssf/yr

7.3 Process Area Employees--Immersion Tin

Complete the following table by indicating the number of employees of each type that perform work duties in the same process room as the immersion tin line, and for what length of time. Consider only workers who have regularly scheduled responsibilities that require them to be physically within the process room. Specify "other" entry. Enter "N/A" in any category that is not applicable.

Type of Surface Finish Area Worker	Number of Employees in Surface Finish Process Area	Average Hours per Week per Employee in Surface Finish Process Area
Line Operators		hrs
Lab Technicians		hrs
Maintenance Workers		hrs
Wastewater Treatment Operators		hrs
Supervisory Personnel		hrs
Other (specify):		hrs

7.4 Physical Settings--Immersion Tin

Size of the room containing the surface finish process:	sq. ft.	Height of room:	ft.
Are the overall process areas/rooms ventilated (circle one)?	Yes No	Air flow rate:	cu. ft./min.
Do you have local vents (circle one)?	Yes No	Local vent air flow rate:	cu. ft./min.
Overall surface finishing process line dimensions Length (ft.):	Width (ft.):	Height (ft.):	

7.5 Rack Dimensions--Immersion Tin

Average number of panels per rack:		Average space between panels in rack:	in.
Average size of panel in rack:	Length (in.):	Width (in.):	
Do you purposely slow the withdraw rate of your panels from process baths to reduce drag-out? (Circle one)			Yes No

7.6 Rinse Bath Water Usage--Immersion Tin

Consult the process schematic in section 2.1 to obtain the process step numbers associated with each of the water rinse baths present in your immersion tin process. Enter, in the table below, the process step number along with the flow control method and flow rate data requested for each water rinse bath. **If the water rinse bath is part of a cascade, you need only report the daily water flow rate of one bath in the cascade.**

Total volume of water used by the surface finish line when operating:	gal./day

Process Step Number [a]	**Flow Control [b]**	**Daily Water Flow Rate [c]**	**Cascade Water Process Steps [d]**
Example: 8	**R**	**2,400 gal./day**	**8→6**
		gal./day	
		gal./day	
		gal./day	
		gal./day	
		gal./day	
		gal./day	

[a] **Process step number** - Consult the process schematic in question 2.1 and enter the process step number of the specific water rinse tank.
[b] **Flow control** - Consult key at right and enter the letter for the flow control method used for that specific rinse bath.
[c] **Daily water flow rate** - Enter the average daily flow rate for the specific water rinse tank.
[d] **Cascade water process steps** - Use the step numbers for rinses that are cascaded together.

Flow Control Methods Key
[C] - Conductivity Meter
[P] - pH Meter
[V] - Operator Control Valve
[R] - Flow Restricter
[N] - None (continuous flow)
[O] - Other (explain)

7.7 Filter Replacement--Immersion Tin

Not Applicable ☐

Bath(s) filtered (enter process step # from flow diagram in 2.1)					
Frequency of replacement:					
Duration of replacement process:					
Personal protective equipment (see key):					

Personal Protective Equipment Key:

[E] - Eye Protection	[G] - Gloves	[Z] - All except Respiratory Protection
[L] - Lab coat/Sleeved garment	[A] - Apron	[N] - None
[R] - Respiratory Protection	[B] - Boots	

7.8 Rack or Conveyor Cleaning--Immersion Tin

Not Applicable	☐
Rack Cleaning Method (see key): **OR**	
Conveyor Cleaning Method (see key):	
Frequency of rack or conveyor cleaning:	
Number of personnel involved:	
Personal protective equipment (see key):	
Average time required to clean:	min.

Rack Cleaning Method:
[C]-Chemical bath on SF process line
[D]-Chemical bath on another line
[T]-Temporary chemical bath
[S]-Manual scrubbing with chemical
[M]-Non-chemical cleaning
[N]-None
[O]-Continuous cleaning

Conveyor Cleaning Method:
[C]-Chemical rinsing or soaking
[S]-Manual scrubbing with chemical
[M]-Non-chemical cleaning
[N]-None
[O]-Continuous cleaning

Personal Protective Equipment:
[E]-Eye Protection [G]-Gloves
[L]-Lab coat/Sleeved garment [A]-Apron
[R]-Respiratory Protection [B]-Boots
[O]-Continuous Cleaning [N]-None
[Z]-All except Respiratory Protection

7.9 Chemical Bath Sampling -Immersion Tin

Bath Type	**Type of Sampling [a]**	**Frequency [b]**	**Duration of Sampling [c]**	**Protective Equipment [d]**	**Method of Sampling [e]**
Example:	**A**	**3 per day**	**5 min**	**E, G, A**	**P**
Cleaner					
Microetch					
Predip					
Immersion Tin					
Other (specify):					

[a] **Type of Sampling**
[A] - Automated
[M] - Manual
[N] - None

[b] **Frequency:** Enter the average time elapsed or number of panel sq. ft. processed between samples. Clearly specify units (e.g., hours, sq. ft.).

[c] **Duration of Sampling:** Enter the a verage time required to manually take a sample from the tank.

[d] **Protective Equipment:** Consult the key for the above table and enter the letters for all protective equipment used by the person performing the chemical sampling.

[e] **Method of Sampling:**
[D] - Drain or spigot
[P] - Pipette
{L] - Ladle
[O] - Other (specify)

7.10 Physical Data and Operating Conditions--Immersion Tin

Complete the tables below by entering the data requested for each specific type of chemical bath listed. If two tanks of the same type are used within the process, list the data for each tank separately.

Average cycle time for a panel to complete entire immersion tin process (includes cleaning and post cleaning steps, if any):	**min.**

Bath	**Physical Data**			**Process Data**		**Operating Conditions**		
	Length (inches)	**Width (inches)**	**Nominal Volume (gal)**	**Immersion Time [a] (seconds)**	**Drip [b] Time (seconds)**	**Temp (ºF)**	**Agitation (see key)**	**Vapor Control (see key)**
Cleaner	**in.**	**in.**	**gal.**	**sec.**	**sec.**	**ºF**		
Microetch	**in.**	**in.**	**gal.**	**sec.**	**sec.**	**ºF**		
Predip	**in.**	**in.**	**gal.**	**sec.**	**sec.**	**ºF**		
Immersion Tin	**in.**	**in.**	**gal.**	**sec.**	**sec.**	**ºF**		
Other (specify):	**in.**	**in.**	**gal.**	**sec.**	**sec.**	**ºF**		

[a] **Immersion Time -** Enter the average elapsed time a rack of panels is immersed in the specific process bath.

[b] **Drip Time -** Enter the average elapsed time that a rack of panels is allowed to hang above the specific process bath to allow drainage from panels.

Agitation Methods Key:
[PA] - Panel agitation
[CP] - Circulation pump
[AS] - Air sparge
[O] - Other (explain)

Vapor Control Methods Key:
[BC] - Bath cover
[FE] - Fully enclosed
[VO] - Vent to outside
[VC] - Vent to control
[PP] - Push pull
[O] - Other (explain)

7.11 Initial Chemical Bath Make-Up Composition --Immersion Tin

Complete the chart below for each chemical component of the bath type listed. Provide the manufacturer name if the chemical used is known only by trade name. If more room is needed, please attach another sheet with the additional information. If two tanks of the same type are used within the process, list the data for a single tank only.

Bath		Chemical Product Name	Manufacturer (if applicable)	Annual Quantity Used [a] (gallons)
Cleaner	**1.**			
	2.			
	3.			
	4.			
Microetch	**1.**			
	2.			
	3.			
	4.			
Predip	**1.**			
	2.			
	3.			
	4.			
Immersion Tin	**1.**			
	2.			
	3.			
	4.			
Other (specify)	**1.**			
	2.			
	3.			
	4.			

[a] **Annual Quantity Used -** If the amount of a particular chemical used is measured by weight (i.e., crystalline chemicals) instead of volume, enter the weight in pounds and clearly specify the units (lbs).

7.12 Chemical Bath Bailout and Additions--Immersion Tin

Complete the following chart detailing the typical bath bailout and chemical additions that are made to maintain the chemical balance of each specific process bath. If more than three chemicals are added to a specific bath, attach another sheet with the additional information. If chemical additions to a bath are made automatically, do not complete the last three columns for that bath. If two tanks of the same type are used within the process, list the data for a single tank only.

Bath Type	**Bailout Frequency**	**Bailout Duration [c] (minutes)**	**Bailout Quantity**	**Personal Protective Equipment [d]**	**Chemical Products Added**		**Criteria for Addition[a]**	**Method of Chemical Addition to Tank[b]**	**Duration of Addition[c] (minutes)**
Cleaner		**min.**			**1**				**min.**
					2				
					3				
Microetch		**min.**			**1**				**min.**
					2				
					3				
Predip		**min.**			**1**				**min.**
					2				
					3				
Immersion Tin		**min.**			**1**				**min.**
					2				
					3				
Other (specify)		**min.**			**1**				**min.**
					2				
					3				
		min.			**1**				**min.**
					2				
					3				

[a] **Criteria for Additions** - Enter the letter for the criteria typically used to determine when bath additions are necessary.

[S] - Statistical process control
[P] - Panel square feet processed
[C] - Chemical testing
[T] - Time
[O] - Other

[b] **Method of Chemical Addition to Tank** - Enter the letter for the method typically used to add chemicals to the tanks.

[PR] - Poured
[P] - Pumped manually [O] - Other
[S] - Scooped

[c] **Duration of Bailout or Addition - Enter the elapsed time from the retrieval of the chemical stock** through the completion of the addition of all chemicals. For bailout, enter the time required to bailout the bath prior to making additions.

[d] **Personal Protective Equipment -** Enter the letters of all the protective equipment used by the workers who physically replace the spent bath.

[E] - Eye protection
[A] - Apron
[L] - Lab coat/Sleeved garment
[B] - Boots
[R] - Respiratory protection
[Z] - All except Respiratory Protection
[N] - None
[G] - Gloves

7.13 Chemical Bath Replacement -- Immersion Tin

Complete the chart below by providing information on the process of replacing, treating, and disposing of a spent chemical bath.

Bath Type	Criteria for Replacement [a]	Replacement Frequency [b]	Method of Spent Bath Removal [c]	Tank Cleaning Method [d]	Duration of Replacement Procedure [e]	Personal Protective Equipment [f]
Cleaner					**min.**	
Microetch					**min.**	
Predip					**min.**	
Immersion Tin					**min.**	
Other (specify)					**min.**	

[a] **Criteria for Replacement -**
[S] - Statistical process control
[P] - Panel square feet processed
[C] - Chemical testing
[T] - Time
[O] - Other (specify)

[b] **Frequency -** Enter the average amount of time elapsed, or number of square feet processed, between bath replacements. Clearly specify units (e.g., hours, sq.ft.).

[c] **Methods of Spent Bath Removal-**
[P] - Pump spent bath from tank
[S] - Siphon spent bath from tank
[D] - Drain spent bath from tank
[O] - Other (specify)

[d] **Tank Cleaning Method -**
[C] - Chemical flush
[W] - Water rinse
[H] - Hand scrub
[O] - Other (specify)

[e] **Duration of Replacement -** Enter the elapsed time from the beginning of bath removal until the replacement bath is finished.

[f] **Personal Protective Equip. -** Enter the letters of <u>all</u> the protective equipment used by the workers who physically replace the spent bath.

[E] - Eye protection
[G] - Gloves
[L] - Lab coat/sleeved garment
[A] - Apron
[R] - Respiratory protection
[B] - Boots
[Z] - All except respiratory protection
[N] - None

7.14 Process Waste Disposal -- Immersion Tin

Bath Type	Annual Volume Treated or Disposed [a]	Method of Treatment or Disposal [b]	RCRA Waste Code (if applicable)	Container Type
Cleaner				
Microetch				
Predip				
Immersion Tin				
Other (specify):				

[a] **Annual Volume Treated or Disposed** - Enter the yearly amount of the specific bath treated or disposed. ***Be sure to consider the volume treated from both bath change outs and bailout before entering the total.***	[b] **Methods of Treatment or Disposal -** [P] - Precipitation pretreatment on-site [N] - pH neutralization pretreatment on-site [S] - Disposed directly to sewer with no treatment [D] - Drummed for off-site treatment or disposal [RN] - Recycled on-site [RF] - Recycled off-site [O] - Other (specify)	**Container Type -** Indicate the type of container used for disposal of bath wastes [OH]- Open-head drum [CH]- Closed-head drum [T]- Chemical tote [O]- Other (specify)

Design
for the
Environment

Printed Wiring Board Project

Performance Demonstration Questionnaire

Please complete this questionnaire, make a copy for your records, and send the original to:

Ellen Moore
Abt Associates
55 Wheeler St.
Cambridge, MA 02138
Fax: (617) 349-2660

Note: The completed questionnaire must be returned <u>PRIOR TO</u> the scheduled site visit.

FACILITY AND CONTACT INFORMATION

Facility Identification:

Company Name:					
Site Name:					
Street Address:					
City:		State:		Zip:	

Contact Identification: Enter the names of the persons who can be contacted regarding this survey.

Name:		
Title:		
Phone:		
Fax:		
E-Mail:		

Section 1. Facility Characterization

Estimate manufacturing data for the previous 12 month period or other convenient time period of 12 consecutive months (e.g., FY96). Only consider the portion of the facility dedicated to PWB manufacturing when entering employee and facility size data.

1.1 General Information

Size of portion of facility used for manufacturing PWBs.	Sq. Ft.	Number of days Surface Finish line is in operation:	days/yr
Size of portion of facility used for surface finishing.	Sq. Ft.		

1.2 Process Type

Estimate the percentage of PWBs manufactured at your facility using the following methods for surface finishing (SF). Specify "other" entry.

Type of PWB process	Percent of total	Type of PWB process	Percent of Total
HASL	%	Electroless Palladium	%
OSP-Thick	%	Electroless Nickel/Immersion Gold	%
OSP-Thin	%	Other:	%
Immersion Tin	%	Other:	%
Immersion Silver	%	TOTAL	100%

1.3 General Process Line Data

Process Data	Hours
Number of hours the Surface Finishing line is in operation per day:	

1.4 Process Area Employees

Complete the following table by indicating the number of employees of each type that perform work duties in the same process room as the Surface Finishing line and for what length of time. Report the number of hours per employee. Consider only workers who have regularly scheduled responsibilities physically within the process room. Specify "other" entry. Enter "N/A" in any category not applicable.

Type of Process Area Worker	**Number of Employees in Process Area**	**Average Hours per Week per Employee in Process Area**
Line Operators		Hrs.
Lab Technicians		Hrs.
Maintenance Workers		Hrs.
Wastewater Treatment Operators		Hrs.
Supervisory Personnel		Hrs.
Other:		Hrs.
Other:		Hrs.

1.5 Wastewater Discharge and Sludge Data

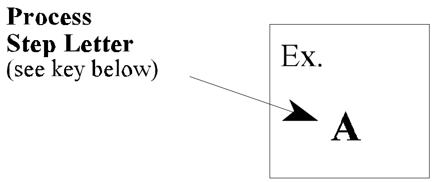
Wastewater discharge type (check one)	Direct		Indirect		Zero	
Annual weight (quantity in pounds) of sludge generated:						
Is sludge dewatered prior to disposal?						
% water content **prior** to dewatering:						
% water content **after** dewatering:						

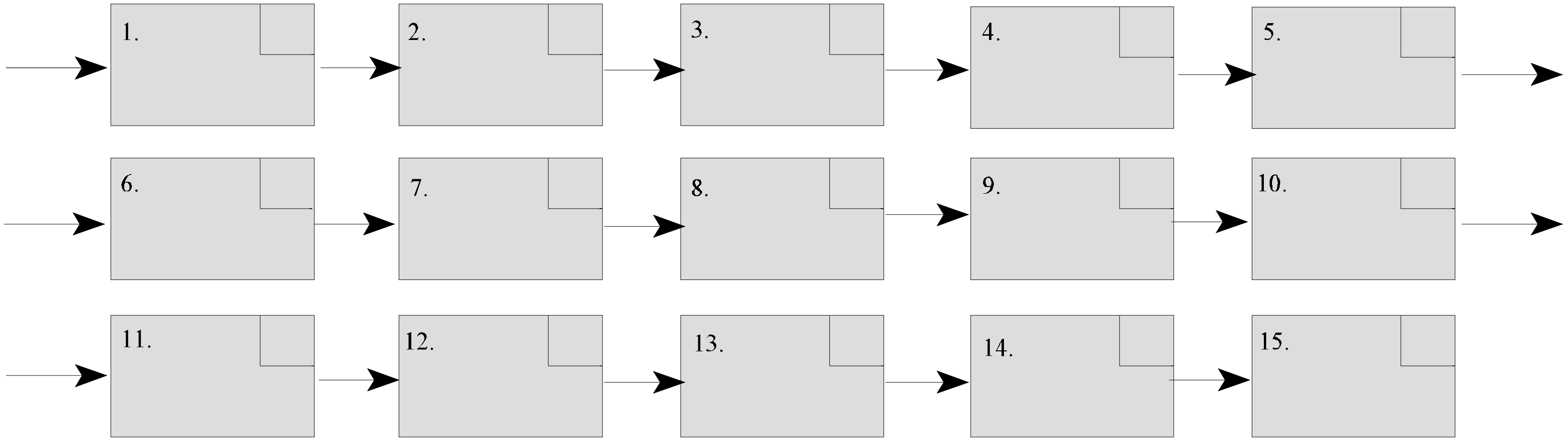
Section 2. Process Description: Immersion Tin

2.1 Process Schematic

Fill in the following table by identifying what type of surface finishing process (e.g., HASL) your facility uses. Then, using the proper key at the bottom of the page, identify which letter corresponds with the first step in your process and write that letter in the first box (see example). Continue using the key to fill in boxes for each step in your process until your entire surface finishing process is represented. If your process is not represented by a key below, complete the chart by writing in the name of each process step in your particular surface finishing line.

Name of Process:





Immersion Tin Process Step Key

[A] - Cleaner	[D] - Immersion Tin
[B] - Microetch	[E] - Water Rinse
[C] - Predip	[F] - Other (specify step)

2.2 Rinse Bath Water Usage

Consult the process schematic in section 2.1 to obtain the process step numbers associated with each of the water rinse baths present. Enter, in the table below, the process step number along with the flow control method and flow rate data requested for each water rinse bath. **If the water rinse bath is part of a cascade, you need only report the daily water flow rate of one bath in the cascade.**

Amount of water used by the surface finishing line when operating:			**gal/day**
Process Step Number [a]	**Flow Control [b]**	**Daily Water Flow Rate [c]**	**Cascade Water Process Steps [d]**
Example: 8	**R**	**2,400 gal./day**	**8 6**
		gal./day	
		gal./day	
		gal./day	
		gal./day	
		gal/.day	
		gal./day	
		gal./day	
		gal./day	
[a] **Process step number** - Consult the process schematic in question 2.1 and enter the process step number of the specific water rinse tank. [b] **Flow control** - Consult key at right and enter the letter for the flow control method used for that specific rinse bath. [c] **Daily water flow rate** - Enter the average daily flow rate for the specific water rinse tank. [d] **Cascade water process steps** - Use the step numbers for rinses that are cascaded together.			**Flow Control Methods Key** [C] - Conductivity Meter [P] - pH Meter [V] - Operator Control Valve [R] - Flow Restricter [N] - None (continuous flow) [O] - Other (explain)

2.3 Process Parameters

Size of the room containing the process	sq. ft.
	Height of room
Are the overall process areas (not tank vent) ventilated? (Circle one)	No
Air flow rate:	cu.ft.min.
Do you have local vents?	No
Local vent air flow rate:	cu. Ft./min.

Type of process automation for surface finishing line: (circle one)

Automated non-conveyorized   Automated conveyorized   Manually controlled hoise

Manual (no automation)   Other, specify:

2.4 Physical, Process, and Operating Conditions

Complete the table below by entering the data requested for each specific type of chemical bath listed. If two tanks of the same type are used within the process, list the data for a single tank only.

BATH	LENGTH (inches)	WIDTH (inches)	NOMINAL VOLUME
Acid cleaner	in.	in..	gal.
Microetch	in.	in..	gal.
Acid predip	in.	in..	gal.
Immersion tin	in.	in..	gal.
Other (specify)	in.	in..	gal.
	in.	in..	gal.
	in.	in..	gal.
	in.	in..	gal.

2.5 Initial Chemical Bath Make-Up Composition

Complete the chart below for each chemical component of the bath type listed. Provide the manufacturer name if the chemical used is known only by trade name. If more room is needed, please attach another sheet with the additional information. If two tanks of the same type are used within the process, list the data for a single tank only.

BATH		CHEMICAL PRODUCT NAME	MANUFACTURER (if applicable)	ANNUAL QUANTITY USED[a] (gallons)
CLEANER	**1.**			
	2.			
	3.			
	4.			
MICROETCH	**1.**			
	2.			
	3.			
	4.			
ACID PREDIP	**1.**			
	2.			
	3.			
	4.			
IMMERSION TIN	**1.**			
	2.			
	3.			
	4.			
OTHER (specify)	**1.**			
	2.			
	3.			
	4.			

[a] **Annual Quantity Used - If the amount of a particular chemical used is measured by weight (i.e., crystalline chemicals) instead of volume, enter the weight in pounds and clearly specify the units (lbs).**

2.6 Chemical Bath Replacement

Complete the chart below by providing information on the process of replacing, treating, and disposing of a spent chemical bath.

Bath Type	Criteria for Replacement[a]	Frequency[b]	Tank Cleaning Method[c]	Duration of Replacement Procedure[d]	Personal Protective Equipment[e]	Method of Treatment or Disposal[f]	Annual Volume Treated or Disposed[g]
ACID CLEANER					**min.**		
MICROETCH					**min.**		
ACID PREDIP					**min.**		
IMMERSION TIN					**min.**		

[a] **Criteria for Replacement -**
[S] - Statistical process control
[P] - Panel square feet processed
[C] - Chemical testing
[T] - Time
[O] - Other (specify)

[b] **Frequency -** Enter the average amount of time elapsed, or number of square feet processed, between bath replacements. Clearly specify units (e.g., hours, sq.ft., etc.)

[c] **Tank Cleaning Method**
[C] - Chemical Flush
[W] - Water Rinse
[H] - Hand Scrub
[O] - Other (specify)

[d] **Duration of Replacement-**
Enter the elapsed time from the beginning of bath removal until the replacement bath is finished.

[f] **Personal Protective Equip. -**
Enter the letters of <u>all</u> the protective equipment used by the workers who physically replace the spent bath.
[E] - Eye protection
[G] - Gloves
[L] - Lab coat/sleeved garment
[A] - Apron
[R] - Respiratory protection
[B] - Boots
[Z] - All except respiratory protection
[N] - None

[f] **Methods of Spent Bath Removal -**
[P] - Precipitation Pretreatment on-site
[N] - PH Neutralization Pretreatment on-site
[S] - Disposed directly to sewer with no treatment
[D] - Drummed for off-site treatment or disposal
[RN] - Recycled on-site
[RF] - Recycled off-site
[O] - Other (specify)

[g] **Annual Vol. Treat. Or Disp. -**
Enter the yearly amount of the specific bath treated or disposed. Needed only if water testing is not done.

2.7 Chemical Bath Additions

Complete the following chart detailing the typical chemical additions that are made to maintain the chemical balance of each specific process bath. If more than four chemicals are added to a specific bath, attach another sheet with the additional information. If chemical additions to a bath are made automatically, do not complete the last three columns for that bath. If two tanks of the same type are used within the process, list the data for a single tank only.

Bath Type		Chemical Products Added	Criteria for Replacement[a]	Method of Chemical Addition to Tank[b]	Duration of Addition[c] (minutes)	Personal Protective Equipment[d]
CLEANER	**1.**					
	2.					
	3.					
	4.					
MICROETCH	**1.**					
	2.					
	3.					
	4.					
ACID PREDIP	**1.**					
	2.					
	3.					
	4.					
IMMERSION TIN	**1.**					
	2.					
	3.					
	4.					
OTHER (specify):	**1.**					
	2.					
	3.					
	4.					

[a] **Criteria for Replacement -**
Enter the letter for the criteria typically used to determine when bath replacement is necessary.
[S] - Statistical Process Control
[P] - Panel Square Feet Processed
[C] - Chemical Testing
[T] - Time
[O] - Other

[b] **Method of Chemical Addition to Tank -**
Enter the letters for the method typically used to add chemicals to the tanks.
[P] - Pumped Manually
[PR] - Poured
[S] - Scooped
[O] - Other

[c] **Duration of Addition -** Enter the average elapsed time from the retrieval of the chemical stock through the completion of the addition of all chemicals

[d] **Personal Protective Equipment** - Enter the letters of all the protective equipment worn by the workers physically replacing the spent bath.
[E] - Eye protection
[G] - Gloves
[L] - Labcoat/Sleeved garment
[A] - Apron
[R] - Respiratory protection
[B] - Boots
[Z] - All except Respiratory Protection
[N] - None

Observer Data Sheet
DfE PWB Performance Demonstrations

Facility name and location: ____

Surface finishing process type and name: ___________________ Installation date: ________

Date: ____________ Contact Name: _______________________________________

Test Panel Run	
Overall Surface Finishing process line dimensions Length (ft.): Width (ft.): Height (ft.):	
Average number of panels per rack:	Average space between panels in rack:
Average size of panel in rack: Length(in): Width (in.):	
At what % of capacity is the line currently running?	At what % of capacity is the line typically running?
What is the overall throughout? surface sq.ft./year How is it calculated:	
Estimated yield for surface finishing line:	
Number of thermal cycles the finished board can withstand:	
Note any unusual storage conditions or oxidation. Load system with layer 4 facing up or toward the operator.	
While running the test panels, verify each process step and complete the table on the next page.	

Test Panel Serial Numbers					
Test Board	**Serial #**	**Test Board**	**Serial #**	**Test Board**	**Serial #**
1.		3.		5.	
2.		4.		6.	

Test Panel Run				
Bath Name (from schematic)	**Equipment**[a]	**Bath Temp**	**Immersion Time**	**Drip Time**
1.				
2.				
3.				
4.				
5.				
6.				
7.				
8.				
9.				
10.				
11.				
12.				
13.				
14.				
Overall System Time:				

[a] List Number, type of

Agitation:
[PA] - Panel agitation
[CP] - Circulation Pump
[AS] - Air Sparge

Vapor Control:
[BC] - Bath Cover
[]FE} - Fully Enclosed
[VO] - Vent to Outside
[VC] - Vent to Control

Filter Type:
[BF] - Bag
[CF] - Cartridge

Heater Control:
[TH] - Thermostat
[TM] - Timer
[PR] - Programmed

Water Rinses:
[CN] - Continuous
[DP] - Continuous During Process
[PP] - Partial During Process

Verification of Part A (mark any changes on working copy of Part A):

Ventilation:

Verify the type of ventilation as recorded in the Questionnaire:

Tank Volumes:

Verify the length, width, and volume of each tank, as recorded in the Questionnaire:

Water use:

Verify water use data, for each tank:

Daily water flow rate verified ☐

Cascade process steps verified ☐

Pollution Prevention:

Have you used any other pollution prevention techniques on the surface finishing line (e.g., covered tanks to reduce evaporation, measures to reduce dragout, changes to conserve water, etc.)?

If yes, describe and quantify results (note: if results have not been quantified, please provide an estimate):

If your throughput changed during the time new pollution prevention techniques were implemented, estimate how much (if any) of the pollution reductions are due to the throughput changes:

Filter Replacement						
Bath(s) filtered (enter process step #)						
Frequency of replacement:						
Duration of replacement process:						
Personal protective equipment (see key):						

Personal Protective Equipment Key:
[E] - Eye Protection
[G] - Gloves
[Z] - All except Respiratory Protection
[L] - Labcoat/Sleeved garment
[A] - Apron
[N] - None
[R] - Respiratory Protection
[B] - Boots

Equipment Maintenance

Estimate the maintenance requirements (excluding filter changes and bath changes) of the surface finishing process equipment for both outside services calls (maintenance by vendor or service company) and in-house maintenance (by facility personnel).

Describe the typical maintenance activities associated with the surface finishing process line (e.g., motor repair/replacement, conveyor repairs, valve leaks, etc.)

Average time spent per week:

Average downtime:

If there a recurring maintenance problem?
If yes, describe:

Rack or Conveyor Cleaning	Not Applicable ☐
Frequency of rack or conveyor cleaning:	
Rack Cleaning Method (see key): OR	
Conveyor Cleaning Method (see key):	
Number of personnel involved:	
Personal protective equipment (see key):	
Average time required to clean:	

Rack Cleaning Method:
[C] - Chemical bath on SF process line
[D] - Chemical bath on another line
[T] - Temporary chemical bath
[S] - Manual scrubbing with chemical
[M] - Non-chemical cleaning
[N] - None
[O] - Continuous cleaning

Conveyor Cleaning Method:
[C] - Chemical rinsing or soaking
[S] - Manual scrubbing with chemical
[M] - Non-chemical cleaning
[N] - None
[O] - Continuous cleaning

Personal Protective Equipment:
[E] - Eye Protection
[G] - Gloves
[L] - Labcoat/Sleeved garment
[R] - Respiratory Protection
[O] - Continuous Cleaning
[Z] - All except Respiratory Protection
[A] - Apron
[B] - Boots
[N] - None

Chemical Bath Sampling

Bath Type	Type of Sampling[a]	Frequency [b]	Duration of Sampling [c]	Protective Equipment [d]	Method of Sampling [e]
Cleaner					
Microetch					
Flux					
Solder					
Post Clean					
Other (specify)					
Other (specify)					

[a] **Type of Sampling**
[A] - Automated
[M] - Manual
[N] - None

[b] **Frequency:**
Enter the average time elapsed or number of panel sq. ft. processed between samples. Clearly specify units (e.g., hours, sq. ft., etc.)

[c] **Duration of Sampling:**
Enter the average time for manually taking a sample from the tank

[d] **Protective Equipment:**
Consult the key for the above table and enter the letters for all protective equipment worn by the person performing the chemical sampling.

[e] **Method of Obtaining Samples:**
[D] - Drain or spigot
[p] - Pipette
[L] - Ladle
[O] - Other (specify)

Process Description

Process Schematic

Fill in the table below by identifying what type of alternative surface finishing process (e.g., immersion tin) your company uses. Then, using the key at the bottom left of the page, identify which letter corresponds with the first bath step in your process and write that letter in the first box (see example). Continue using the key to fill in boxes for each step in your process until your entire alternative surface finishing process is represented. If your process step is not represented by the key below, complete the chart by writing in the name of the process step in your particular surface finishing line.

Process Automation Letter (see key below right)

Type of Process
(write in process name)

Ex. A T

Process Steps of Your Facility
(begin here)

1. → 2. → 3. → 4. → 5. → 6. → 7. → 8. → 9. → 10. → 11. → 12. → 13. → 14. → 15. → 16.

<u>Standard Bath Types</u>
[A] - Center
[B] - Conditioner
[C] - Micro Etch
[D] - Pre-dip
[E] - Catalyst
[F] - Activator
[G] - Accelerator
[H] - Enhancer
[J] - Electroless Nickel
[K] - Electroless Gold
[L] - Electroless Palladium
[M] - Immersion Palladium
[N] - Immersion Gold
[P] - Immersion Tin
[Q] - Immersion Silver
[R] - OSP
[S] - Anti-tarnish
[W] - Water rinse
[O] - Other (specify step)

<u>Process Automation</u>
Please list all the process types with which the above process may be operated in:___________________

<u>Process Automation Key</u>
[P] - Automated on-conveyorized
[Q] - Automated conveyorized
[R] - Partially automated
[S] - Manually controlled hoist
[T] - Manual (no information)
[A] - All of the above
[V] - Other (specify)

Comparative Evaluation:
If the facility has switched from a previous system to the current system, complete this page.

Product Quality:
What, if any, changes were noticed in the quality of the boards produced? (Yield change?)

Installation:
How long was the debug period when this system was installed?

What were the types of problems encountered:

Manufacturing Process Changes: How did you change your upstream or downstream processes when this system was installed (e.g., did you have to make changes in your solder mask)?

Waste Treatment:
Have any of your waste treatment methods or volumes changed due to the installation of this system (not associated with volume changes due to throughput changes)?

If yes, describe the change(s) and attach quantitative information, if available:

Process Safety:
Have any additional OSHA-related procedures or issues arisen as a result of changing to the present system (e.g., machinery lock-outs while cleaning, etc)? If so, describe:

Customer Acceptance:
Have customers accepted the new process? Why or why not:

Other:
Describe any other issues that have arisen as a result of the new process.

Supplier Data Sheet

DfE Printed Wiring Board Project
Alternative Technologies for Surface Finishing

Manufacturer/Supplier Product Data Sheet

Manufacturer Name: ______________________________
Address: ______________________________
____
Contact: ______________________________
Phone: ______________________________
Fax: ______________________________

How many alternative making holes conductive product lines will you submit for testing? __________

Please complete a Data Sheet for each product line you wish to submit for testing. In addition, if you have not already done so, please submit the material safety data sheets (MSDS), product literature, and the standard manufacturer instructions for each product line submitted.

Product Line Name: ______________________________ **Category:**[*] ______

[*] **Categories of Product Lines:**
A. HASL
B. Immersion Tin
C. Immersion Palladium
D. Electroless Nickel/Immersion Gold
E. Nickel/Palladium/Immersion Gold
F. OSP - (Thin)
G. OSP - (Thick)

For the product line listed above, please identify one or two facilities that are currently using the product line at which you would like your product demonstrated. Also, identify the location of the site (city, state) and whether the site is 1) a customer production site, 2) a customer test site, or 3) your own supplier testing site.

Facility 1 Name and Location: ______________________________
Type of Site: ______________________________
Facility Contact: ______________________________
May we contact the facility at this time (yes or no): ______________________________

Facility 2 Name and Location: ______________________________
Type of Site: ______________________________
Facility Contact: ______________________________ Phone: ______________________________
May we contact the facility at this time (yes or no): ______________________________

Energy Usage

For each piece of equipment in the surface finishing line using energy, complete the table below:

Equipment Type	Tank or Station # [a]	Power Rating (from nameplate)	Load (1% capacity in use)	Equipment Cost	Period of Usage	Machine Control
					_ continuous _ continuous during process cycle _ partial during process cycle. If partial, record how often: _ other:	_ timer _ program _ operator/manual _ other:
					_ continuous _ continuous during process cycle _ partial during process cycle. If partial, record how often: _ other:	_ timer _ program _ operator/manual _ other:
					_ continuous _ continuous during process cycle _ partial during process cycle. If partial, record how often: _ other:	_ timer _ program _ operator/manual _ other:
					_ continuous _ continuous during process cycle _ partial during process cycle. If partial, record how often: _ other:	_ timer _ program _ operator/manual _ other:
					_ continuous _ continuous during process cycle _ partial during process cycle. If partial, record how often: _ other:	_ timer _ program _ operator/manual _ other:

[a] **Specify whether tank number of process flow diagram step numbers are used.**

Special Product Characteristics

1. Does the process operate as a vertical process, horizontal process, or either? ________________________

2. Average number of thermal excursions the finished board can withstand? __________________________

____

3. Most likely process step preceding the beginning of the surface finish application? ___________________

____

4. Should the application of solder mask occur after the application of the surface finish, or before? ______

____

5. Which of the following technologies is the surface finish compatible with?
(Circle all applicable choices.)

A. SMT
B. Flip Chip
C. BGA
D. Gold Wire Bonding
E. Aluminum Wire Bonding
F. Other, Explain: ____

6. Please state cycle time of surface finish process line. ______________________________

7. Please describe any special process equipment recommended (e.g., high pressure rinse, air knife, dryer, aging equipment, etc.). ____

____

Product Line Constraints

1. Please list any substrate incompatibilities (e.g., BT, cyanate ester, Teflon, Kevlar, copper invar copper, polyethylene, other [specify]) ____

2. Please list compatibilities with solder masks. ____

____

3. Are there any special requirements needed for the soldering process (e.g., type of flux, etc.)? __________

____

4. Average shelf-life of finished boards? ____

5. Other general comments about the product line (include any known impacts on other process steps).____

____

____

Bath Life

Please fill in the following table (for bath listings, please refer back to your process description on page 2).

Bath	Recommended Treatment/Disposal Method [a]	Criteria for Dumping Bath (e.g., time, surface sq ft of panel processed, concentration, etc.)	Recommended Bath Life (in terms of criteria listed at left)
1.			
2.			
3.			
4.			
5.			
6.			
7.			
8.			

[a] Attach and reference materials, if necessary.

Costs:

Chemical Cost
Please provide the cost per gallon (or pound) of chemical for each chemical product required to operate this alternative surface finishing product line. It is recognized that the cost of chemicals is, in part, dependant on the amount of chemical purchased (i.e., volume discounts) and may vary accordingly. If cost would decrease, please write decreased cost in margin along with volume of chemical required for pricing discount.

Bath Name	Product Name	Chemical Cost ($/gal or $/lb)
1.	A.	
	B.	
	C.	
2.	A.	
	B.	
	C.	
3.	A.	
	B.	
	C.	
4.	A.	
	B.	
	C.	
5.	A.	
	B.	
	C.	
6.	A.	
	B.	
	C.	
7.	A.	
	B.	
	C.	

Equipment Cost

Do you recommend or suggest any specific equipment manufacturers to customers for obtaining process equipment to operate this surface finish line? If so, why? Please provide the contact information for equipment manufacturer below.

Equipment Company # 1
Company Name: ___________________________
Contact Name: _____________________________
Phone number: _____________________________
Equipment Type: ___________________________

Equipment Company # 2
Company Name: ___________________________
Contact Name: _____________________________
Phone number: _____________________________
Equipment Type: ___________________________

Do either of the companies listed above manufacture equipment specifically designed for your product line? Which one?
____

If so, what is special or different about the equipment design?
____

____
____

Appendix B

Bath Chemistry Data

Contents

Table B-1. Bath Concentrations for the HASL Technology

Bath	Chemicals	Concentration in Bath (g/l)
Cleaner	Alkylphenolpolyethoxyethanol Ethylene glycol monobutyl ether Fluoboric acid Phosphoric acid Sulfuric acid *9 other confidential chemicals	18.00 22.90 12.33 61.11 110.40
Microetch	1,4-Butenediol Copper sulfate pentahydrate Hydrogen peroxide Sodium hydroxide Sulfuric acid *7 other confidential chemicals	12.72 45.00 50.73 0.170 103.50

Table B-2. Bath Concentrations for the Electroless Nickel/Immersion Gold Technology

Bath	Chemicals	Concentration in Bath (g/l)
Cleaner	Phosphoric acid Sulfuric acid Hydrochloric acid Alkylphenolpolyethoxyethanol *Two other confidential chemicals	50.8 138 17.85 18.00
Microetch	Sodium hydroxide Hydrogen peroxide Copper sulfate pentahydrate Sulfuric acid *Two other confidential chemicals	0.170 35.88 45.00 87.40
Catalyst	Hydrochloric acid *Four other confidential chemicals	55.80
Acid Dip	*Two confidential chemicals	
Electroless Nickel	Nickel sulfate *13 other confidential chemicals	37.24
Immersion Gold	Potassium gold cyanide *Four other confidential chemicals	2.999

Table B-3. Bath Concentrations for the Electroless Nickel/Electroless Palladium/Immersion Gold Technology

Bath	Chemical	Concentration in Bath (g/l)
Cleaner	Phosphoric acid *2 other confidential chemicals	50.80
Microetch	Sodium hydroxide Hydrogen peroxide Copper sulfate pentahydrate Sulfuric acid *1 other confidential chemical	0.17 35.88 45.00 156.40
Catalyst	*4 confidential chemicals	
Acid Dip	*1 confidential chemical	
Electroless Nickel	Nickel sulfate *10 other confidential chemicals	58.65
Preinitiator	*4 confidential chemicals	
Electroless Palladium	Ethylenediamine Propionic acid Maleic acid *6 other confidential chemicals	4.45 7.30 2.00
Immersion Gold	Potassium gold cyanide *4 other confidential chemicals	3.00

Table B-4. Bath Concentrations for the OSP Technology

Bath	Chemical	Concentration in Bath (g/l)
Cleaner	Phosphoric acid Sulfuric acid *3 other confidential chemicals	50.80 9.20
Microetch	Sodium hydroxide Hydrogen peroxide Copper sulfate pentahydrate Sulfuric acid *6 other confidential chemicals	0.170 18.165 45.00 250.70
OSP	Copper ion *5 other confidential chemicals	50.50

Table B-5. Bath Concentrations for the Immersion Silver Technology

Bath	Chemical	Concentration in Bath (g/l)
Cleaner	Phosphoric acid	122.90
Microetch	1,4-Butenediol Sulfuric acid Hydrogen peroxide	12.72 4.60 113.00
Predip	Sodium hydroxide *4 other confidential chemicals	29.36
Immersion Silver	Sodium hydroxide *5 other confidential chemicals	26.43

Table B-6. Bath Concentrations for the Immersion Tin Technology

Bath	Chemical	Concentration in Bath (g/l)
Cleaner	Ethylene glycol monobutyl ether Fluoboric acid Sulfuric acid Phosphoric acid *6 other confidential chemicals	22.90 12.33 184.00 30.25
Microetch	Sulfuric acid *1 other confidential chemical	18.40
Predip	Methane sulfonic acid Sulfuric acid *10 other confidential chemicals	337.50 0.0092
Immersion Tin	Sulfuric acid Urea 1,3-Diethylthiourea Tin chloride Methane sulfonic acid Stannous methane sulfonic acid *14 other confidential chemicals	92.18 90.00 20.00 13.98 69.17 111.80

Appendix C

Chemical Properties Data

Contents

CHEMICAL SUMMARY FOR 1,3-DIETHYLTHIOUREA

This summary is based on information retrieved from a systematic search limited to secondary sources. The only exception is summaries of studies from unpublished TSCA submissions that may have been included. These sources include online databases, unpublished EPA information, government publications, review documents, and standard reference materials. No attempt has been made to verify information in these databases and secondary sources.

I. CHEMICAL IDENTITY AND PHYSICAL/CHEMICAL PROPERTIES

The chemical identity and physical/chemical properties of 1,3-diethylthiourea are summarized in Table 1.

TABLE 1. CHEMICAL IDENTITY AND CHEMICAL/PHYSICAL PROPERTIES OF 1,3-DIETHYLTHIOUREA

Characteristic/Property	Data	Reference
CAS No.	105-55-5	Lide (1995)
Common Synonyms	N,N-diethylthiourea	Lide (1995)
Molecular Formula	$C_5H_{12}N_2S$	Lide (1995)
Chemical Structure	$C_2H_5NHCSNHC_2H_5$	Lewis (1993)
Physical State	buff solid	Lewis (1993)
Molecular Weight	132.32	Lide (1995)
Melting Point	78 °C	Lide (1995)
Boiling Point	decomposes	Lide (1995)
Water Solubility	4.56 g/L	PHYSPROP (1998)
Density	1.11 mg/m^3	Ohm (1997)
Vapor Density (air = 1)	no data	
Koc	49 (estimated)	HSDB (1998)
Log Kow	0.57	PHYSPROP (1998)
Vapor Pressure	0.240 mm Hg at 25 °C (estimated)	PHYSPROP (1998)
Reactivity	no data	
Flammability	no data	
Flash Point	no data	
Dissociation Constant	no data	
Molecular Diffusivity Constant	no data	
Air Diffusivity Constant	no data	
Henry's Law Constant	6.9×10^{-8} atm m^3/mole (estimated)	PHYSPROP (1998)
Fish Bioconcentration Constant	2 (estimated)	HSDB (1998)
Odor Threshold	no data	

II. ENVIRONMENTAL FATE

A. Aquatic Fate

If released into aquatic waters, 1,3-diethylthiourea is not expected to adsorb to suspended solids and sediments in water based upon an estimated Koc of 49 (HSDB, 1998; Swann et al., 1983), determined from a log Kow of 0.57 (Govers et al., 1986, as cited in PHYSPROP, 1998) and a regression-derived equation (Lyman et al., 1990). Volatilization from the water column to the atmosphere is not expected to occur (Lyman et al., 1990) based on an estimated Henry's Law constant of 6.9×10^{-8} atm-m^3/mole (PHYSPROP, 1998; SRC, 1998) . Since thiourea, a structurally similar compound, was found to be stable to hydrolysis and photolysis (Schmidt-Bleek et al., 1982, as cited in HSDB, 1998), 1,3-diethylthiourea is also expected to be stable to both hydrolysis and photolysis. According to a classification scheme (Franke et al., 1994), an estimated BCF of 2 (HSDB, 1998; Lyman et al., 1990) suggests that the potential for bioconcentration in aquatic organisms is low.

B. Atmospheric Fate

According to a model of gas/particle partitioning of semivolatile organic compounds in the atmosphere (Bidleman, 1988), 1,3-Diethylthiourea, which has an estimated vapor pressure of 0.24 mm Hg at 25 °C (PHYSPROP, 1998; SRC, 1998), should exist solely as a vapor in the ambient atmosphere. The predominant removal process of 1,3-diethylthiourea from the atmosphere is reaction with photochemically-produced hydroxyl radicals; the half-life for this reaction in air is estimated to be 4 hours (Atkinson, 1988). 1,3-diethylthiourea, which has a high estimated water solubility of 4.56 g/L (PHYSPROP, 1998; SRC, 1998), is expected to adsorb onto atmospheric particulate material; the small amount of 1,3-diethylthiourea deposited onto particulate material may be physically removed by wet and dry deposition (HSDB, 1998).

C. Terrestrial Fate

Based on a classification scheme (Swann et al., 1983), an estimated Koc of 49 (HSDB, 1998), determined from a log Kow of 0.57 (Govers et al., 1986, as cited in PHYSPROP, 1998) and a regression-derived equation (Lyman et al., 1990), indicates that 1,3-diethylthiourea is expected to have very high mobility in soil. Volatilization of 1,3-diethylthiourea from moist soil surfaces is not expected to be important (Lyman et al., 1990) given an estimated Henry's Law constant of 6.9×10^{-8} atm-m^3/mole (PHYSPROP, 1998). In addition, 1,3-diethylthiourea is not expected to volatilize from dry soil given its estimated vapor pressure of 0.24 mm Hg (PHYSPROP, 1998; SRC, 1998).

D. Summary

If released to air, an estimated vapor pressure of 0.24 mm Hg at 25 °C indicates that 1,3-diethylthiourea should exist solely as a vapor in the ambient atmosphere. Gas-phase 1,3-diethylthiourea will be degraded in the atmosphere by reaction with photochemically-produced hydroxyl radicals; the half-life for this reaction in air is estimated to be 4 hours. 1,3-Diethylthiourea is not expected to adsorb to suspended solids and sediments in water. An estimated BCF of 2 suggests the potential for bioconcentration in aquatic organisms is low. If released to soil, 1,3-diethylthiourea is expected to have very high mobility based upon an estimated Koc of 49, and, therefore, it has the potential to leach to groundwater. Volatilization from water and from moist soil surfaces is not expected to be an important fate process based upon a Henry's Law constant of 6.9×10^{-8} atm-m^3/mole. Volatilization from dry soil surfaces is not expected to occur based upon the vapor pressure of this compound.

SUMMARY FOR 1,4-BUTENEDIOL

This summary is based on information retrieved from a systematic search limited to secondary sources. The only exception is summaries of studies from unpublished TSCA submissions that may have been included. These sources include online databases, unpublished EPA information, government publications, review documents, and standard reference materials. No attempt has been made to verify information in these databases and secondary sources.

I. CHEMICAL IDENTITY AND PHYSICAL/CHEMICAL PROPERTIES

The chemical identity and physical/chemical properties of 1,4-butenediol are summarized in Table 1.

TABLE 1. CHEMICAL IDENTITY AND CHEMICAL/PHYSICAL PROPERTIES OF 1,4-BUTENEDIOL

Characteristic/Property	Data	Reference
CAS No.	110-64-5	Grafje et al. (1985)
Common Synonyms	2-butene-1,4-diol (mixed isomers)	Grafje et al. (1985)
Molecular Formula	$C_4H_8O_2$	Grafje et al. (1985)
Chemical Structure	$HOCH_2CH=CHCH_2OH$	Grafje et al. (1985)
Physical State	pale, yellow liquid	Grafje et al. (1985)
Molecular Weight	88.1	Grafje et al. (1985)
Melting Point	4 °C (cis); 25 °C (trans)	Howard and Meylan (1997)
Boiling Point	235 °C (cis); 135 °C @ 12 mm Hg (trans)	Howard and Meylan (1997)
Water Solubility	soluble; estimated to be >$1x10^3$ g/l	Grafje et al. (1985); SRC (1998)
Density	specific gravity = 1.07 @ 25 °C (liquid)	Weiss (1986)
Vapor Density (air = 1)	no data	
Koc	8.6 (estimated)	Lyman et al. (1990)
Log Kow	-0.81	Hansch et al. (1995)
Vapor Pressure	$4.7x10^{-3}$ mm Hg @ 25 °C (extrapolated)	Grafje et al. (1985)
Reactivity	no data	
Flammability	not flammable: flash point >100 °F	Cote (1997)
Flash Point	263 °F (Cleveland open cup)	Flick (1991)
Dissociation Constant	no data	
Molecular Diffusivity Constant	no data	
Air Diffusivity Constant	no data	
Henry's Law Constant	$1.54x10^{-10}$ atm m^3/mole (estimated)	Meylan and Howard (1991)
Fish Bioconcentration Constant	0.14 (estimated)	Boethling et al. (1994)
Odor Threshold	no data	

II. ENVIRONMENTAL FATE

A. Aquatic Fate

An estimated Koc of 8.6, determined from a log Kow of -0.81 (Hansch et al., 1995) and a regression-derived equation (Lyman et al., 1990), indicates that 1,4-butenediol is not expected to adsorb to suspended solids and sediment in water. Also, an estimated Henry's Law constant of $1.54x10^{-10}$ atm m^3/mole at 25 °C (Meylan and Howard, 1991) indicates that 1,4-butenediol is not expected to volatilize from water surfaces (Lyman et al., 1990). Hydrolysis is not expected to be an important fate process for 1,4-butenediol due to the lack of hydrolyzable functional groups (Lyman et al., 1990). No data were available in the scientific literature for the biodegradation of 1,4-butenediol in aquatic media under aerobic or anaerobic conditions. However, using a structure estimation method (Boethling et al., 1994), aerobic biodegradation is expected to be rapid (days to weeks). According to a classification scheme (Franke et al., 1994), an estimated BCF of 0.14 (Lyman et al., 1990), obtained from the log Kow, suggests the potential for bioconcentration of 1,4-butenediol in aquatic organisms is low.

B. Atmospheric Fate

According to a model of gas/particle partitioning of semivolatile organic compounds in the atmosphere (Bidleman, 1988), 1,4-butenediol, which has an extrapolated vapor pressure of 4.7×10^{-3} mm Hg at 25 °C (Grafje et al., 1985), is expected to exist solely as a gas in the ambient atmosphere. Gas-phase 1,4-butenediol is degraded in the atmosphere by reaction with photochemically-produced hydroxyl radicals; the half-life for this reaction in air is estimated to be 5-6 hours, depending upon the isomer (Meylan and Howard, 1993). The half-life for the reaction of 1,4-butenediol with ozone in the atmosphere is estimated to be 1-2 hours, depending upon the isomer (Meylan and Howard, 1993). 1,4-Butenediol is not expected to directly photolyze in the atmosphere due to the lack of absorption in the environmental UV spectrum greater than 290 nm (Lyman et al., 1990). Because 1,4-butenediol is miscible with water, physical removal from the atmosphere by wet deposition may occur.

C. Terrestrial Fate

An estimated Koc of 8.6 (Lyman, 1990), determined from a log Kow of -0.81 (Hansch et al., 1995), indicates that 1,4-butenediol is expected to have very high mobility in soil (Swann et al., 1983). Volatilization of 1,4-butenediol from moist soil surfaces is not expected to be important (Lyman et al., 1990) given an estimated Henry's Law constant of 1.54×10^{-10} atm m^3/mole (Meylan and Howard, 1991). In addition, an extrapolated vapor pressure of 4.7×10^{-3} mm Hg (Grafje et al., 1985) indicates that 1,4-butenediol is not expected to volatilize from dry soil surfaces. No data were available in the scientific literature for the biodegradation of 1,4-butenediol in soil under aerobic or anaerobic conditions. However, using a structure estimation method (Boethling et al., 1994), aerobic biodegradation is expected to be rapid (days to weeks).

D. Summary

1,4-Butenediol exists as a mixture of the cis and trans isomers that are expected to behave similarly in the environment. If released to air, an extrapolated vapor pressure of 4.7×10^{-3} mm Hg at 25 °C indicates 1,4-butenediol should exist solely as a gas in the ambient atmosphere. Gas-phase 1,4-butenediol will be degraded in the atmosphere by reaction with photochemically-produced hydroxyl radicals; the half-life for this reaction in air is estimated to be 5-6 hours, depending upon the isomer. The gas phase reactions of 1,4-butenediol with photochemically produced ozone corresponds to a half-life of 1-2 hours. Physical removal of gas-phase 1,4-butenediol from the atmosphere may also occur via wet deposition processes based on the miscibility of this compound with water. If released to soil, 1,4-butenediol is expected to have very high mobility and is not expected to adsorb to soil surfaces. Volatilization from water and moist soil surfaces is not expected to be an important fate process based upon an estimated Henry's Law constant of 1.54×10^{-10} atm m^3/mole. In addition, volatilization from dry soil surfaces is not expected to occur based upon the vapor pressure of 1,4-butenediol. Biodegradation data were not available from the scientific literature; however, a computer model estimates that aerobic biodegradation in both soil and water may occur within days to weeks. In water, 1,4-butenediol is not expected to bioconcentrate in fish and aquatic organisms based on its estimated BCF of 0.14.

CHEMICAL SUMMARY FOR ACETIC ACID

This summary is based on information retrieved from a systematic search limited to secondary sources. The only exception is summaries of studies from unpublished TSCA submissions that may have been included. These sources include online databases, unpublished EPA information, government publications, review documents, and standard reference materials. No attempt has been made to verify information in these databases and secondary sources.

I. CHEMICAL IDENTITY AND PHYSICAL/CHEMICAL PROPERTIES

The chemical identity and physical/chemical properties of acetic acid are summarized in Table 1.

TABLE 1. CHEMICAL IDENTITY AND CHEMICAL/PHYSICAL PROPERTIES OF ACETIC ACID

Characteristic/Property	Data	Reference
CAS No.	64-19-7	Howard and Neal (1992)
Common Synonyms	ethanoic acid; vinegar acid	Howard and Neal (1992)
Molecular Formula	$C_2H_4O_2$	Budavari et al. (1996)
Chemical Structure	CH_3COOH	Budavari et al. (1996)
Physical State	clear liquid	Budavari et al. (1996)
Molecular Weight	60.05	Budavari et al. (1996)
Melting Point	16.7 °C	Budavari et al. (1996)
Boiling Point	118 °C	Budavari et al. (1996)
Water Solubility	$1x10^3$ g/l, 25 °C	U.S. EPA (1981)
Density	$d^{25/25}$, 1.049	Budavari et al. (1996)
Vapor Density (air = 1)	no data	
Koc	6.5-228	Sansone et al. (1987)
Log Kow	-0.17	Hansch et al. (1995)
Vapor Pressure	15.7 mm Hg @ 25 °C	Daubert and Danner (1985)
Reactivity	corrosive, particularly when dilute	Weiss (1986)
Flammability	flammable	Budavari et al. (1996)
Flash Point	103 °F (39 °C), closed cup	Budavari et al. (1996)
Dissociation Constant	pKa = 4.76	Serjeant and Dempsey (1979)
Molecular Diffusivity Constant	no data	
Air Diffusivity Constant	no data	
Henry's Law Constant	$1.00x10^{-9}$ atm m^3/mole @ 25 °C	Gaffney et al. (1987)
Fish Bioconcentration Factor	<1 (calculated)	Lyman et al. (1990)
Odor Threshold	no data	

II. ENVIRONMENTAL FATE

A. Aquatic Fate

The dominant environmental fate process for acetic acid in water is expected to be biodegradation. A large number of biological screening studies have determined that acetic acid biodegrades readily under both aerobic (Zahn and Wellens, 1980; Dore et al., 1975; Price et al., 1974; Placak and Ruchhoft, 1947 as cited in HSDB, 1998) and anaerobic (Kameya et al., 1995; Mawson et al., 1991; Swindoll et al., 1988 as cited in HSDB, 1998) conditions. Two aqueous adsorption studies found that acetic acid exists primarily in the water column and not in sediment (Hemphill and Swanson, 1964; Gordon and Millero, 1985 as cited in HSDB, 1998). In general, organic ions are not expected to volatilize from water to adsorb to particulate matter in water to the degree that would be predicted for their neutral counterparts. Volatilization from the water column to the atmosphere is not expected to occur (Lyman et al., 1990 as cited in HSDB, 1998) based on a Henry's Law constant of $1x10^{-9}$ atm-m^3/mole at pH 7 (Gaffney et al., 1987 as cited in HSDB, 1998). According to a classification scheme (Franke et al., 1994 as cited in HSDB, 1998), an estimated BCF of <1 (Lyman, 1990 as cited in HSDB, 1998), calculated from a log Kow of -0.17 (Hansch et al., 1995 as cited in HSDB, 1998), suggests that the potential for bioconcentration in aquatic organisms is low.

B. Atmospheric Fate

According to a model of gas/particle partitioning of semivolatile organic compounds in the atmosphere (Bidleman, 1988 as cited in HSDB, 1998), acetic acid, which has a vapor pressure of 15.7 mm Hg at 25°C (Daubert and Danner, 1989 as cited in HSDB, 1998), should exist solely as a gas in the ambient atmosphere. This is consistent with a study in which over 91% of the total measured acetic acid in an air sample was found to be in the gas phase (Khwaja, 1995 as cited in HSDB, 1998). Acetic acid has been identified as one of the major sources of free acidity in precipitation from remote regions of the world (Keene and Galloway, 1984 as cited in HSDB, 1998), indicating that physical removal by wet deposition is an important fate process (Hartmann et al., 1989 as cited in HSDB, 1998). Another important removal process of acetic acid from the atmosphere is reaction with photochemically-produced hydroxyl radicals; the half-life for this reaction in air is estimated to be 22 days (Atkinson, 1989 as cited in HSDB, 1998). Acetic acid has also been detected adsorbed to atmospheric particulate material as the acetate (Gregory et al., 1986; Khwaja, 1995 as cited in HSDB, 1998); the small amount of acetic acid associated with particulate material may be physically removed by wet and dry deposition (Grosjean, 1992).

C. Terrestrial Fate

The major environmental fate process for acetic acid in soil is expected to be biodegradation. A large number of biological screening studies have determined that acetic acid biodegrades readily under both aerobic ,Zahn and Wellens, 1980; Dore et al., 1975; Price et al., 1974; Placak and Ruchhoft, 1947 as cited in HSDB, 1998) and anaerobic (Kameya et al., 1995; Mawson et al., 1991; Swindoll et al., 1988 as cited in HSDB, 1998) conditions. Based on a classification scheme (Swann et al., 1983 as cited in HSDB, 1998), Koc values of 6.5 to 228 (Sansone et al., 1987 as cited in HSDB, 1998) indicate that acetic acid is expected to have moderate to very high mobility in soil. This is consistent with a study in which no sorption was reported for three different soils/sediments (Von Oepen et al., 1991 as cited in HSDB, 1998). Volatilization of acetic acid from moist soil surfaces is not expected to be important (Lyman et al., 1990, as cited in HSDB, 1998) given a Henry's Law constant of $1x10^{-9}$ atm-m^3/mole (Gaffney et al., 1987 as cited in HSDB, 1998) and because acetic acid will exist predominantly as the acetate at environmental pH's. However, the potential for volatilization of acetic acid from dry soil surfaces may exist based on it's vapor pressure of 15.7 mm Hg (Daubert and Danner, 1989 as cited in HSDB, 1998). Volatilization will be attenuated depending upon pH and the amount of acetic acid dissociated.

D. Summary

Acetic acid occurs throughout nature as a normal metabolite of both plants and animals. Consequently, acetic acid's fate in the environment will, in part, be dependent on its participation in natural cycles. With a pKa of 4.76, acetic acid and its conjugate base will exist in environmental media in varying proportions that are pH dependent; under typical environmental conditions (pHs of 5 to 9), acetic acid will exist almost entirely in the ionized (dissociated) form. If released to air, a vapor pressure of 15.7 mm Hg at 25 °C indicates that acetic acid should exist solely as a gas in the ambient atmosphere. Gas-phase acetic acid will be degraded in the atmosphere by reaction with photochemically-produced hydroxyl radicals; the half-life for this reaction in air is estimated to be 22 days. Physical removal of vapor-phase acetic acid from the atmosphere may occur via wet deposition processes based on its miscibility with water. An estimated BCF of <1 suggests the potential for bioconcentration on aquatic organisms is low. Adsorption studies indicate that acetic acid is not expected to adsorb to suspended solids and sediments in water. If released to soil, acetic acid is expected to have very high to moderate mobility based upon measured Koc values ranging from 6.5 to 228 and, therefore, it has the potential to leach to groundwater. If released to soil in high concentrations, such as those encountered in a spill, acetic acid may travel through soil and reach groundwater. Volatilization from water and from moist soil surfaces is not expected to be an important fate process based upon a Henry's Law constant of $1x10^{-9}$ atm-m^3/mole. Yet, volatilization from dry soil surfaces may occur based upon the vapor pressure of this compound. However, volatilization of acetic acid will be pH dependent; if acetic acid is dissociated, very little (about 1%) will be available for volatilization. Biodegradation is expected to be rapid and may be the dominant fate process in both soil and water under non-spill conditions; a large number of biological screening studies have determined that acetic acid biodegrades readily under both aerobic and anaerobic conditions.

CHEMICAL SUMMARY FOR BRANCHED OCTYLPHENOL, ETHOXYLATED[1]
(alkylphenol polyethoxyethanol)

This summary is based on information retrieved from a systematic search limited to secondary sources. The only exception is summaries of studies from unpublished TSCA submissions that may have been included. These sources include online databases, unpublished EPA information, government publications, review documents, and standard reference materials. No attempt has been made to verify information in these databases and secondary sources. The search identified sources of information for branched octylphenol, ethoxylated.

I. CHEMICAL IDENTITY AND PHYSICAL/CHEMICAL PROPERTIES

The chemical identity and physical/chemical properties of branched octylphenol, ethoxylated[1] are summarized in Table 1.

TABLE 1. CHEMICAL IDENTITY AND CHEMICAL/PHYSICAL PROPERTIES OF BRANCHED OCTYLPHENOL, ETHOXYLATED[1]

Characteristic/Property	Data	Reference
CAS No.	9036-19-5, 9002-93-1	Howard and Neal (1992)
Common Synonyms	Triton X-100[1], OPIOSP	Howard and Neal (1992)
Molecular Formula	$C_{14}H_{22}O.(C_2H_4O)_{100}$	Howard and Neal (1992)
Chemical Structure	$(C_8H_{17})C6H4O(C_2H_4O)_{100}$	Howard and Neal (1992)
Physical State	Clear viscous liquid	MSDS
Molecular Weight	polymer, >4000	Howard and Neal (1992)
Melting Point	7.2°C	MSDS
Boiling Point	271°C	MSDS
Water Solubility	Dispersible, >100 g/L	MSDS
Density	d^{25}, 1.07	MSDS
Vapor Density (air = 1)	>1	MSDS
Koc	No data	
Log Kow	No data	
Vapor Pressure	<0.001 torr	MSDS
Reactivity	No data	
Flammability	No data	
Flash Point	288°C	MSDS
Dissociation Constant	No data	
Molecular Diffusivity Constant	No data	
Air Diffusivity Constant	No data	
Henry's Law Constant	No data	
Fish Bioconcentration Constant	No data	
Odor Threshold	No data	

[1] The properties are given for TritonX100 (manufacturer Rohm and Haas).

CHEMICAL SUMMARY FOR AMMONIUM CHLORIDE

This summary is based on information retrieved from a systematic search limited to secondary sources. The only exception is summaries of studies from unpublished TSCA submissions that may have been included. These sources include online databases, unpublished EPA information, government publications, review documents, and standard reference materials. No attempt has been made to verify information in these databases and secondary sources.

I. CHEMICAL IDENTITY AND PHYSICAL/CHEMICAL PROPERTIES

The chemical identity and physical/chemical properties of ammonium chloride are summarized in Table 1.

TABLE 1. CHEMICAL IDENTITY AND CHEMICAL/PHYSICAL PROPERTIES OF AMMONIUM CHLORIDE

Characteristic/Property	Data	Reference
CAS No.	12125-02-9	CAS (1998)
Common Synonyms	Ammonium muriate	Budavari et al. (1996)
Molecular Formula	ClH_4 N	Budavari et al. (1996)
Chemical Structure	NH_4Cl	Budavari et al. (1996)
Physical State	colorless cubic crystals	Lide (1995)
Molecular Weight	53.492	Lide (1995)
Melting Point	sublimes at 350°C	Lewis (1993)
Boiling Point	no data	
Water Solubility	approximately 300 g/L [1]	Estimated
Density	1.519 g/cm^3	Lide (1995)
Vapor Density (air = 1)	no data	
Koc	no data; expected to be < 10	Estimated
Log Kow	no data; expected to be < 1	Estimated
Vapor Pressure	$1.84X10^{-12}$ mm Hg at 25°C (extrapolated)	Daubert and Danner (1992)
Reactivity	no data	
Flammability	not flammable	Weiss (1986)
Flash Point	not flammable	Weiss (1986)
Dissociation Constant	dissociates to NH_4^+ and Cl^-	Bodek et al. (1988)
Molecular Diffusivity Constant	no data	
Air Diffusivity Constant	no data	
Henry's Law Constant	no data; expected to be < $1x10^{-8}$	Estimated
Fish Bioconcentration Constant	no data	
Odor Threshold	odorless	Weiss (1986)

[1] Estimated from a reported solubility of 37 parts in 100 parts water at 20°C (Dean 1985).

II. ENVIRONMENTAL FATE

A. Aquatic Fate

If ammonium chloride is released into water, it is expected to dissociate into ammonium (NH_4^+) and chloride (Cl^-) ions (Bodek et al., 1988). The counter ion associated with the NH_4^+ will vary depending on the concentration and type of ions available and the pH in the receiving water. In addition, NH_4^+ and NH_3 (ammonia) are in equilibrium in the environment and since the pKa of the ammonium ion, NH_4^+, is 9.26, most ammonia in water is present as the protonated form rather than as NH_3 (Manahan, 1991). Ammonia is, however, present in the equilibrium and will volatilize to the atmosphere (based upon its Henry's Law constant of $1.6X10^{-5}$ atm m^3/mole [Betterton, 1992 as cited in PHYSPROP, 1998]); the rate of volatilization will increase with increasing pH and, to a lesser degree, temperature

(ATSDR, 1990). In the aquatic environment, ammonium can undergo sequential transformation by the nitrification and denitrification processes of the nitrogen cycle; within this process, ionic nitrogen compounds are formed (ATSDR, 1990). In addition, ammonium can be taken up by aquatic plants as a source of nutrition, and the uptake of ammonium by fish has also been documented (ATSDR, 1990). Adsorption of ammonium to sediment should increase with increasing organic content, increased metal content, and decreasing pH; however, ammonium can be produced in, and subsequently released from, sediment (ATSDR, 1990). The dissociation of ammonium chloride into its component ions indicates that ammonium chloride is not expected to bioconcentrate in aquatic organisms. Ammonium ions may be adsorbed by negatively charged surfaces of sediment in the water column, however ammonium ions are expected to be replaced by other cations present in natural waters (Evans, 1989). The chloride ion may complex with heavy metals, thereby increasing their solubility (Bodek et al., 1988). Adsorption of the chloride ion to suspended solids and sediment in the water column is not expected to be an important fate process.

B. Atmospheric Fate

If ammonium chloride is released to the atmosphere, this compound's low vapor pressure (Daubert and Danner, 1992) indicates it will exist as a particulate in the ambient atmosphere. Ammonium chloride is expected to undergo wet deposition (ATSDR, 1990) in rain, snow, or fog based upon its high water solubility (Dean, 1985). Dry deposition of ammonium chloride is expected to be an important fate process in the atmosphere (ATSDR, 1990). The rate of dry deposition will depend on the prevailing winds and particle size (Bodek et al., 1988). In addition, NH_4^+ and NH_3 (ammonia) are in equilibrium. The gas-phase reactions of ammonia with photochemically produced hydroxyl radicals has been reported to be $1.6\text{x}10^{-13}$ cm^3/molc-sec, with a calculated half-life of approximately 100 days; this process contributes approximately 10% to the removal of atmospheric ammonia (ATSDR, 1990).

C. Terrestrial Fate

If ammonium chloride is released to soil, it is expected to dissociate into its component ions in moist soils. As noted above, NH_4^+ and NH_3 (ammonia) are in equilibrium in the environment and since the pKa of the ammonium ion, NH_4^+, is 9.26, most ammonia in water is present as the protonated form rather than as NH_3 (Manahan, 1991). The low vapor pressure and Henry's Law constant expected for an ionic salt indicates that ammonium chloride will not volatilize from either dry or moist soil surfaces. Nonetheless, ammonia is present in the equilibrium and will volatilize to the atmosphere (based upon its Henry's Law constant of $1.6\text{X}10^{-5}$ atm m^3/mole [Betterton, 1992 as cited in PHYSPROP, 1998]); the rate of volatilization will increase with increasing pH and, to a lesser degree, temperature (ATSDR, 1990). The mobility of ammonium ions through soil may be attenuated by attraction to negatively charged surfaces of soil particles, however ammonium ions are expected to be replaced by other cations present in soil (Evans, 1989). In soil, ammonium will serve as a source of nutrient taken up by plants and other organisms and converted to organic-nitrogen compounds. Ammonium can be converted to nitrate by microbial populations through nitrification; the nitrate formed will either leach through soil or be taken up by plants and other organisms. It has been determined that minerals and dry soils can rapidly and effectively adsorb ammonia from air. Chloride is extremely mobile in soils (Bodek et al., 1988). The chloride ion may complex with heavy metals, thereby increasing their solubility (Bodek et al., 1988) and potential for leaching into groundwater.

D. Summary

If released into water, ammonium chloride is expected to dissociate into ammonium and chloride ions. The dissociation of ammonium chloride into its component ions indicates that ammonium chloride is not expected to bioconcentration in aquatic organisms. Ammonium, however, will be used as a nutrient source by microorganisms and plants, and rapid uptake is anticipated. Ammonium is in equilibrium with ammonia, but the majority will be in the ammonium form under most environmental pHs. When present, ammonia's Henry's Law constant indicates that volatilization from water surfaces may occur. If released to soil, ammonium chloride is expected to dissociate into its component ions in moist soils and will be used as a nutrient by microorganisms and plants. The dissociation of ammonium chloride into its component ions in moist soils indicates that volatilization of ammonium from moist soil surfaces is not expected to occur. The mobility of ammonium ions in soil is expected to be attenuated by cation exchange processes. The low vapor pressure expected for an ionic salt indicates that ammonium chloride is not expected to volatilize from dry soil surfaces, however, when ammonia is present in equilibrium, volatilization may occur. If released to the atmosphere, ammonium chloride's low vapor pressure indicates this compound will exist as a particulate. Wet and dry deposition will be the dominant fate processes in the atmosphere. The rate of dry deposition will depend on the prevailing wind patterns and particle size. Some atmospheric oxidation may occur.

CHEMICAL SUMMARY FOR AMMONIUM HYDROXIDE

This summary is based on information retrieved from a systematic search limited to secondary sources. The only exception is summaries of studies from unpublished TSCA submissions that may have been included. These sources include online databases, unpublished EPA information, government publications, review documents, and standard reference materials. No attempt has been made to verify information in these databases and secondary sources.

I. CHEMICAL IDENTITY AND PHYSICAL/CHEMICAL PROPERTIES

The chemical identity and physical/chemical properties of ammonium hydroxide are summarized in Table 1.

TABLE 1. CHEMICAL IDENTITY AND CHEMICAL/PHYSICAL PROPERTIES OF AMMONIUM HYDROXIDE

Characteristic/Property	Data	Reference
CAS No.	1336-21-6	Lide (1995)
Common Synonyms	ammonia solution; aqua ammonia; ammonium hydrate	Lewis (1993)
Molecular Formula	H_5NO	PHYSPROP (1998)
Chemical Structure	NH_4OH	Lide (1995)
Physical State	colorless liquid	Lewis (1993)
Molecular Weight	35.05	Lide (1995)
Melting Point	no data	
Boiling Point	no data	
Water Solubility	soluble in water	Sax (1984)
Density	no data	
Vapor Density (air = 1)	no data	
Koc	no data; estimated to be < 10	Estimated
Log Kow	no data; estimated to be < 1	Estimated
Vapor Pressure	no data	
Reactivity	incompatible w/ HCl, HNO3, Ag compounds	Sax (1984)
Flammability	not flammable	Weiss (1986)
Flash Point	no data; estimated to be > 350 °C	Estimated
Dissociation Constant	9.26 (water solution)	Manahan (1991)
Molecular Diffusivity Constant	no data	
Air Diffusivity Constant	no data	
Henry's Law Constant	no data[1]	
Fish Bioconcentration Constant	no data	
Odor Threshold	no data	

[1] In the environment, ammonium ion is expected to predominate in the ammonia-ammonium ion equilibrium; however, this equilibrium is highly dependent on both pH and temperature (ATSDR, 1990). Ammonia is expected to have a very high Henry's Law constant, while ammonium is expected to have a negligible Henry's Law constant (SRC, 1998).

II. ENVIRONMENTAL FATE

A. Aquatic Fate

If released into the water column at low concentrations, ammonia or ammonium hydroxide will volatilize to the atmosphere; the rate of volatilization will increase with increasing pH and, to a lesser degree, temperature (ATSDR, 1990). Since the pKa of the ammonia is 9.26, most ammonia in most environmental waters is present as the protonated, NH_4^+, form rather than as NH_3 (Manahan, 1991). In the aquatic environment, ammonia can undergo sequential transformation by the nitrification and denitrification processes of the nitrogen cycle; within this process, ionic nitrogen compounds are formed (ATSDR, 1990). In addition, ammonia can be taken up by aquatic plants as a source of nutrition, and the uptake of ammonia by fish has also been documented (ATSDR, 1990). Adsorption of ammonia to sediment should increase with increasing organic content, increased metal content, and decreasing pH; however, ammonia can be produced in, and subsequently released from sediment (ATSDR, 1990). Large releases of the concentrated base into water, such as may result from a spill, will result in an increase of the pH (ATSDR, 1990).

B. Atmospheric Fate

If ammonia is released to the atmosphere, its vapor pressure indicates it will exist as a vapor in the ambient atmosphere. If ammonium hydroxide is released to the atmosphere, it is anticipated that the dominant form will be as a particulate, but during equilibrium between ammonium and ammonia, the ammonia will rapidly leave the particle as a vapor. The dominant fate process for the removal of ammonia from the atmosphere is the reaction with acid air pollutants to form ammonium compounds (e.g., ammonium sulfate, ammonium nitrate); these ammonium compounds can then be removed by wet or dry deposition (ATSDR, 1990). In addition, gas-phase reactions of ammonia with photochemically produced hydroxyl radicals has been reported to be 1.6×10^{-13} cm^3/molc-sec, with a calculated half-life of approximately 100 days; this process contributes approximately 10% to the removal of atmospheric ammonia (ATSDR, 1990).

C. Terrestrial Fate

If ammonia or ammonium hydroxide is released to soil, it will serve as a source of nutrient taken up by plants and other organisms and converted to organic-nitrogen compounds. Ammonia can be converted to nitrate by microbial populations through nitrification; the nitrate formed will either leach through soil or be taken up by plants and other organisms. It has been determined that minerals and dry soils can rapidly and effectively adsorb ammonia from air. Specifically, ammonia may be either bound to soil or undergo volatilization to the atmosphere. (ATSDR, 1990)

D. Summary

Ammonia is a base, and as such, the environmental fate of ammonia is pH and temperature dependent. If released into water, ammonia and ammonium hydroxide will volatilize to the atmosphere, depending on the pH. At high pHs, where the equilibrium more favors ammonia, volatilization will become increasingly important. At low pHs, volatilization will be less important. Adsorption of ammonia to sediment and suspended organic material can be important under proper conditions (i.e., organic matter content, metal content, and pH). In addition, ammonia will be taken up by aquatic organisms and plants as a source of nutrition. The dominant fate of ammonia in water will be its participation in the nitrogen cycle. The predominant removal process of ammonia and ammonium hydroxide from the atmosphere is expected to be wet and dry deposition. To a lesser extent, reactions with photochemically-produced hydroxyl radicals will occur. If released to soil, ammonia is expected to be taken up by plants and other organisms and converted to organic-nitrogen compounds. These compounds will either be taken up by plants or other organisms or leach through the soil. Volatilization of ammonia from soil surfaces is expected to occur.

CHEMICAL SUMMARY FOR SODIUM CITRATE (citric acid)

This summary is based on information retrieved from a systematic search limited to secondary sources. The only exception is summaries of studies from unpublished TSCA submissions that may have been included. These sources include online databases, unpublished EPA information, government publications, review documents, and standard reference materials. No attempt has been made to verify information in these databases and secondary sources.

I. CHEMICAL IDENTITY AND PHYSICAL/CHEMICAL PROPERTIES

The chemical identity and physical/chemical properties of sodium citrate are summarized in Table 1.

TABLE 1. CHEMICAL IDENTITY AND CHEMICAL/PHYSICAL PROPERTIES OF SODIUM CITRATE

Characteristic/Property	Data	Reference
CAS No.	68-04-2	
Common Synonyms	trisodium citrate; sodium citrate anhydrous; 2-hydroxy-1,2,3-propanetricarboxylic acid, trisodium salt	Lockheed Martin 1991
Molecular Formula	$C_6H_5Na_3O_7$	Budavari et al. 1989
Chemical Structure	$CH_2(COONa)C(OH)(COONa)CH_2COONa$	Osol 1980
Physical State	dihydrate, white crystals, granules, or powder; pentahydrate, relatively large, colorless crystals or white granules	Budavari et al. 1989
Molecular Weight	258.07	Budavari et al. 1989
Melting Point	150°C (-2 H_2O)	Fisher Scientific 1985
Boiling Point	decomposed at red heat	Lewis 1993
Water Solubility	72 g/100 mL at 25°C (dihydrate)	Weast 1983-1984
Density	1.9	Fisher Scientific 1985
Vapor Density (air = 1)	no data	
K_{OC}	no data	
Log K_{OW}	no data	
Vapor Pressure	no data	
Reactivity	0 (nonreactive, NFPA classification); aqueous solution slightly acid to litmus	Lockheed Martin 1991 Osol, 1980
Flammability	1 (slightly combustible, NFPA classification);	Lockheed Martin 1991
Flash Point	no data	
Dissociation Constant	no data	
Henry's Law Constant	no data	
Molecular Diffusivity Coefficient	no data	
Air Diffusivity Coefficient	no data	
Fish Bioconcentration Factor	no data	
Odor Threshold	no data; odorless	Lewis 1993
Conversion Factors	no data	

II. ENVIRONMENTAL FATE

A. Environmental Release

Sodium citrate is a solid with a cool, saline taste that is soluble in water (Fisher Scientific 1985). It is used in soft drinks, frozen desserts, meat products, cheeses, and as a nutrient for cultured buttermilk; in photography; in detergents; as a sequestrant and buffer; as an anticoagulant for blood withdrawn from the body; and in the removal of sulfur dioxide from smelter waste gases (Lewis 1993). Medicinally, sodium citrate is used as expectorant and systemic alkalizer. Sodium citrate is a chelating agent and has been used to facilitate elimination of lead from the body (Osol 1980).

No data were found on the environmental releases of sodium citrate. The chemical is not listed on U.S. EPA's Toxics Release Inventory, requiring certain U.S. industries to report on chemical releases to the environment (TRI93 1995). The chemical could potentially enter the environment when used for the removal of sulfur dioxide from smelter waste gases.

B. Transport

No data were found on the environmental transport of sodium citrate in the secondary sources searched. Its water solubility suggests that the sodium citrate would remain in the water phase.

C. Transformation/Persistence

No data were found on the transformation/persistence of potassium bisulfate in the secondary sources searched.

CHEMICAL SUMMARY FOR CUPRIC SULFATE (copper ion)

This summary is based on information retrieved from a systematic search limited to secondary sources. The only exception is summaries of studies from unpublished TSCA submissions that may have been included. These sources include online databases, unpublished EPA information, government publications, review documents, and standard reference materials. No attempt has been made to verify information in these databases and secondary sources.

I. CHEMICAL IDENTITY AND PHYSICAL/CHEMICAL PROPERTIES

The chemical identity and physical/chemical properties of cupric sulfate are summarized in Table 1.

TABLE 1. CHEMICAL IDENTITY AND CHEMICAL/PHYSICAL PROPERTIES OF CUPRIC SULFATE

Characteristic/Property	Data	Reference
CAS No.	7758-99-8	Lide (1995)
Common Synonyms	cupric sulfate pentahydrate; blue Vitriol	Budavari et al. (1996)
Molecular Formula	$CuO_4S{\cdot}5H_2O$	ATSDR (1990)
Chemical Structure	$CuSO_4{\cdot}5H_2O$	Lide (1995)
Physical State	large, blue, triclinic crystals; blue powder	Budavari et al. (1996)
Molecular Weight	249.68	Lide (1995)
Melting Point	decomposes @ 110°C	Lide (1995)
Boiling Point	decomposes to CuO @ 650°C	ATSDR (1990)
Water Solubility	316 g/L @ 0°C	Weast et al. (1985)
Density	2.286 g/cm^3	Lide (1995)
Vapor Density (air = 1)	no data	
Koc	no data	
Log Kow	no data	
Vapor Pressure	no data	
Reactivity	reacts with Mg to produce Cu_2O, $MgSO_4$, and H_2	U.S. Air Force (1990)
Reactivity	reacts with NH_4Cl producing $(NH_4)_2SO_4$ and $CuCl_2$; reacts with alkali (R)OH to produce $Cu(OH)_2$ and RSO_4; reacts with excess aq. NH_3 producing $Cu(NH_3)_2^{2+} + OH^-$;decomposition products include SO_2.	HSDB (1998)
Flammability	non-flammable	HSDB (1998)
Flash Point	non-flammable	HSDB (1998)
Dissociation Constant	no data	
Molecular Diffusivity Constant	no data	
Air Diffusivity Constant	no data	
Henry's Law Constant	no data	
Fish Bioconcentration Constant	10-100 for copper; 30,000 for copper in oysters	ATSDR (1990)
Odor Threshold	no data	

II. ENVIRONMENTAL FATE

A. Aquatic Fate

Copper (Cu) commonly exists in three valence states, Cu^0 (metal), Cu^+ (cuprous), and Cu^{2+} (cupric). It can also be oxidized to a Cu^{3+} state, but Cu^{3+} ions are rapidly reduced to Cu^{2+} in the environment (ATSDR, 1990). Copper in solution is present almost exclusively as the Cu^{2+} valence state (U.S. EPA, 1987). Copper in the Cu^{2+} valence state forms compounds and complexes with a variety of organic and inorganic ligands binding to -NH_2, -SH, and, to a lesser extent, -OH groups (ATSDR, 1990). The predominant form of copper in aqueous solution is dependent on the pH of the solution. Below pH 6, the cupric ion (Cu^{2+}) predominates; copper complexes with carbonate usually predominate above pH 6 (U.S. EPA, 1987; ATSDR, 1990). The association of copper with organic or inorganic ligands also depends on the pH and on the $CaCO_3$ alkalinity. Most of the copper entering surface water is in the form of particulate matter, which settles out, precipitates, or adsorbs to organic matter, hydrous iron and manganese oxides, and clay; however, the predominating form can change with the amount of rain, pH, content of runoff, and the availability of ligands (ATSDR, 1990). The processes of complexation, adsorption and precipitation limit the concentration of copper (Cu^{2+}) to very low values in most natural waters (ATSDR, 1990). Calculations of the bioconcentration factor in fish for copper have ranged from 10 to 100; however, the majority of copper measurements in fish tissues under environmental conditions have indicated little, if any, bioconcentration. Filter feeding shellfish, especially oysters, however, were found to significantly concentrate copper with bioconcentration factors as high as 30,000 (ATSDR, 1990).

B. Atmospheric Fate

Most of the copper in the air is in the form of particulate matter (dust) or is adsorbed to particulate matter. Larger particles (>5 µm) are removed by gravitational settling, smaller particles are removed by other forms of dry and wet deposition (ATSDR, 1990). Atmospheric copper resulting from combustion is associated with sub-micron particles that can remain in the troposphere for an estimated 7-30 days and may be carried long distances (ATSDR, 1990).

C. Terrestrial Fate

Most of the copper deposited in the soil is strongly adsorbed primarily to organic matter, carbonate minerals, clay minerals, and hydrous iron and manganese oxides. Movement through the soil is dependent on the presence of these substances, the pH, and other physical and chemical parameters. The greatest potential for leaching is seen in sandy soils with low pH (ATSDR, 1990). Laboratory experiments using controlled models and field experiments utilizing core samples have shown that very little copper moves through the soil. Core samples showed that some movement occurred as far as the 22.5-25 cm layer of soil, but little, if any, moved below this zone. The evidence indicates that hazardous amounts of copper should not leach into groundwater from sludge, even from sandy soils (ATSDR, 1990).

D. Summary

Copper (Cu) commonly exists in three valence states, Cu^0 (metal), Cu^+ (cuprous), and Cu^{2+} (cupric). It can also be oxidized to a Cu^{3+} state, but there are no important industrial Cu^{3+} chemicals, and Cu^{3+} ions are rapidly reduced to Cu^{2+} in the environment. If released to water, copper in solution will be present almost exclusively as the Cu^{2+} valence state. The predominant form of copper in aqueous solution is dependent on the pH of the solution. Most of the copper entering surface water is in the form of particulate matter; however, the predominating form can change with the amount of rain, pH, content of runoff, and the availability of ligands. Copper in the Cu^{2+} valence state will form compounds and complexes with a variety of organic and inorganic ligands. Calculations of the bioconcentration factor in fish for copper have ranged from 10 to 100; however, the majority of copper measurements in fish tissues under environmental conditions have indicated little, if any, bioconcentration. If released to soil, the majority of copper deposited in the soil is strongly adsorbed. Movement through the soil is dependent on the presence of organic matter, carbonate minerals, clay minerals, hydrous iron and manganese oxides, the pH, and other physical and chemical parameters. The greatest potential for leaching is seen in sandy soils with low pH. If released into the atmosphere, copper is expected to exist as a dust particulate or adsorb to particulate matter. Studies have shown that copper can remain in the atmosphere up to 30 days and be carried long distances.

CHEMICAL SUMMARY FOR CUPRIC ACETATE (copper sulfate pentahydrate)

This summary is based on information retrieved from a systematic search limited to secondary sources. The only exception is summaries of studies from unpublished TSCA submissions that may have been included. These sources include online databases, unpublished EPA information, government publications, review documents, and standard reference materials. No attempt has been made to verify information in these databases and secondary sources.

I. CHEMICAL IDENTITY AND PHYSICAL/CHEMICAL PROPERTIES

The chemical identity and physical/chemical properties of cupric acetate are summarized in Table 1.

TABLE 1. CHEMICAL IDENTITY AND CHEMICAL/PHYSICAL PROPERTIES OF COPPER ACETATE

Characteristic/Property	**Data**	**Reference**
CAS No.	6046-93-1	Lide (1995)
Common Synonyms	copper (II) acetate monohydrate	Lide (1995)
Molecular Formula	$(CH_3CO_2)_2 Cu{\cdot}H_2O$	Aldrich (1996)
Chemical Structure	$Cu(C_2H_3O_2)_2{\cdot}H_2O$	Lide (1995)
Physical State	dark, green monoclinic crystals	Budavari et al. (1996)
Physical State	greenish-blue, fine powder	Lewis (1993)
Molecular Weight	199.65	Lide (1995)
Melting Point	115 °C	Lide (1995)
Boiling Point	decomposes at 240 °C	Lide (1995)
Water Solubility	72 g/L cold water; 200 g/L hot water	Weast et al. (1985)
Density	1.88 g/cm^3	Lide (1995)
Vapor Density (air = 1)	no data	
Koc	no data	
Log Kow	no data	
Vapor Pressure	no data	
Reactivity	stable	Weiss (1986)
Flammability	not flammable	Weiss (1986)
Flash Point	not flammable	Weiss (1986)
Dissociation Constant	no data	
Molecular Diffusivity Constant	no data	
Air Diffusivity Constant	no data	
Henry’s Law Constant	no data	
Fish Bioconcentration Constant	10-100 for copper; 30,000 for copper in oysters	ATSDR (1990)
Odor Threshold	no data	

II. ENVIRONMENTAL FATE

A. Aquatic Fate

Copper (Cu) commonly exists in three valence states, Cu^0 (metal), Cu^+ (cuprous), and Cu^{2+} (cupric). It can also be oxidized to a Cu^{3+} state, but Cu^{3+} ions are rapidly reduced to Cu^{2+} in the environment (ATSDR, 1990). Copper in solution is present almost exclusively as the Cu^{2+} valence state (U.S. EPA, 1987). Copper in the Cu^{2+} valence state forms compounds and complexes with a variety of organic and inorganic ligands binding to $-NH_2$, -SH, and, to a lesser extent, -OH groups (ATSDR, 1990). The predominant form of copper in aqueous solution is dependent on the pH of the solution. Below pH 6, the cupric ion (Cu^{2+}) predominates; copper complexes with carbonate usually predominate above pH 6 (U.S. EPA, 1987; ATSDR, 1990). The association of copper with organic or inorganic ligands also depends on the pH and on the $CaCO_3$ alkalinity. Most of the copper entering surface water is in the form of particulate matter, which settles out, precipitates, or adsorbs to organic matter, hydrous iron and manganese oxides, and clay; however, the predominating form can change with the amount of rain, pH, content of runoff, and the availability of ligands (ATSDR, 1990). The processes of complexation, adsorption and precipitation limit the concentration of copper (Cu^{2+}) to very low values in most natural waters (ATSDR, 1990). Calculations of the bioconcentration factor in fish for copper have ranged from 10 to 100; however, the majority of copper measurements in fish tissues under environmental conditions have indicated little, if any, bioconcentration. Filter feeding shellfish, especially oysters, however, were found to significantly concentrate copper with bioconcentration factors as high as 30,000 (ATSDR, 1990).

B. Atmospheric Fate

Most of the copper in the air is in the form of particulate matter (dust) or is adsorbed to particulate matter. Larger particles (>5 µm) are removed by gravitational settling, smaller particles are removed by other forms of dry and wet deposition (ATSDR, 1990). Atmospheric copper resulting from combustion is associated with sub-micron particles that can remain in the troposphere for an estimated 7-30 days and may be carried long distances (ATSDR, 1990).

C. Terrestrial Fate

Most of the copper deposited in the soil is strongly adsorbed primarily to organic matter, carbonate minerals, clay minerals, and hydrous iron and manganese oxides. Movement through the soil is dependent on the presence of these substances, the pH, and other physical and chemical parameters. The greatest potential for leaching is seen in sandy soils with low pH (ATSDR, 1990). Laboratory experiments using controlled models and field experiments utilizing core samples have shown that very little copper moves through the soil. Core samples showed that some movement occurred as far as the 22.5-25 cm layer of soil, but little, if any, moved below this zone. The evidence indicates that hazardous amounts of copper should not leach into groundwater from sludge, even from sandy soils (ATSDR, 1990).

D. Summary

Copper (Cu) commonly exists in three valence states, Cu^0 (metal), Cu^+ (cuprous), and Cu^{2+} (cupric). It can also be oxidized to a Cu^{3+} state, but there are no important industrial Cu^{3+} chemicals, and Cu^{3+} ions are rapidly reduced to Cu^{2+} in the environment. If released to water, copper in solution will be present almost exclusively as the Cu^{2+} valence state. The predominant form of copper in aqueous solution is dependent on the pH of the solution. Most of the copper entering surface water is in the form of particulate matter; however, the predominating form can change with the amount of rain, pH, content of runoff, and the availability of ligands. Copper in the Cu^{2+} valence state will form compounds and complexes with a variety of organic and inorganic ligands. Calculations of the bioconcentration factor in fish for copper have ranged from 10 to 100; however, the majority of copper measurements in fish tissues under environmental conditions have indicated little, if any, bioconcentration. If released to soil, the majority of copper deposited in the soil is strongly adsorbed. Movement through the soil is dependent on the presence of organic matter, carbonate minerals, clay minerals, hydrous iron and manganese oxides, the pH, and other physical and chemical parameters. The greatest potential for leaching is seen in sandy soils with low pH. If released into the atmosphere, copper is expected to exist as a dust particulate or adsorb to particulate matter. Studies have shown that copper can remain in the atmosphere up to 30 days and be carried long distances.

CHEMICAL SUMMARY FOR ETHYLENEDIAMINE

This summary is based on information retrieved from a systematic search limited to secondary sources. The only exception is summaries of studies from unpublished TSCA submissions that may have been included. These sources include online databases, unpublished EPA information, government publications, review documents, and standard reference materials. No attempt has been made to verify information in these databases and secondary sources.

I. CHEMICAL IDENTITY AND PHYSICAL/CHEMICAL PROPERTIES

The chemical identity and physical/chemical properties of ethylene diamine are summarized in Table 1.

TABLE 1. CHEMICAL IDENTITY AND CHEMICAL/PHYSICAL PROPERTIES OF ETHYLENE DIAMINE

Characteristic/Property	Data	Reference
CAS No.	107-15-3	Howard and Neal (1992)
Common Synonyms	1,2-diamineethane; 1,2-ethanediamine	Budavari et al. (1996)
Molecular Formula	$C_2H_8N_2$	Budavari et al. (1996)
Chemical Structure	$H_2NCH_2CH_2NH_2$	Budavari et al. (1996)
Physical State	colorless, clear, thick, liquid	Budavari et al. (1996)
Molecular Weight	60.10	Budavari et al. (1996)
Melting Point	8.5 °C	Budavari et al. (1996)
Boiling Point	116-117 °C	Budavari et al. (1996)
Water Solubility	$1x10^3$ g/l @ 25 °C	Riddick et al. (1986)
Density	$d^{25/4}$, 0.898	Budavari et al. (1996)
Vapor Density (air = 1)	no data	
Koc	2 (calculated)	Lyman et al. (1990)
Log Kow	-2.04	Hansch et al. (1995)
Vapor Pressure	12.0 mm Hg @ 25 °C	Boublik et al. (1984)
Reactivity	volatile w/ steam; absorbs CO_2 from air	Budavari et al. (1996)
Flammability	flammable	Aldrich (1997)
Flash Point	110 °F (43 °C), closed cup	Budavari et al. (1996)
Dissociation Constant	$pKa_1 = 9.92$; $pKa_2 = 6.86$	Perrin (1972)
Molecular Diffusivity Constant	no data	
Air Diffusivity Constant	no data	
Henry's Law Constant	$1.73x10^{-9}$ atm m^3/mole @ 25 °C	Hine and Mookerjee (1975)
Fish Bioconcentration Factor	0.02 (calculated)	Lyman et al. (1990)
Odor Threshold	100% recognizable @11.2 ppm	Verschueren (1996)

II. ENVIRONMENTAL FATE

A Aquatic Fate

The dominant environmental fate process for ethylenediamine in surface water is expected to be biodegradation. A number of biological screening studies have determined that ethylenediamine biodegrades readily under aerobic conditions (Price et al., 1974; Takemoto et al., 1981; Pitter, 1976 ; Mills and Stack, 1955, as cited in HSDB, 1998). No data were available for the biodegradation of ethylenediamine under anaerobic conditions. An estimated Koc value of 2, determined from an experimental log Kow of -2.04 (Hansch et al., 1995) and a regression-derived equation (Lyman et al., 1990), indicates that ethylenediamine is not expected to adsorb to suspended solids and sediment in water. In general, organic ions are not expected to volatilize from water or adsorb to particulate matter in water to the degree that would be predicted for their neutral counterparts. Based on an estimated BCF of 0.02

(Lyman et al., 1990) calculated from the log Kow, a classification scheme (Franke et al., 1994) suggests the potential for bioconcentration in aquatic organisms is low. Ethylenediamine is not expected to volatilize from water surfaces (Lyman et al., 1990) based upon an experimental Henry's Law constant of 1.73×10^{-9} atm-m^3/mole (Hine and Mookerjee, 1975). However, volatilization of ethylenediamine will be pH dependent and attenuated if it is protonated; very little, about 1%, will be available for volatilization. Hydrolysis of ethylenediamine is not expected to occur due to the lack of hydrolyzable functional groups (Lyman et al., 1990).

B. Atmospheric Fate

According to a model of gas/particle partitioning of semivolatile organic compounds in the atmosphere (Bidleman, 1988), ethylenediamine, which has a vapor pressure of 12 mm Hg at 25 °C (Boublik et al, 1984), should exist solely as a gas in the ambient atmosphere. Gas-phase ethylenediamine is degraded in the atmosphere by reaction with photochemically-produced hydroxyl radicals; the half-life for this reaction in air is estimated to be 6 hours (Meylan and Howard, 1993). Due to its miscibility with water, ethylenediamine may also be removed physically from the atmosphere by wet deposition. Ethylenediamine is not expected to directly photolyze in the atmosphere due to the lack of absorption in the environmental UV spectrum (>290 nm) (Lyman et al., 1990).

C. Terrestrial Fate

The major environmental fate process for ethylenediamine in aerobic soils is expected to be biodegradation. A number of biological screening studies have determined that ethylenediamine biodegrades readily under aerobic conditions (Price et al., 1974; Takemoto et al., 1981; Pitter, 1976 ; Mills and Stack, 1955, as cited in HSDB, 1998). No data on the biodegradation of ethylenediamine under anaerobic conditions were located in the available literature. An estimated Koc value of 2 (Lyman et al., 1990), determined from an experimental log Kow of -2.04 (Hansch et al., 1995), indicates that ethylenediamine is expected to have very high mobility in soil (Swann et al., 1983). Volatilization of ethylenediamine from moist soil surfaces is not expected to be important (Lyman et al., 1990) given an experimental Henry's Law constant of 1.73×10^{-9} atm-m^3/mole (Hine and Mookerjee, 1975), although it may volatilize from dry soil surfaces based upon a vapor pressure of 12 mm Hg (Boublik et al., 1984). However, at environmental pH's of 5-7, ethylenediamine will most likely be a salt and volatilization will be attenuated.

D. Summary

The dominant removal mechanisms of ethylenediamine from the environment are expected to be biodegradation on the earth's surface and reaction with photochemically-produced hydroxyl radicals in the atmosphere. In both soil and water, biodegradation is expected to be rapid; a large number of biological screening studies have determined that ethylenediamine biodegrades readily under aerobic conditions. If released to air, a vapor pressure of 12 mm Hg indicates ethylenediamine should exist solely as a gas in the ambient atmosphere. Gas-phase ethylenediamine will be degraded in the atmosphere by reaction with photochemically-produced hydroxyl radicals; the half-life for this reaction in air is estimated to be 6 hours. Physical removal of gas-phase ethylenediamine from the atmosphere may also occur via wet deposition processes based on the miscibility of this compound with water. With a pKa_1 of 9.92, ethylenediamine and its conjugate acid will exist in environmental media in varying proportions that are pH dependent. If released to soil, ethylenediamine may display very high mobility based upon an estimated Koc of 2. If released to soil in high concentrations, such as those encountered in a spill, ethylenediamine may travel through soil and reach groundwater. Volatilization of ethylenediamine from water and moist soil surfaces is not expected to be an important fate process based upon a Henry's Law constant of 1.73×10^{-9} atm-m^3/mole, although its vapor pressure indicates that volatilization from dry soil surfaces may occur. However, at environmental pH's of 5-7, ethylenediamine will most likely be a salt and volatilization will be attenuated. In water, ethylenediamine is not expected to bioconcentrate in fish and aquatic organisms based on an estimated BCF of 0.02.

CHEMICAL SUMMARY FOR ETHYLENE GLYCOL

This summary is based on information retrieved from a systematic search limited to secondary sources. The only exception is summaries of studies from unpublished TSCA submissions that may have been included. These sources include online databases, unpublished EPA information, government publications, review documents, and standard reference materials. No attempt has been made to verify information in these databases and secondary sources.

I. CHEMICAL IDENTITY AND PHYSICAL/CHEMICAL PROPERTIES

The chemical identity and physical/chemical properties of ethylene glycol are summarized in Table 1.

TABLE 1. CHEMICAL IDENTITY AND CHEMICAL/PHYSICAL PROPERTIES OF ETHYLENE GLYCOL

Characteristic/Property	Data	Reference
CAS No.	107-21-1	Budavari et al. (1996)
Common Synonyms	1,2-ethanediol	Budavari et al. (1996)
Molecular Formula	$C_2H_6O_2$	Budavari et al. (1996)
Chemical Structure	$HOCH_2CH_2OH$	Budavari et al. (1996)
Physical State	slightly viscous liquid	Budavari et al. (1996)
Molecular Weight	62.07	Budavari et al. (1996)
Melting Point	-13 °C	Budavari et al. (1996)
Boiling Point	197.6 °C	Budavari et al. (1996)
Water Solubility	miscible (1,000 g/l)	Riddick et al (1986)
Density	1.11 g/cm^3	Budavari et al. (1996)
Vapor Density (air = 1)	2.1	Verschueren (1996)
Koc	4 (estimated)	SRC (1998)
Log Kow	-1.36	Hansch et al. (1995), as cited in HSDB (1998)
Vapor Pressure	0.092 mm Hg	Daubert and Danner (1989)
Reactivity	no data	no data
Flammability	combustible	Lewis (1993)
Flash Point	240 °F (115 °C)	Budavari et al. (1996)
Dissociation Constant	15.1	Howard and Meylan (1997)
Molecular Diffusivity Constant	no data	
Air Diffusivity Constant	no data	
Henry's Law Constant	6.0×10^{-8} atm m^3/mol	Howard and Meylan (1997)
Fish Bioconcentration Constant	10	HSDB (1998)
Odor Threshold	25 ppm	ECDIN (1998)

II. ENVIRONMENTAL FATE

A. Aquatic Fate

The dominant environmental fate process for ethylene glycol in water is expected to be biodegradation. A large number of biological screening studies have determined that ethylene glycol biodegrades readily under both aerobic and anaerobic conditions (Bridie et al. 1979; Pitter 1976; and Price et al. 1974, as cited in HSDB, 1998). Aerobic degradation is essentially complete in <1-4 days, although 100% theoretical biological oxygen demand may not be realized for several weeks (Bridie et al., 1979; Pitter 1976; and Price et al., 1974, as cited in HSDB, 1998). Ethylene glycol is not expected to adsorb to suspended solids and sediments in water based upon an estimated Koc of 4 (Swann et al., 1983, as cited in HSDB, 1998), determined from a log Kow of -1.36 (Hansch et al., 1995, as cited in

HSDB, 1998) and a regression-derived equation (Lyman et al., 1990, as cited in HSDB, 1998). Volatilization from the water column to the atmosphere is not expected to occur (Lyman et al., 1990, as cited in HSDB, 1998) based on a Henry's Law constant of 6.0×10^{-8} atm-m^3/mole (Butler and Ramchandani 1935, as cited in Howard and Meylan 1997) . Ethylene glycol is expected to be stable to hydrolysis in the pH range of 5-9 typically encountered in the environment (Lyman et al., 1990, as cited in HSDB, 1998). According to a classification scheme (Franke et al., 1994), a BCF of 10 in golden ide fish (Freitag et al., 1985, as cited in HSDB, 1998) suggests that the potential for bioconcentration in aquatic organisms is low.

B. Atmospheric Fate

According to a model of gas/particle partitioning of semivolatile organic compounds in the atmosphere (Bidleman 1989, as cited in HSDB, 1998), ethylene glycol, which has a vapor pressure of 0.092 mm Hg at 25°C (Daubert and Danner 1989), should exist solely as a gas in the ambient atmosphere. Nonetheless, ethylene glycol has been detected adsorbed onto atmospheric particulate material (Abdelghani et al., 1990, as cited in HSDB, 1998); the small amount of ethylene glycol deposited onto particulate material may be physically removed by wet and dry deposition. The predominant removal process of ethylene glycol from the atmosphere is reaction with photochemically-produced hydroxyl radicals; the half-life for this reaction in air is estimated to be 50 hours (Atkinson 1989, as cited in HSDB, 1998). Ethylene glycol may undergo some degradation by direct photolysis; 12.1% of applied ethylene glycol was degraded after 17 hours following irradiation by light > 290 nm (Freitag et al., 1985, as cited in HSDB, 1998).

C. Terrestrial Fate

The major environmental fate process for ethylene glycol in soil is expected to be biodegradation. A large number of biological screening studies have determined that ethylene glycol biodegrades readily under both aerobic and anaerobic conditions; complete biodegradation was shown in one soil within 2 days and 97% biodegradation in 12 days was reported for a second soil (McGahey and Bower 1992, as cited in HSDB, 1998). Based on a classification scheme (Swann et al., 1983, as cited in HSDB, 1998), an estimated Koc of 4, determined from a log Kow of -1.36 (Hansch et al., 1995, as cited in HSDB, 1998) and a regression-derived equation (Lyman, 1990 et al., as cited in HSDB, 1998), indicates that ethylene glycol is expected to have very high mobility in soil. Percent adsorption to 4 soils (2 clay and 2 sandy clay soils) ranged from 0-0.5% (Abdelghani et al 1990, as cited in HSDB, 1998). Volatilization of ethylene glycol from moist soil surfaces is not expected to be important (Lyman et al., 1990, as cited in HSDB, 1998) given a Henry's Law constant of 6.0×10^{-8} atm-m^3/mole (Butler and Ramchandani 1935, as cited in Howard and Meylan 1997). Ethylene glycol may volatilize from dry soil given its vapor pressure of 0.092 mm Hg (Daubert and Danner, 1989); this may be attenuated by hydrogen bonding to soil materials (SRC, 1998).

D. Summary

If released to air, a vapor pressure of 0.092 mm Hg at 25 °C indicates that ethylene glycol should exist solely as a gas in the ambient atmosphere; however, experimental results show that at least some ethylene glycol is associated with atmospheric particulates. Gas-phase ethylene glycol will be degraded in the atmosphere by reaction with photochemically-produced hydroxyl radicals; the half-life for this reaction in air is estimated to be 50 hours. Adsorption studies indicate that ethylene glycol is not expected to adsorb to suspended solids and sediments in water. A BCF of 10 in golden ide fish suggests the potential for bioconcentration in aquatic organisms is low. If released to soil, ethylene glycol is expected to have very high mobility based upon an estimated Koc of 4, and, therefore, it has the potential to leach to groundwater. Volatilization from water and from moist soil surfaces is not expected to be an important fate process based upon a Henry's Law constant of 6.0×10^{-8} atm-m^3/mole. Volatilization from dry soil surfaces may occur based upon the vapor pressure of this compound, although this may be attenuated by hydrogen bonding to soil materials. Biodegradation is expected to be rapid and may be the dominant fate process in both soil and water under non-spill conditions; a large number of biological screening studies have determined that ethylene glycol biodegrades readily under both aerobic and anaerobic conditions.

CHEMICAL SUMMARY FOR ETHYLENE GLYCOL MONOBUTYL ETHER

This summary is based on information retrieved from a systematic search limited to secondary sources. The only exception is summaries of studies from unpublished TSCA submissions that may have been included. These sources include online databases, unpublished EPA information, government publications, review documents, and standard reference materials. No attempt has been made to verify information in these databases and secondary sources. The search identified sources of information for ethylene glycol monobutyl ether.

I. CHEMICAL IDENTITY AND PHYSICAL/CHEMICAL PROPERTIES

The chemical identity and physical/chemical properties of ethylene glycol monobutyl ether are summarized in Table 1.

TABLE 1. CHEMICAL IDENTITY AND CHEMICAL/PHYSICAL PROPERTIES OF ETHYLENE GLYCOL MONOBUTYL ETHER

Characteristic/Property	Data	Reference
CAS No.	111-76-2	Howard and Neal (1992)
Common Synonyms	BUCS, butoxyethanol, Dowanol EB	Howard and Neal (1992)
Molecular Formula	C6H14O2	Howard and Neal (1992)
Chemical Structure	CH3(CH2)3OCH2CH2OH	Howard and Neal (1992)
Physical State	Clear, colorless liquid	HSDB (1998)
Molecular Weight	118.18	Howard and Neal (1992)
Melting Point	-70°C	Budavari et al. (1996)
Boiling Point	171°C, 743 mm Hg	Budavari et al. (1996)
Water Solubility	>1000 g/L, 25°C	HSDB (1998)
Density	$d^{20/20}$, 0.9012	HSDB (1998)
Vapor Density (air = 1)	4.07	HSDB (1998)
Koc	1	EPI
Log Kow	0.83	Howard and Meylan (1997)
Vapor Pressure	0.88 mm Hg @ 25°C	Howard and Meylan (1997)
Reactivity	Inert	Sax and Lewis (1987)
Flammability	Combustible	Sax and Lewis (1987)
Flash Point	60°C	HSDB (1998)
Dissociation Constant	No data	
Molecular Diffusivity Constant	No data	
Air Diffusivity Constant	No data	
Henry's Law Constant	2.08×10^{-8} atm m^3/mol	Howard and Meylan (1997)
Fish Bioconcentration Constant	No data	
Odor Threshold	No data	

CHEMICAL SUMMARY FOR FLUOROBORIC ACID (fluoride)

This chemical was identified by one or more suppliers as a bath ingredient for the electroless copper and tin-palladium processes. This summary is based on information retrieved from a systematic search limited to secondary sources. The only exception is summaries of studies from unpublished TSCA submissions that may have been included. These sources include online databases, unpublished EPA information, government publications, review documents, and standard reference materials. No attempt has been made to verify information in these databases and secondary sources. Very little information on the environmental fate and toxicity of fluoroboric acid or fluoroborates was found in the available secondary sources. Supplemental information is provided for fluoride which may be a degradation product and for sodium bifluoride.

I. CHEMICAL IDENTITY AND PHYSICAL/CHEMICAL PROPERTIES

The chemical identity and physical/chemical properties of fluoroboric acid are summarized in Table 1.

TABLE 1. CHEMICAL IDENTITY AND CHEMICAL/PHYSICAL PROPERTIES OF FLUOROBORIC ACID

Characteristic/Property	**Data**	**Reference**
CAS No.	16872-11-0	HSDB (1995)
Common Synonyms	hydrogen tetrafluoroborate fluoboric acid hydrofluoroboric acid	HSDB (1995)
Molecular Formula	HBF_4	HSDB (1995)
Chemical Structure	$B\text{-}F_4\text{-}H$	Fisher Scientific (1993)
Physical State	colorless liquid	HSDB (1995)
Molecular Weight	87.82	HSDB (1995)
Melting Point	-90°C	Fisher Scientific (1993)
Boiling Point	130°C (decomposes)	HSDB (1995)
Water Solubility	miscible; sol. in hot water	HSDB (1995)
Density	~1.84 g/mL	HSDB (1995)
K_{OC}	NA	
Log K_{OW}	NA	
Vapor Pressure	5.1 mm Hg at 20°C	Fisher Scientific (1993)
Vapor Density	3.0	Fisher Scientific (1993)
Reactivity	strong acid; corrosive	HSDB (1995)
Flammability	NA	
Flash Point	NA	
Dissociation Constant (-pK)	-4.9	HSDB (1995)
Henry's Law Constant	NA	
Molecular Diffusivity Coefficient	NA	
Air Diffusivity Coefficient	NA	
Fish Bioconcentration Factor	NA	
Odor Threshold	NA	
Conversion Factors	Na	

The chemical identity and physical/chemical properties of sodium tetrafluoroborate are summarized in Table 2.

TABLE 2. CHEMICAL IDENTITY AND CHEMICAL/PHYSICAL PROPERTIES OF SODIUM TETRAFLUOROBORATE

Characteristic/Property	**Data**	**Reference**
CAS No.	013755-29-8	Lockheed Martin (1994)
Common Synonyms	sodium fluoroborate STB sodium borfluoride sodium boron tetrafluoride	Lockheed Martin (1994)
Molecular Formula	$NaNF_4$	
Chemical Structure	$Na\text{-}F_4\text{-}B$	
Physical State	white crystalline powder	Sigma-Aldrich (1992)
Molecular Weight	109.82	Budavari et al. (1989)
Melting Point	384°C	Budavari et al. (1989)
Boiling Point		
Water Solubility	108 g/100 mL at 26°C 210 g/100 mL at 100 °C	Budavari et al. (1989)
Density	2.470	Sigma-Aldrich (1992)
K_{OC}	NA	
Log K_{OW}	NA	
Vapor Pressure	NA	
Reactivity	reacts with strong oxidizing agents; sensitive to moisture	Sigma-Aldrich (1992)
Flammability	noncombustible	Lockheed Martin (1994)
Flash Point	NA	
Dissociation Constant (-pK)		
Henry's Law Constant		
Molecular Diffusivity Coefficient	NA	
Air Diffusivity Coefficient	NA	
Fish Bioconcentration Factor	NA	
Odor Threshold	NA	
Conversion Factors	NA	

The chemical identity and physical/chemical properties of sodium fluoride are summarized in Table 3.

TABLE 3. CHEMICAL IDENTITY AND CHEMICAL/PHYSICAL PROPERTIES OF SODIUM FLUORIDE

Characteristic/Property	**Data**	**Reference**
CAS No.	7681-49-4	
Common Synonyms	sodium hydrofluoride sodium monfluoride floridine	
Molecular Formula	NaF	
Chemical Structure	Na-F	
Physical State	crystals	Budavari et al. (1989)
Molecular Weight	42.00	Budavari et al. (1989)
Melting Point	993 °C	Budavari et al. (1989)
Boiling Point	1704 °C	Budavari et al. (1989)
Water Solubility	4.0 g/100 mL at 15 °C 4.3 g/100 mL at 25 °C	Budavari et al. (1989)
Density	2.78	Budavari et al. (1989)
K_{OC}	NA	
Log K_{OW}	NA	
Vapor Pressure	1 mm Hg at 1077 °C	Keith and Walters (1985)
Reactivity	stable under normal conditions	Keith and Walters (1985)
Flammability	nonflammable	Keith and Walters (1985)
Flash Point		
Dissociation Constant (-pK)		
Henry's Law Constant		
Molecular Diffusivity Coefficient		
Air Diffusivity Coefficient		
Fish Bioconcentration Factor		
Odor Threshold		
Conversion Factors		

The chemical identity and physical/chemical properties of sodium bifluoride are summarized in Table 4.

TABLE 4. CHEMICAL IDENTITY AND CHEMICAL/PHYSICAL PROPERTIES OF SODIUM BIFLUORIDE

Characteristic/Property	Data	Reference
CAS No.	1333-83-1	HSDB (1995)
Common Synonyms	sodium hydrogen difluoride sodium hydrogen fluoride sodium acid fluoride	HSDB (1995)
Molecular Formula	$NaHF_2$	Lewis (1993)
Chemical Structure	F_2-H-Na	HSDB (1995)
Physical State	white, crystalline powder	Budavari et al. (1989)
Molecular Weight	62.01	Budavari et al. (1989)
Melting Point	decomposes on heating	Lewis (1993)
Boiling Point	NA	
Water Solubility	soluble in cold and hot water	Lide (1991)
Density	2.08	Lewis (1993)
K_{OC}	NA	
Log K_{OW}	NA	
Vapor Pressure	NA	
Vapor Density	NA	
Reactivity	aqueous solution corrodes glass	Budavari et al. (1989)
Flammability	slightly combustible	Lockheed Martin (1990)
Flash Point	NA	
Dissociation Constant (-pK)	NA	
Henry's Law Constant	NA	
Molecular Diffusivity Coefficient	NA	
Air Diffusivity Coefficient	NA	
Fish Bioconcentration Factor	NA	
Odor Threshold	NA	
Conversion Factors	NA	

II. ENVIRONMENTAL FATE

A. Environmental Release

Fluoroboric acid may be released into the environment in emissions and effluents from facilities involved in its manufacture or use. It is used primarily in industrial metal plating solutions (60%), in the synthesis of diazo salts (20%), and in metal finishing (20%) (HSDB 1995). It is used in bright dipping solutions for Sn-Pb alloys in printed circuits and other electrical components (HSDB 1995).

B. Transport

No information was found in the available secondary sources on the environmental transport of fluoroboric acid. Its miscibility with water indicates that transport in aqueous systems is very likely.

C. Transformation/Persistence

FLUOROBORIC ACID:

1. Air — No information was found in the available secondary sources on the transformation and persistence of fluoroboric acid or fluoroborates in the atmosphere.
2. Soil — No information was found in the available secondary sources on the transformation and persistence of fluoroboric acid or fluoroborates in soil. Fluoroboric acid may undergo limited hydrolysis in moist soils (Budavari et al. 1989).
3. Water — Fluoroboric acid undergoes limited hydrolysis in water to form hydroxyfluoroborate ions, the major product is BF_3OH^- (Budavari et al. 1989).
4. Biota — No information was found in the available secondary sources on the biotransformation or bioconcentration of fluoroboric acid or fluoroborates. Rapid urinary excretion of tetrafluoroborates suggests that these salts would not bioaccumulate.

FLUORIDES:

1. Air — Gaseous inorganic fluorides undergo hydrolysis in the atmosphere; however, particulate forms are relatively stable and do not hydrolyze readily (ATSDR 1993).
2. Soil — Fluorides tend to persist in soils as fluorosilicate complexes under acidic conditions and as calcium fluoride under alkaline conditions. Sandy acidic soils favor the formation of soluble forms (ATSDR 1993).
3. Water — In dilute solutions and at neutral pH, fluoride is generally present as dissolved fluoride ion. High calcium carbonate levels may lead to precipitation as calcium fluoride (ATSDR 1993).
4. Biota — Fluorides have been shown to accumulate in some aquatic organisms (ATSDR 1993). Soluble forms of fluoride are taken up by terrestrial plants and converted into fluoro-organic compounds (ATSDR 1993).

CHEMICAL SUMMARY FOR HYDROCHLORIC ACID

This summary is based on information retrieved from a systematic search limited to secondary sources. The only exception is summaries of studies from unpublished TSCA submissions that may have been included. These sources include online databases, unpublished EPA information, government publications, review documents, and standard reference materials. No attempt has been made to verify information in these databases and secondary sources.

I. CHEMICAL IDENTITY AND PHYSICAL/CHEMICAL PROPERTIES

The chemical identity and physical/chemical properties of hydrochloric acid are summarized in Table 1.

TABLE 1. CHEMICAL IDENTITY AND CHEMICAL/PHYSICAL PROPERTIES OF HYDROCHLORIC ACID

Characteristic/Property	**Data**	**Reference**
CAS No.	7647-01-0	Budavari et al. (1996)
Common Synonyms	muriatic acid	Budavari et al. (1996)
Molecular Formula	HCl	Budavari et al. (1996)
Chemical Structure	HCl	Budavari et al. (1996)
Physical State	fuming liquid	Lewis (1993)
Molecular Weight	36.46	Lide (1995)
Melting Point	-25.4 °C (39.17% soln)	Budavari et al. (1996)
Boiling Point	108.58 °C at 760 mm Hg	Budavari et al. (1996)
Water Solubility	479.1 g/l (40% soln)	Weast et al. (1985)
Density	1.20 g/cm^3 (39.11% soln)	Budavari et al. (1996)
Vapor Density (air = 1)	1.639 g/l	Austin and Glowacki (1989)
Koc	expected to be < 50	SRC (1998)
Log Kow	expected to be < 1	SRC (1998)
Vapor Pressure	no data	
Reactivity	toxic, corrosive fumes w/H_2O or steam	Sax (1984)
Flammability	non-combustible	Lewis (1993)
Flash Point	no data	
Dissociation Constant	~ -3	Bodek et al. (1988)
Molecular Diffusivity Constant	no data	
Air Diffusivity Constant	no data	
Henry's Law Constant	no data	
Fish Bioconcentration Constant	no data	
Odor Threshold	no data	

II. ENVIRONMENTAL FATE

A. Aquatic Fate

If hydrochloric acid is released into the water column at low concentrations, a pK_a of ~ -3.00 (Bodek et al., 1988) indicates it will dissociate completely into chloride (Cl^-) and hydrogen (H^+) ions. The amount of gaseous hydrochloric acid dissolved in water is affected by the pH of the solution. A higher pH allows more aqueous hydrochloric acid to dissociate, thereby increasing the solubility of hydrochloric acid gas (Bodek et al., 1988). As a result, dilute solutions of hydrochloric acid are not expected to volatilize from water surfaces or to bioconcentrate in aquatic organisms. Chloride ions generally do not react with many species in water and are harmless at relatively low concentrations (Manahan, 1991). Hydrochloric acid will protonate amines and other electron pair donators present in natural waters, forming salts; this will be dependent upon pH. Large releases of the concentrated acid into water, such as may result from a spill, will result in a lowering of the pH (Bodek et al., 1988).

B. Atmospheric Fate

If hydrochloric acid is released to the atmosphere, its vapor pressure indicates it will exist as a vapor in the ambient atmosphere. Wet deposition of hydrochloric acid in rain, snow, or fog is expected to be the dominant fate process in the atmosphere based upon its high water solubility (Arimoto, 1989).

C. Terrestrial Fate

If hydrochloric acid is released to soil, it will dissociate into chloride and hydrogen ions in moist soils. Hydrochloric acid will protonate amines and other electron pair donators present in soils, forming salts; this will be dependent upon pH. The chloride ion is extremely mobile in soils and almost no soil retention occurs (Bodek et al., 1988). Chloride is typically the predominant ion in saline soils and the second most abundant anion in sodic soils; thus, it is readily available for the formation of metal complexes in soil (Bodek et al., 1988; SRC, 1998).

D. Summary

If released into water, hydrochloric acid will dissociate into chloride (Cl^-) and hydrogen (H^+) ions. Therefore, hydrochloric acid is not expected to adsorb to suspended solids or sediment in the water column, bioconcentrate in aquatic organisms, nor volatilize from water surfaces. Chloride ions generally do not react with many species in water and are harmless at relatively low concentrations. Hydrochloric acid will protonate amines and other electron pair donators present in natural waters and soils, forming salts; this will be dependent upon pH. If released to soil, hydrochloric acid is expected to dissociate into its component ions in moist soils. Because the chloride ion is extremely mobile in soils, almost no soil retention occurs. Chloride is typically the predominant ion in saline soils and the second most abundant anion in sodic soils; thus, it is readily available for the formation of metal complexes in soil. Volatilization of hydrochloric acid from soil surfaces is not expected to occur. If released to the atmosphere, hydrochloric acid is expected to exist as a gas. Hydrochloric acid is expected to be physically removed from the atmosphere by wet deposition based upon its high water solubility.

CHEMICAL SUMMARY FOR HYDROGEN PEROXIDE

This chemical was identified by one or more suppliers as a bath ingredient for the electroless copper, non-formaldehyde electroless copper, and tin-palladium processes. This summary is based on information retrieved from a systematic search limited to secondary sources (see Attachment C-1). These sources include online databases, unpublished EPA information, government publications, review documents, and standard reference materials. No attempt has been made to verify information in these databases and secondary sources.

I. CHEMICAL IDENTITY AND PHYSICAL/CHEMICAL PROPERTIES

The chemical identity and physical/chemical properties of hydrogen peroxide are summarized in Table 1.

TABLE 1. CHEMICAL IDENTITY AND CHEMICAL/PHYSICAL PROPERTIES OF HYDROGEN PEROXIDE

Characteristic/Property	Data	Reference
CAS No.	7722-84-1	
Common Synonyms	hydrogen dioxide; hydroperoxide; albone; hioxyl	Budavari et al. 1989
Molecular Formula	H_2O_2	Budavari et al. 1989
Chemical Structure	H_2O_2	IARC 1985
Physical State	colorless, unstable liquid, bitter taste	Budavari et al. 1989
Molecular Weight	34.02	Budavari et al. 1989
Melting Point	–0.43 °C	Budavari et al. 1989
Boiling Point	152 °C	Budavari et al. 1989
Water Solubility	miscible	Budavari et al. 1989
Density	1.463 @ 0 °C	Budavari et al. 1989
Vapor Density (air = 1)	no data	
K_{OC}	no data	
Log K_{OW}	no data	
Vapor Pressure	1.97 mm Hg @ 25° C (measured)	CHEMFATE 1995
Reactivity	strong oxidizer; may decompose violently if traces of impurities are present molecular additions, substitutions, oxidations, reduction; can form free radicals	Budavari et al. 1989 IARC 1985
Flammability	not flammable, but can cause spontaneous combustion of flammable materials	HSDB 1995
Flash Point	no data	
Dissociation Constant	no data	
Henry's Law Constant	no data	
Molecular Diffusivity Coefficient	no data	
Air Diffusivity Coefficient	no data	
Fish Bioconcentration Factor	no data	
Odor Threshold	odorless	Budavari et al. 1989
Conversion Factors	1 ppm = 1.39 mg/m^3 1 mg/m^3 = 0.72 ppm 30% soln 1.1 kg/L anhydrous 1.46 kg/L	IARC 1985 Budavari et al. 1989

II. ENVIRONMENTAL FATE

A. Environmental Release

No information was found in the secondary sources searched regarding the environmental release of hydrogen peroxide. Solutions of hydrogen peroxide gradually deteriorate (Budavari et al., 1989). Hydrogen peroxide is a naturally occurring substance. Gaseous hydrogen peroxide is recognized to be a key component and product of the earth's lower atmospheric photochemical reactions, in both clean and polluted atmospheres. Atmospheric hydrogen peroxide is also believed to be generated by gas-phase photochemical reactions in the remote troposphere (IARC, 1985)

B. Transport

No information was found in the secondary sources searched regarding the transport of hydrogen peroxide.

C. Transformation/Persistence

1. Air — Hydrogen peroxide may be removed from the atmosphere by photolysis giving rise to hydroxyl radicals, by reaction with hydroxyl radicals, or by heterogenous loss processes such as rain-out (IARC, 1985).
2. Soil — No information was found in the secondary sources searched regarding the transformation or persistence of hydrogen peroxide in soil, however, solutions of hydrogen peroxide gradually deteriorate (Budavari et al., 1989).
3. Water — Hydrogen peroxide is a naturally occurring substance. Surface water concentrations of hydrogen peroxide have been found to vary between 51-231 mg/L, increasing both with exposure to sunlight and the presence of dissolved organic matter (IARC, 1985).
4. Biota — Hydrogen peroxide is a naturally occurring substance. Endogenous hydrogen peroxide has been found in plant tissues at the following levels (mg/kg frozen weight): potato tubers, 7.6; green tomatoes, 3.5; red tomatoes, 3.5; and castor beans in water, 4.7 (IARC, 1985).

CHEMICAL SUMMARY FOR LEAD

This summary is based on information retrieved from a systematic search limited to secondary sources. The only exception is summaries of studies from unpublished TSCA submissions that may have been included. These sources include online databases, unpublished EPA information, government publications, review documents, and standard reference materials. No attempt has been made to verify information in these databases and secondary sources. The search identified sources of information for Lead.

I. CHEMICAL IDENTITY AND PHYSICAL/CHEMICAL PROPERTIES

The chemical identity and physical/chemical properties of Lead are summarized in Table 1.

TABLE 1. CHEMICAL IDENTITY AND CHEMICAL/PHYSICAL PROPERTIES OF LEAD

Characteristic/Property	**Data**	**Reference**
CAS No.	7439-92-1	Howard and Neal (1992)
Common Synonyms		
Molecular Formula	Pb	Howard and Neal (1992)
Chemical Structure	N/A	
Physical State	Metal	Weast (1983)
Molecular Weight	207.2	Weast (1983)
Melting Point	327.4°C	Weast (1983)
Boiling Point	1740°C	Weast (1983)
Water Solubility	Insoluble	Weast (1983)
Density	10.65	Budavari et al. (1996)
Vapor Density (air = 1)	no data	
Koc	no data	
Log Kow	no data	
Vapor Pressure	1.77 mm Hg @ 1000°C	Budavari et al. (1996)
Reactivity	Flammable solid	
Flammability	no data	
Flash Point	no data	
Dissociation Constant	no data	
Molecular Diffusivity Constant	no data	
Air Diffusivity Constant	no data	
Henry's Law Constant	no data	
Fish Bioconcentration Constant	no data	
Odor Threshold	no data	

CHEMICAL SUMMARY FOR MALEIC ACID

This summary is based on information retrieved from a systematic search limited to secondary sources. The only exception is summaries of studies from unpublished TSCA submissions that may have been included. These sources include online databases, unpublished EPA information, government publications, review documents, and standard reference materials. No attempt has been made to verify information in these databases and secondary sources.

I. CHEMICAL IDENTITY AND PHYSICAL/CHEMICAL PROPERTIES

The chemical identity and physical/chemical properties of maleic acid are summarized in Table 1.

TABLE 1. CHEMICAL IDENTITY AND CHEMICAL/PHYSICAL PROPERTIES OF MALEIC ACID

Characteristic/Property	Data	Reference
CAS No.	110-16-7	Lide (1995)
Common Synonyms	(Z)-butenedioic acid; toxilic acid	Budavari et al. (1996)
Common Synonyms	cis-1,2-ethylenedicarboxylic acid	Budavari et al. (1996)
Common Synonyms	maleinic acid	Lewis (1993)
Molecular Formula	$C_4H_4O_4$	Budavari et al. (1996)
Chemical Structure	HOOCCH=CHCOOH	Aldrich (1996)
Physical State	white crystals	Budavari et al. (1996)
Molecular Weight	116.07	Budavari et al. (1996)
Melting Point	130.5°C	Lide (1995)
Boiling Point	no data	
Water Solubility	441 g/l at 25 °C	PHYSPROP (1998)
Density	1.59 g/cm^3 at 20 °C	Lide (1995)
Vapor Density (air = 1)	no data	
Koc	16 (estimated)	Lyman et al. (1990)
Log Kow	-0.34	Hansch et al. (1995)
Vapor Pressure	3.06×10^{-5} mm Hg at 25 °C	Daubert and Danner (1991)
Reactivity	stable	Weiss (1986)
Flammability	combustible	Lewis (1993)
Flash Point	not pertinent	Weiss (1986)
Dissociation Constant	$pK_1 = 1.83$; $pK_2 = 6.07$	Howard (1989)
Molecular Diffusivity Constant	no data	
Air Diffusivity Constant	no data	
Henry's Law Constant	no data; estimated to be < 1×10^{-8} atm m^3/mol	Estimated
Fish Bioconcentration Constant	10-11	HSDB (1998)
Odor Threshold	no data	

II. ENVIRONMENTAL FATE

A. Aquatic Fate

If released into water, maleic acid is not expected to adsorb to suspended solids or sediments in water based upon an estimated Koc of 16 (Swann et al., 1983), determined from a log Kow of -0.34 (Hansch et al., 1995) and a regression-derived equation (Lyman et al., 1990). Volatilization from the water column to the atmosphere is not expected to occur (Lyman et al., 1990) based on an estimated Henry's Law constant of <10^{-8} atm-m^3/mole . Maleic acid is expected to be stable to hydrolysis in the pH range of 5-9 typically encountered in the environment (Lyman et al., 1990). According to a classification scheme (Franke et al., 1994), a BCF of 10 in golden ide fish (Freitag, 1985, as cited in HSDB, 1998) suggests that the potential for bioconcentration in aquatic organisms is low. Maleic acid was determined to be readily degraded in biodegradation screening tests; however, no biodegradation studies were available in environmental waters (Howard, 1989).

B. Atmospheric Fate

According to a model of gas/particle partitioning of semivolatile organic compounds in the atmosphere (Bidleman, 1988), maleic acid, which has a vapor pressure of 3.06×10^{-5} mm Hg at 25 °C (Daubert and Danner, 1991), is expected to exist as both a particulate and vapor in the ambient atmosphere. Because maleic acid has pKa's of 1.83 and 6.07 (Howard, 1989), it is expected to exist in the dissociated form in the environment and form salts with cations (HSDB, 1998). Removal of maleic acid from the atmosphere by reaction with photochemically-produced hydroxyl radicals results in an estimated half-life of 2 days (Meylan and Howard, 1993). The reaction of maleic acid with ozone in the atmosphere results in a gas-phase half-life ranging from 7-13 days (Meylan and Howard, 1993). Maleic acid may undergo some degradation by direct photolysis; 17% of applied maleic acid was degraded after 17 hours following irradiation by light > 290 nm (Freitag et al., 1985, cited in HSDB, 1998). Wet deposition of maleic in rain, snow, or fog is expected to be an important transport process in the atmosphere based upon its high water solubility (Arimoto, 1989).

C. Terrestrial Fate

Based on a classification scheme (Swann et al., 1983), an estimated Koc of 16, determined from a log Kow of -0.34 (Hansch et al., 1995) and a regression-derived equation (Lyman et al., 1990), indicates that maleic acid is expected to have very high mobility in soil. Volatilization of maleic acid from moist soil surfaces is not expected to be important (Lyman et al., 1990) given an estimated Henry's Law constant of $<10^{-8}$ atm-m^3/mole. In addition, maleic acid is not expected to volatilize from dry soil given its vapor pressure of 3.06×10^{-5} mm Hg (Daubert and Danner, 1991). While maleic acid is readily biodegradable in screening studies, no degradation data were available for soil systems (Howard, 1989).

D. Summary

If released to air, a vapor pressure of 3.06×10^{-5} mm Hg at 25 °C indicates that maleic acid should exist as both a gas and particulate in the ambient atmosphere. Gas-phase maleic acid will be degraded in the atmosphere by reaction with photochemically-produced hydroxyl radicals; the half-life for this reaction in air is estimated to be 2 hours. The reaction of maleic acid with ozone in the atmosphere results in a gas-phase half-life ranging from 7-13 days. Wet deposition of maleic acid from the atmosphere is expected to be an important transport process. Screening studies suggest that direct photolysis if maleic acid may occur. A BCF of 10 in golden ide fish suggests the potential for bioconcentration in aquatic organisms is low. If released to soil, maleic acid is expected to have very high mobility based upon an estimated Koc of 16, and, therefore, it has the potential to leach to groundwater. Volatilization from water and from moist soil surfaces is not expected to be an important fate process based upon an estimated Henry's Law constant of $<10^{-8}$ atm-m^3/mole. Volatilization from dry soil surfaces is not expected to occur based upon the vapor pressure of this compound. Maleic acid was determined to be readily biodegraded in screening studies, although no data were available for biodegradation in water or soil.

CHEMICAL SUMMARY FOR MALIC ACID

This summary is based on information retrieved from a systematic search limited to secondary sources. The only exception is summaries of studies from unpublished TSCA submissions that may have been included. These sources include online databases, unpublished EPA information, government publications, review documents, and standard reference materials. No attempt has been made to verify information in these databases and secondary sources.

I. CHEMICAL IDENTITY AND PHYSICAL/CHEMICAL PROPERTIES

The chemical identity and physical/chemical properties of malic acid are summarized in Table 1.

TABLE 1. CHEMICAL IDENTITY AND CHEMICAL/PHYSICAL PROPERTIES OF MALIC ACID

Characteristic/Property	Data	Reference
CAS No.	6915-15-7	Lewis (1993)
Common Synonyms	hydroxysuccinic acid; apple acid	Lewis (1993)
Molecular Formula	$C_4H_6O_5$	Budavari et al. (1996)
Chemical Structure	$COOHCH_2CH(OH)COOH$	Lewis (1993)
Physical State	colorless crystals	Lewis (1993)
Molecular Weight	134.09	Budavari et al. (1996)
Melting Point	100 °C	Budavari et al. (1996)
Boiling Point	140 °C, decomposes	Budavari et al. (1996)
Water Solubility	592 g/l at 25 °C	PHYSPROP (1998)
Density	1.6 g/cm^3	Lewis (1993)
Vapor Density (air = 1)	no data	
Koc	5 (estimated)	Lyman et al. (1990)
Log Kow	-1.26	Hansch et al. (1995)
Vapor Pressure	3.28×10^{-8} mm Hg at 25 °C	Yaws (1994)
Reactivity	no data	
Flammability	combustible	Lewis (1993)
Flash Point	no data	
Dissociation Constant	3.40	PHYSPROP (1998)
Molecular Diffusivity Constant	no data	
Air Diffusivity Constant	no data	
Henry's Law Constant	no data; expected to be $< 10^{-8}$ atm m^3/mol	Estimated
Fish Bioconcentration Constant	no data; expected to be <1	Estimated
Odor Threshold	no data	

II. ENVIRONMENTAL FATE

A. Aquatic Fate

If released into aquatic waters, malic acid is not expected to adsorb to suspended solids and sediments in water based upon an estimated Koc of 5 (Swann et al., 1983), determined from a log Kow of -1.26 (Hansch et al., 1995) and a regression-derived equation (Lyman et al., 1990). Volatilization from the water column to the atmosphere is not expected to occur (Lyman et al., 1990) based on an estimated Henry's Law constant of $<10^{-8}$ atm-m^3/mole . Malic acid is expected to be stable to hydrolysis in the pH range of 5-9 typically encountered in the environment (Lyman et al., 1990). According to a classification scheme (Franke et al., 1994), an estimated BCF of <1 suggests that the potential for bioconcentration in aquatic organisms is low and not an important fate process. Results from a number of biological screening tests have shown that malic acid biodegrades relatively fast (Fischer et al., 1974; Malaney and Gerhold, 1969; Heukelekian and Rand, 1955; as cited in HSDB, 1998).

B. Atmospheric Fate

According to a model of gas/particle partitioning of semivolatile organic compounds in the atmosphere (Bidleman, 1988), malic acid, which has a vapor pressure of 3.28×10^{-8} mm Hg at 25 °C (Yaws, 1994), should exist almost entirely as a particulate in the ambient atmosphere. Removal of malic acid from the atmosphere by reaction with photochemically-produced hydroxyl radicals results in an estimated half-life of 2 days (Meylan and Howard, 1993). Wet deposition of malic acid in rain, snow, or fog is expected to be the dominant transport process in the atmosphere based upon its high water solubility (Arimoto, 1989). Because carboxylic acids are generally resistant to hydrolysis, malic acid is not expected to hydrolyze in environmental media (Lyman et al., 1990).

C. Terrestrial Fate

Based on a classification scheme (Swann et al., 1983), an estimated Koc of 5, determined from a log Kow of -1.26 (Hansch et al., 1995) and a regression-derived equation (Lyman et al., 1990), indicates that malic acid is expected to have very high mobility in soil and may leach to groundwater. Volatilization of malic acid from moist soil surfaces is not expected to be important (Lyman et al., 1990) given an estimated Henry's Law constant of $<10^{-8}$ atm-m^3/mole. In addition, malic acid is not expected to volatilize from dry soil given its vapor pressure of 3.28×10^{-8} mm Hg (Yaws, 1994). Biodegradation screening studies reveal that malic acid biodegrades relatively fast (Fischer et al., 1974; Malaney and Gerhold, 1969; Heukelekian and Rand, 1955; as cited in HSDB, 1998).

D. Summary

If released to air, a vapor pressure of 3.28×10^{-8} mm Hg at 25 °C indicates that malic acid should exist as a particulate in the ambient atmosphere. Removal of malic acid from the atmosphere by reaction with photochemically-produced hydroxyl radicals results in an estimated half-life of 2 days. Wet deposition is expected to be the dominant transport process of malic acid from the atmosphere. An estimated BCF of <1 suggests the potential for bioconcentration in aquatic organisms is low. If released to soil, malic acid is expected to have very high mobility based upon an estimated Koc of 5, and, therefore, it has the potential to leach to groundwater. Volatilization from water and from moist soil surfaces is not expected to be an important fate process based upon an estimated Henry's Law constant of $<10^{-8}$ atm-m^3/mole, also volatilization from dry soil surfaces is not expected to occur based upon the vapor pressure of this compound. Hydrolysis of malic acid in environmental media is not expected to occur. Malic acid was determined to be readily biodegraded in screening studies, although no data were available for biodegradation in water or soil.

CHEMICAL SUMMARY FOR METHANESULFONIC ACID

This summary is based on information retrieved from a systematic search limited to secondary sources. The only exception is summaries of studies from unpublished TSCA submissions that may have been included. These sources include online databases, unpublished EPA information, government publications, review documents, and standard reference materials. No attempt has been made to verify information in these databases and secondary sources.

I. CHEMICAL IDENTITY AND PHYSICAL/CHEMICAL PROPERTIES

The chemical identity and physical/chemical properties of methanesulfonic acid are summarized in Table 1.

TABLE 1. CHEMICAL IDENTITY AND CHEMICAL/PHYSICAL PROPERTIES OF METHANESULFONIC ACID

Characteristic/Property	**Data**	**Reference**
CAS No.	75-75-2	Lide (1995)
Common Synonyms	methylsulfonic acid	Budavari et al. (1996)
Molecular Formula	CH_4O_3S	Budavari et al. (1996)
Chemical Structure	CH_3SO_2OH	Budavari et al. (1996)
Physical State	solid	Budavari et al. (1996)
Physical State	liquid at room temperature	Lewis (1993)
Molecular Weight	96.11	Budavari et al. (1996)
Melting Point	20 °C	Lide (1995)
Boiling Point	200 °C; 167 °C at 10 mm Hg	Lewis (1993); Lide (1995)
Water Solubility	1.0×10^3 g/L at 20 °C	PHYSPROP (1998)
Density	1.48 g/cm^3	Lide (1995)
Vapor Density (air = 1)	no data	
Koc	1 (estimated)	HSDB (1998)
Log Kow	no data; estimated to be < 1	Estimated
Vapor Pressure	4.28×10^{-4} mm Hg at 25 °C	Daubert and Danner (1991)
Reactivity	thermally stable at mod. elevated temps	Budavari et al. (1996)
Flammability	no data	
Flash Point	112 °C	ECDIN (1998)
Dissociation Constant	-1.86	Serjeant and Dempsey (1979)
Molecular Diffusivity Constant	no data	
Air Diffusivity Constant	no data	
Henry's Law Constant	1.3×10^{-8} atm m^3/mol (estimated)	Meylan and Howard (1991)
Fish Bioconcentration Constant	3 (estimated)	Meylan et al. (1997)
Odor Threshold	no data	

II. ENVIRONMENTAL FATE

A. Aquatic Fate

If released into aquatic waters, methanesulfonic acid is not expected to adsorb to suspended solids and sediments in water based upon an estimated Koc of 1 (Swann et al., 1983), determined from a structure fragment estimation method (Meylan et al., 1992). Volatilization from the water column to the atmosphere is not expected to occur (Lyman et al., 1990) based on an estimated Henry's Law constant of 1.3×10^{-8} atm-m^3/mole (Meylan and Howard, 1991; SRC, 1998). Methanesulfonic acid is expected to be stable to hydrolysis in the pH range of 5-9 typically encountered in the environment (Lyman et al., 1990). According to a classification scheme (Franke et al., 1994), an estimated BCF of 3 (Meylan et al., 1997) suggests that the potential for bioconcentration in aquatic organisms is low. It was determined that many bacterial types can degrade methanesulfonic acid through diverse routes and at different rates, although specifics were not given (Baker et al., 1991, as cited in HSDB, 1998). Because methanesulfonic acid has pKa of -1.86 (Serjeant and Dempsey, 1979), it is expected to exist in the dissociated form in the environment.

B. Atmospheric Fate

According to a model of gas/particle partitioning of semivolatile organic compounds in the atmosphere (Bidleman, 1988), methanesulfonic acid, which has a vapor pressure of 4.28×10^{-4} mm Hg at 25 °C (Daubert and Danner, 1991), has the potential to exist as both a vapor and particulate in the ambient atmosphere. Because methanesulfonic acid has pKa of -1.86 (Serjeant and Dempsey, 1979), it is expected to exist in the dissociated form in the environment. Removal of methanesulfonic acid from the atmosphere by reaction with photochemically- produced hydroxyl radicals results in an estimated half-life of 58 days (Meylan and Howard, 1993). In the atmosphere, methanesulfonic acid is concentrated in the smaller size particles, 0.25-2 um in diameter (Kolaitis et al., 1989, as cited in HSDB, 1998). Removal of particulate methanesulfonic acid from the atmosphere can occur through wet and dry deposition (HSDB, 1998).

C. Terrestrial Fate

Based on a classification scheme (Swann et al., 1983), an estimated Koc of 1, determined from a structure fragment estimation method (Meylan et al., 1992), indicates that methanesulfonic acid is expected to have very high mobility in soil. Volatilization of methanesulfonic acid from moist soil surfaces is not expected to be important (Lyman et al., 1990) given an estimated Henry's Law constant of 1.3×10^{-8} atm-m^3/mole (Meylan and Howard, 1991; SRC, 1998). In addition, methanesulfonic acid is not expected to volatilize from dry soil given its vapor pressure of 4.28×10^{-4} mm Hg (Daubert and Danner, 1991). It was determined that many bacterial types can degrade methanesulfonic acid through diverse routes and at different rates, although specifics were not given (Baker et al., 1991, as cited in HSDB, 1998).

D. Summary

If released to air, a vapor pressure of 4.28×10^{-4} mm Hg at 25 °C indicates that methanesulfonic acid has the potential to exist as both a vapor and particulate in the ambient atmosphere. Gas-phase methanesulfonic acid will be degraded in the atmosphere by reaction with photochemically-produced hydroxyl radicals; the half-life for this reaction in air is estimated to be 58 hours. Removal of particulate methanesulfonic acid from the atmosphere can occur through wet and dry deposition. An estimated BCF of 3 suggests the potential for bioconcentration in aquatic organisms is low. If released to soil, methanesulfonic acid is expected to have very high mobility based upon an estimated Koc of 1, and, therefore, it has the potential to leach to groundwater. Volatilization from water and from moist soil surfaces is not expected to be an important fate process based upon an estimated Henry's Law constant of 1.3×10^{-8} atm-m^3/mole. Hydrolysis of methanesulfonic acid is not expected to occur. Volatilization from dry soil surfaces is not expected to occur based upon the vapor pressure of this compound. Methanesulfonic acid was determined to be biodegraded by many bacterial types, although specifics were not given.

CHEMICAL SUMMARY FOR NICKEL SULFATE

This summary is based on information retrieved from a systematic search limited to secondary sources. The only exception is summaries of studies from unpublished TSCA submissions that may have been included. These sources include online databases, unpublished EPA information, government publications, review documents, and standard reference materials. No attempt has been made to verify information in these databases and secondary sources. The search identified sources of information for nickel and soluble salts of nickel, including nickel sulfate and nickel sulfate hexahydrate.

I. CHEMICAL IDENTITY AND PHYSICAL/CHEMICAL PROPERTIES

The chemical identity and physical/chemical properties of nickel sulfate are summarized in Table 1.

TABLE 1. CHEMICAL IDENTITY AND CHEMICAL/PHYSICAL PROPERTIES OF NICKEL SULFATE

Characteristic/Property	Data	Reference
CAS No.	7786-81-4	Lide (1995)
Common Synonyms	sulfuric acid, nickel (2+) salt	Howard and Neal (1992)
Molecular Formula	NiO_4S	Budavari et al. (1996)
Chemical Structure	$NiSO_4$	Lide (1995)
Physical State	green-yellow orthorhombic crystals	Lide (1995)
Molecular Weight	154.757	Lide (1995)
Melting Point	840 °C, decomposes	Lide (1995)
Boiling Point	no data	
Water Solubility	293 g/L at 0 °C	Dean (1985)
Density	4.01 g/cm^3	Lide (1995)
Vapor Density (air = 1)	no data	
Koc	no data; expected to be < 10	SRC (1998)
Log Kow	no data; expected to be < 1	SRC (1998)
Vapor Pressure	no data; expected to be <10-6 mm Hg at 25 C	Estimated
Reactivity	no data	
Flammability	not flammable	Prager (1995)
Flash Point	no data; expected to be > 350 °C	SRC (1998)
Dissociation Constant	no data	
Molecular Diffusivity Constant	no data	
Air Diffusivity Constant	no data	
Henry's Law Constant	no data; expected to be < $1x10^{-8}$	SRC (1998)
Fish Bioconcentration Constant	no data	
Odor Threshold	no data	

II. ENVIRONMENTAL FATE

A. Aquatic Fate

If released into water, nickel sulfate is expected to dissociate into nickel (Ni^{2+}) and sulfate [$(SO_4)^{2-}$] ions. The dissociation of nickel sulfate into its component ions indicates that the compound nickel sulfate is not expected to volatilize from water surfaces. In aqueous solutions, nickel exists as the hexaquonickel ion, [$Ni(H_2O)_6{}^{2+}$]; this ion is poorly absorbed by most living organisms (Sunderman and Oskarsson, 1991). In natural waters, nickel exists both in the ionic form and as stable organic complexes (Sunderman and Oskarsson, 1991). Nickel compounds are generally soluble at pH values less than 6.5, but at pH values greater than 6.7 nickel exists predominantly as insoluble nickel hydroxides (Sunderman and Oskarsson, 1991). Shellfish and crustacea generally contain higher concentrations of nickel in their flesh than do other species of fish (Sunderman and Oskarsson, 1991).

B. Atmospheric Fate

If released to the atmosphere, nickel sulfate's high melting point (Lide, 1995) and low vapor pressure (SRC, 1998) indicate that it will exist as a particulate (Bidleman, 1988). Wet and dry deposition of nickel sulfate is expected to be the dominant fate process in the atmosphere (Arimoto, 1989). The rate of dry deposition will depend on the prevailing winds and particle size (Bodek et al., 1988). Nickel sulfate's high water solubility (Dean, 1985) indicates that it is expected to undergo wet deposition in rain, snow, or fog.

C. Terrestrial Fate

If nickel sulfate is released to soil, it is expected to dissociate into Ni^{2+} and $(SO_4)^{2-}$ ions in the presence of moisture. Iron and manganese oxides, clay minerals, and organic matter may be important sorbents of nickel (Bodek et al., 1988) and will retard its migration through soil. Complexing ligands, such as organic acids, may reduce the sorption of nickel (Bodek et al., 1988). Acid rain has a tendency to mobilize nickel from soil and increase leaching into groundwater due to the high solubility of nickel compounds at pH values less than 6.5 (Sunderman and Oskarsson, 1991). The high melting point, low vapor pressure, and low Henry's Law constant expected for an ionic salt indicate that nickel sulfate will not volatilize from either moist or dry soil surfaces (Bodek et al., 1988).

D. Summary

If released into water, nickel sulfate is expected to dissociate into nickel (Ni^{2+}) and sulfate $(SO_4)^{2-}$ ions. Therefore, nickel sulfate is not expected to adsorb to suspended solids or sediment in the water column, bioconcentrate in aquatic organisms, or volatilize from water surfaces. In natural waters, nickel exists in both the ionic form and as stable organic complexes; at pH values greater than 6.7 it exists as insoluble nickel hydroxides. In moist soils, nickel sulfate is expected to dissociate into its component ions. Ionic nickel may be sorbed by iron and manganese oxides, clay minerals, and organic matter; acid rain and complexing ligands may reduce the sorption of nickel. Volatilization of nickel sulfate from soil surfaces is not expected to occur. If released to the atmosphere, nickel sulfate is expected to exist as a particulate. Nickel sulfate is expected to be physically removed from the atmosphere by wet and dry deposition. The rate of dry deposition will depend on particle size and prevailing wind patterns.

CHEMICAL SUMMARY FOR PALLADIUM CHLORIDE

This summary is based on information retrieved from a systematic search limited to secondary sources. The only exception is summaries of studies from unpublished TSCA submissions that may have been included. These sources include online databases, unpublished EPA information, government publications, review documents, and standard reference materials. No attempt has been made to verify information in these databases and secondary sources.

I. CHEMICAL IDENTITY AND PHYSICAL/CHEMICAL PROPERTIES

The chemical identity and physical/chemical properties of palladium chloride are summarized in Table 1.

TABLE 1. CHEMICAL IDENTITY AND CHEMICAL/PHYSICAL PROPERTIES OF PALLADIUM CHLORIDE

Characteristic/Property	Data	Reference
CAS No.	7647-10-1	CAS (1998)
Common Synonyms	Palladous chloride	Budavari et al. (1996)
Common Synonyms	Palladium (II) chloride	Lide (1995)
Molecular Formula	Cl_2Pd	Budavari et al. (1996)
Chemical Structure	$PdCl_2$	Budavari et al. (1996)
Physical State	red rhombohedral crystals; hygroscopic	Lide (1995)
Molecular Weight	177.33	Lide (1995)
Melting Point	500 °C (decomposes)	Lide (1995)
Boiling Point	decomposed at high temperatures	Budavari et al. (1996)
Water Solubility	soluble[1]	Dean (1985)
Density	4.0 g/cm^3	Lide (1995)
Vapor Density (air = 1)	no data	
Koc	no data; expected to be <10	SRC (1998)
Log Kow	no data; expected to be <1	SRC (1998)
Vapor Pressure	no data; expected to be <10^{-6} mm Hg	SRC (1998)
Reactivity	no data	
Flammability	no data	
Flash Point	no data	
Dissociation Constant	expected to dissociate into Pd^{2+} and Cl^-	SRC (1998)
Molecular Diffusivity Constant	no data	
Air Diffusivity Constant	no data	
Henry's Law Constant	no data; expected to be <1X10^{-8}	SRC (1998)
Fish Bioconcentration Constant	no data	
Odor Threshold	no data	

[1] This form of expressing solubility cannot be converted into g/L units

II. ENVIRONMENTAL FATE

A. Aquatic Fate

If palladium chloride is released into the water column, it is expected to dissociate into palladium (Pd^{2+}) and chloride (Cl^-) ions. The dissociation of palladium chloride into its component ions indicates that palladium chloride is not expected to bioconcentrate in aquatic organisms or volatilize from water surfaces. Palladium ions may adsorb to charged surfaces of suspended sediments and humic materials in the water column (Evans, 1989). The chloride ion may complex with heavy metals in natural waters, thereby increasing their solubility (Bodek et al., 1988). Adsorption of the chloride ion to suspended solids and sediment in the water column is not expected to be an important fate process.

B. Atmospheric Fate

If palladium chloride is released to the atmosphere, the low vapor pressure expected for an ionic salt indicates that it will exist as a particulate. Dry deposition of palladium chloride is expected to be the dominant fate process in the atmosphere (Arimoto, 1989). The rate of dry deposition will depend on the prevailing winds and particle size (Bodek et al., 1988). Palladium chloride is expected to undergo wet deposition (Arimoto, 1989) in rain, snow, or fog, based upon its water solubility (Dean, 1985).

C. Terrestrial Fate

If palladium chloride is released to soil, it is expected to dissociate into its component ions in moist soils. The dissociation of palladium chloride in moist soils indicates that palladium chloride is not expected to volatilize from moist soil surfaces. While no specific information concerning the sorption of ionic palladium in soils was available, some metals adsorb to charged surfaces of soil particles or form inner sphere complexes with variable-charge soil surfaces (Evans, 1989). If this occurs with palladium then its rate of migration through soil may be slow. Chloride is extremely mobile in soils (Bodek et al., 1988). The chloride ion may complex with heavy metals, thereby increasing their solubility (Bodek et al., 1988) and potential for leaching into groundwater. The low vapor pressure expected for an ionic salt indicates that palladium chloride will not volatilize from dry soil surfaces.

D. Summary

If released into water, palladium chloride will dissociate into palladium and chloride ions. Therefore, palladium chloride is not expected to adsorb to suspended solids or sediment in the water column, bioconcentrate in aquatic organisms, nor volatilize from water surfaces. Palladium ions may adsorb to charged surfaces of suspended sediments and humic matter in the water column. Adsorption of the chloride ion to suspended solids and sediment in the water column is not expected to be an important fate process. If released to soil, palladium chloride is expected to dissociate into its component ions in moist soils. The dissociation of palladium chloride into its component ions indicates that palladium chloride is not expected to volatilize from moist soil surfaces. Ionic palladium may adsorb to charged surfaces of soil particles or form inner sphere complexes with variable-charge soil surfaces. Chloride is extremely mobile in soils. The low vapor pressure expected for an ionic salt indicates that volatilization of palladium chloride from soil surfaces is not expected to be an important fate process. If released to the atmosphere, palladium chloride is expected to exist as a particulate. Palladium chloride is expected to be physically removed from the atmosphere by wet and dry deposition. The rate of dry deposition will depend on particle size and prevailing wind patterns.

CHEMICAL SUMMARY FOR PHOSPHORIC ACID

This summary is based on information retrieved from a systematic search limited to secondary sources. The only exception is summaries of studies from unpublished TSCA submissions that may have been included. These sources include online databases, unpublished EPA information, government publications, review documents, and standard reference materials. No attempt has been made to verify information in these databases and secondary sources.

I. CHEMICAL IDENTITY AND PHYSICAL/CHEMICAL PROPERTIES

The chemical identity and physical/chemical properties of phosphoric acid are summarized in Table 1.

TABLE 1. CHEMICAL IDENTITY AND CHEMICAL/PHYSICAL PROPERTIES OF PHOSPHORIC ACID

Characteristic/Property	Data	Reference
CAS No.	7664-38-2	Lide (1995)
Common Synonyms	orthophosphoric acid	Budavari et al. (1996)
Molecular Formula	$H_3O_4^-P$	Budavari et al. (1996)
Chemical Structure	H_3PO_4	Budavari et al. (1996)
Physical State	unstable, orthorhombic crystals; clear, syrupy liquid	Budavari et al. (1996)
Molecular Weight	98.00	Budavari et al. (1996)
Melting Point	42.35 °C (crystals); -11.8 °C (30% soln)	Gard (1996)
Boiling Point	261 °C (crystals); 101.8 °C (30% soln)	Gard (1996)
Water Solubility	5,480 g/l at 20 °C (crystals); 354.1 g/l at 20 °C (30% soln)	Weast et al. (1985)
Density	1.86 g/cm^3 at 25 °C (crystals); 1.18 g/cm^3 at 25 °C (30% soln)	Gard (1996)
Vapor Density (air = 1)	no data	
Koc	expected to be < 10	SRC (1998)
Log Kow	expected to be < 1	SRC (1998)
Vapor Pressure	0.03 mm Hg at 20 °C (crystals); 16.3 mm Hg at 20 °C (30% soln)	Gard (1996)
Reactivity	relatively unreactive at room temperature	Gard (1996)
Flammability	no data	
Flash Point	no data	
Dissociation Constant	pK_1: 2.15; pK_2: 7.09; pK_3: 12.32	Budavari et al. (1996)
Molecular Diffusivity Constant	no data	
Air Diffusivity Constant	no data	
Henry's Law Constant	expected to be < 1×10^{-8} atm m^3/mole	SRC (1998)
Fish Bioconcentration Constant	no data	
Odor Threshold	no data	

II. ENVIRONMENTAL FATE

A. Aquatic Fate

Phosphoric acid is a weak tribasic acid with a pK_1 of 2.15 (Budavari et al., 1996) and, if released into the water column at low concentrations, it will dissociate into dihydrogen phosphate (H_2PO_4) and hydrogen (H^+) ions. Dihydrogen phosphate then dissociates into hydrogen phosphate ion (HPO_4^{-2}; pK_2 of 7.09) and orthophosphate ion (PO_4^{-3}; pK_3 of 12.32). As a result, phosphoric acid is not expected to volatilize or bioconcentrate in aquatic organisms. The phosphates become available in the water column and form salts, thus affecting biological productivity (Bodek et al., 1988). Phosphorous, in the form of phosphate, is an essential nutrient to plants in aquatic environments (Bodek et al., 1988). In addition, the phosphates can complex with metal ions in sediment and water to form insoluble species such as $FePO_4$ and $CaHPO_4$ (Bodek et al., 1988).

B. Atmospheric Fate

If phosphoric acid is released to the atmosphere, its vapor pressure indicates it will exist predominantly as a vapor in the ambient atmosphere. Wet deposition of phosphoric acid in rain, snow, or fog is expected to be the dominant fate process in the atmosphere based upon its solubility in water (Arimoto, 1989).

C. Terrestrial Fate

If phosphoric acid is released to soil, it will dissociate into dihydrogen phosphate and hydrogen ions, ultimately dissociating to the orthophosphate ion at high pH's. Phosphate added to soil as fertilizer is quickly sorbed and later "fixed" (probably precipitated) into less soluble forms (Bodek et al., 1988). A similar fate is anticipated for phosphate species from phosphoric acid. While the exact mechanism of sorption is uncertain, phosphate fixation is appreciable in all but very coarse-textured soils; only about one-fourth of the fertilizer phosphate is usable by plants, the rest being lost to the occluded soil fraction (Bodek et al., 1988). Phosphorous, in the form of phosphate, is an essential nutrient to plants (Bodek et al., 1988).

D. Summary

Phosphoric acid is a tribasic acid in which the first hydrogen is strongly ionizing, the second moderately weak, and the third very weak. Both acidic and basic salts can be formed from phosphoric acid. If released into water, phosphoric acid will dissociate into dihydrogen phosphate (H_2PO_4) and hydrogen (H^+) ions, eventually dissociating into the orthophosphate ion (PO_4^{-3}) under the proper conditions. Therefore, phosphoric acid is not expected to adsorb to suspended solids or sediment in the water column, bioconcentrate in aquatic organisms, nor volatilize from water surfaces. The phosphates become available in the water column and form salts, affecting biological productivity, and complexing with metal ions form insoluble species such as $FePO_4$ and $CaHPO_4$. If released to soil, phosphoric acid is expected to dissociate into its component ions in moist soils. Phosphate added to soil as fertilizer is quickly sorbed and later "fixed" into less soluble forms; phosphate fixation is appreciable in all but very coarse-textured soils; only about one-fourth of the fertilizer phosphate is usable by plants, the rest being lost to the occluded soil fraction. Phosphorous, in the form of phosphate, is an essential nutrient for aquatic and terrestrial plants. Volatilization of phosphoric acid from soil surfaces is not expected to occur. If released to the atmosphere, phosphoric acid is expected to exist as a gas. Phosphoric acid is expected to be physically removed from the atmosphere by wet deposition based upon its water solubility.

CHEMICAL SUMMARY FOR POTASSIUM AUROCYANIDE

This summary is based on information retrieved from a systematic search limited to secondary sources. The only exception is summaries of studies from unpublished TSCA submissions that may have been included. These sources include online databases, unpublished EPA information, government publications, review documents, and standard reference materials. No attempt has been made to verify information in these databases and secondary sources.

I. CHEMICAL IDENTITY AND PHYSICAL/CHEMICAL PROPERTIES

The chemical identity and physical/chemical properties of potassium aurocyanide are summarized in Table 1.

TABLE 1. CHEMICAL IDENTITY AND CHEMICAL/PHYSICAL PROPERTIES OF POTASSIUM AUROCYANIDE[1]

Characteristic/Property	Data	Reference
CAS No. (deleted)	554-07-4	CAS (1998)
CAS No.	13967-50-5	CAS (1998)
Common Synonyms	gold potassium cyanide	Budavari et al. (1996)
Common Synonyms	potassium dicyanoaurate(I)	Budavari et al. (1996)
Molecular Formula	C_2AuKN_2	Budavari et al. (1996)
Chemical Structure	$KAu(CN)_2$	Budavari et al. (1996)
Physical State	dihydrate, crystalline powder	Budavari et al. (1996)
Molecular Weight	288.13	Budavari et al. (1996)
Melting Point	no data; expected to be > 350 °C	SRC (1998)
Boiling Point	no data; expected to be > 500 °C	SRC (1998)
Water Solubility	Approximately 130 g/L[2]	Budavari et al. (1996)
Water Solubility	1 g dissolves in 0.5 ml boiling H_2O	Budavari et al. (1996)
Density	3.45 g/cm^3	Weast (1986)
Vapor Density (air = 1)	no data	
Koc	no data; expected to be < 10	SRC (1998)
Log Kow	no data; expected to be < 1	SRC (1998)
Vapor Pressure	no data; expected to be <10-6 mm Hg at 25 C	SRC (1998)
Reactivity	stable in aqueous solution[2]	Cotton and Wilkinson (1966)
Flammability	not flammable	ECDIN (1998)
Flash Point	no data; expected to be > 350 °C	SRC (1998)
Dissociation Constant	readily dissociates to K^+ and $[Au(CN)_2]^-$	Cohn and Stern (1994)
Molecular Diffusivity Constant	no data	
Air Diffusivity Constant	no data	
Henry's Law Constant	no data; expected to be < $1x10^{-8}$	SRC (1998)
Fish Bioconcentration Constant	no data	
Odor Threshold	no data	

[1] Both electrochemical and electroless gold plating processes that use potassium aurocyanide under basic conditions may contain potassium cyanide as a complexing agent (Gmelin, 1998; Cohn and Stern, 1994; McDermott, 1974). The concentration of KCN is typically approximately 6 g/L (0.1 M), although values as high as 200 g/L (3 M) have been reported (Gmelin, 1988).

[2] Estimated from a reported solubility of 1 g dissolves in 7 ml H_2O (Budavari et al., 1996).

[3] Potassium aurocyanide is stable in aqueous solution under both basic and neutral conditions (Cotton and Wilkinson, 1966; Cohn and Stern, 1994). It is also stable in aqueous solutions under acidic conditions (Cohn and Stern, 1994), although common acids such as HCl, H_2SO_4, HNO_3, and H_2S are known to degrade potassium aurocyanide (Gmelin, 1998) and release HCN and gold monocyanide (Budavari et al., 1996; Gmelin, 1998). Concentrated acids and elevated temperatures, or both, are required (Gmelin, 1998). Potassium aurocyanide is commonly used in warm (35-55°C) acidic plating solutions at a pH of approximately 4 (Gmelin, 1998) and stabilized acidic plating baths containing

potassium aurocyanide have been reported down to a pH of 1.5 (McDermott, 1974), yet it is generally considered stable in water above pH 3 (Renner and Johns, 1989). These data indicate that potassium aurocyanide is expected to be chemically stable in the pH range 5-9 typically found in the environment (Lyman et al, 1990), but not under highly acidic conditions such as those found in the stomach (pH 1-2).

II. ENVIRONMENTAL FATE

A. Aquatic Fate

If released to water, potassium aurocyanide will rapidly and completely dissociate into potassium (K^+) and aurocyanide ($[Au(CN)_2]^-$) ions (Cohn and Stern, 1994). The aurocyanide ion is expected to be stable to hydrolysis in the pH range of 5-9 typically encountered in the environment (Lyman et al, 1990; SRC, 1998). The dissociation of potassium aurocyanide into its component ions also indicates that it is not expected to volatilize from water surfaces to the atmosphere, adsorb to sediment and suspended organic matter, or bioconcentrate in fish and aquatic organisms (Bodek et al., 1988).

B. Atmospheric Fate

If released to the atmosphere, potassium aurocyanide will exist as a particulate. Its atmospheric fate will be dominated by deposition to the Earth's surface via wet and dry processes, as potassium aurocyanide is not expected to undergo degradation by the most common atmospheric oxidant, hydroxyl radicals (Lyman et al, 1990; SRC, 1998). The rate of dry deposition will be dependent on the prevailing winds and particle size; fine particles of potassium aurocyanide have the potential to be transported significant distances from their original point of release (Bodek et al, 1988). Potassium aurocyanide is expected to undergo efficient wet deposition in either rain or fog due to its water solubility. Dissolution in clouds followed by wet deposition may also occur. Potassium aurocyanide is stable to light (Cohn and Stern, 1994), and is not expected to undergo degradation by direct photolyis.

C. Terrestrial Fate

If potassium aurocyanide is released to soil, it is expected to display very high mobility based on its water solubility of 143 g/L (Budavari, 1996). Therefore, it has the potential to leach into groundwater. Its rate of leaching through soil may be attenuated by the formation of insoluble soil/aurocyanide complexes that can arise from reactions with metals naturally present in soil (Bodek et al, 1988). The importance of complex formation for potassium aurocyanide in soil is not known. The very high melting point and low vapor pressure expected for an ionic salt indicates that potassium aurocyanide will not volatilize from either moist or dry soils to the atmosphere (Bodek et al, 1988).

D. Summary

If released to water, potassium aurocyanide will dissociate into K^+ and $[Au(CN)_2]^-$ ions. Therefore, it is not expected to adsorb to sediment and suspended organic matter, bioconcentrate in fish and aquatic organisms, or volatilize from water surfaces to the atmosphere. The aurocyanide ion is expected to be chemically stable and it is not expected to hydrolyze in the pH range 5-9 typically found in the environment. In soil, potassium aurocyanide is likely to display very high mobility as a result of its relatively high water solubility and it has the potential to leach to groundwater. Its rate of leaching through soil may be attenuated by the formation of insoluble soil/aurocyanide complexes although the importance of this process is not known. Volatilization from soil surfaces to the atmosphere is not expected to occur. If released to the atmosphere, potassium aurocyanide is expected to exist as a particulate. Its atmospheric fate is expected to be dominated by wet and dry deposition to the Earth's surface. Efficient removal from the atmosphere during rain events is expected although the rate of dry deposition will be dependent on its particle size and the prevailing wind patterns. Therefore, fine particles of potassium aurocyanide have the potential to travel significant distances from their original point of release.

CHEMICAL SUMMARY FOR POTASSIUM PEROXYMONOSULFATE

This summary is based on information retrieved from a systematic search limited to secondary sources. The only exception is summaries of studies from unpublished TSCA submissions that may have been included. These sources include online databases, unpublished EPA information, government publications, review documents, and standard reference materials. No attempt has been made to verify information in these databases and secondary sources.

I. CHEMICAL IDENTITY AND PHYSICAL/CHEMICAL PROPERTIES

The chemical identity and physical/chemical properties of potassium peroxymonosulfate are summarized in Table 1.

TABLE 1. CHEMICAL IDENTITY AND CHEMICAL/PHYSICAL PROPERTIES OF POTASSIUM PEROXYMONOSULFATE

Characteristic/Property	**Data**	**Reference**
CAS No.	10058-23-8	CAS (1998)
Common Synonyms	Monopotassium peroxymonosulfurate	Howard and Neal (1992)
Common Synonyms	Peroxymonosulfuric acid, monopotassium salt	Howard and Neal (1992)
Molecular Formula	$HO_5S.K$	Howard and Neal (1992)
Chemical Structure	HOOS(O)(O)OK	CAS (1998)
Physical State	no data	
Molecular Weight	153.18	Howard and Neal (1992)
Melting Point	no data	
Boiling Point	no data	
Water Solubility	no data	
Density	no data	
Vapor Density (air = 1)	no data	
Koc	no data; expected to be <10	Estimated
Log Kow	no data; expected to be <1	Estimated
Vapor Pressure	no data; expected to be $<1X10^{-6}$ mm Hg	Estimated
Reactivity	no data	
Flammability	no data	
Flash Point	no data	
Dissociation Constant	expected to dissociate	Bodek et al. (1988)
Molecular Diffusivity Constant	no data	
Air Diffusivity Constant	no data	
Henry's Law Constant	no data; expected to be $<1X10^{-8}$	Estimated
Fish Bioconcentration Constant	no data	
Odor Threshold	no data	

II. ENVIRONMENTAL FATE

A. Aquatic Fate

Most potassium salts are highly dissociated in natural waters (Bodek et al., 1988). Therefore, if potassium peroxymonosulfate is released into water, it is expected to dissociate into potassium (K^+) and peroxymonosulfate (SO_5^-) ions. The potassium ion is expected to exist predominately as the free ion in most natural waters (Bodek et al., 1988). Ion exchange processes with suspended solids and sediment in the water column are expected to remove ionic potassium from solution; however, ionic potassium may be displaced by other cations present in natural waters with a higher affinity for ion exchange sites (Bodek et al., 1988). Aqueous solutions of the impure potassium peroxymonosulfate, i.e., those containing dipotassium sulfate and monopotassium sulfate, decompose yielding mainly O_2 and sulfate (SO_4^{2-}), hydrogen peroxide and peroxydisulfate ($S_2O_8^{2-}$) occur in small amounts (Cotton and Wilkinson, 1980). Sulfate ions may participate in oxidation-reduction reactions or react with cations present in the water column to form soluble complexes or insoluble precipitates (Bodek et al., 1988). Sulfate-reducing microorganisms are important mediators in redox reactions involving this ion (Bodek et al., 1988). Peroxy compounds are short-lived because of the inherent instability of the O-O bond and are expected to degrade rapidly (U.S. EPA, 1993).

B. Atmospheric Fate

If potassium peroxymonosulfate is released to the atmosphere, the low vapor pressure expected for an ionic salt indicates that potassium peroxymonosulfate will exist as a particulate. Wet and dry deposition of potassium peroxymonosulate is expected to be an important fate process in the atmosphere (Arimoto, 1989). The rate of dry deposition will depend on the prevailing winds and particle size (Bodek et al., 1988).

C. Terrestrial Fate

If potassium peroxymonosulfate is released to soil, it may decompose in moist soils; the importance of this process is not known. The low vapor pressure expected for an ionic salt indicates that potassium peroxymonosulfate will not volatilize from dry soil surfaces. The uncomplexed potassium ion is expected to be the predominant species in well-drained soils from pH 4 to pH 10 (Bodek et al., 1988). Ion exchange reactions are expected to attenuate the mobility of the potassium ion in the subsurface environment, however ionic potassium may be displaced by other cations with a higher affinity for ion exchange sites (Bodek et al., 1988). Peroxy compounds are short-lived because of the inherent instability of the O-O bond and are expected to degrade rapidly (U.S. EPA, 1993).

D. Summary

If released into water, potassium peroxymonosulfate is expected to dissociate into potassium and peroxymonosulfate ions. The dissociation of potassium peroxymonosulfate into its component ions indicates that potassium peroxymonosulfate is not expected to volatilize from water surfaces or bioconcentrate in aquatic organisms. In most natural waters, the potassium ion is expected to exist predominately as the free ion. Ion exchange processes with suspended solids and sediment in the water column are expected to remove ionic potassium from solution; however ionic potassium may be displaced by other cations in natural waters with a higher affinity for ion exchange sites. Sulfate ions may participate in oxidation-reduction reactions or react with cations present in the water column to form soluble complexes or insoluble precipitates; sulfate-reducing microorganisms are important mediators in redox reactions involving this ion. If released to soil, potassium peroxymonosulfate may decompose in moist soils or dissociate into its component ions. As a result, potassium peroxymonosulfate is not expected to volatilize from moist soil surfaces. The low vapor pressure expected for an ionic salt indicates that potassium peroxymonosulfate is not expected to volatilize from dry soil surfaces. The mobility of potassium ions will be retarded by ion exchange processes with charged surfaces of soil particles. However, since the potassium ion is held weakly by ion exchange processes, it may leach into groundwater. Peroxy compounds are short-lived because of the inherent instability of the O-O bond and are expected to degrade rapidly. If released to the atmosphere, potassium peroxymonosulfate is expected to exist as a particulate based upon the low vapor pressure expected for an ionic salt. Wet and dry deposition is expected to be the dominant fate process in the atmosphere.

CHEMICAL SUMMARY FOR PROPIONIC ACID

This summary is based on information retrieved from a systematic search limited to secondary sources. The only exception is summaries of studies from unpublished TSCA submissions that may have been included. These sources include online databases, unpublished EPA information, government publications, review documents, and standard reference materials. No attempt has been made to verify information in these databases and secondary sources.

I. CHEMICAL IDENTITY AND PHYSICAL/CHEMICAL PROPERTIES

The chemical identity and physical/chemical properties of propionic acid are summarized in Table 1.

TABLE 1. CHEMICAL IDENTITY AND CHEMICAL/PHYSICAL PROPERTIES OF PROPIONIC ACID

Characteristic/Property	Data	Reference
CAS No.	79-09-4	Howard and Neal (1992)
Common Synonyms	methyl acetic acid; ethyl formic acid	Budavari et al. (1996)
Molecular Formula	$C_3H_6O_2$	Budavari et al. (1996)
Chemical Structure	CH_3CH_2COOH	Budavari et al. (1996)
Physical State	oily liquid	Budavari et al. (1996)
Molecular Weight	74.08	Budavari et al. (1996)
Melting Point	-21.5 °C	Budavari et al. (1996)
Boiling Point	141.1 °C	Budavari et al. (1996)
Water Solubility	$1\times10^{+3}$ g/l @ 25 °C	U.S. EPA (1981)
Density	$d^{25/4}$, 0.99336	Budavari et al. (1996)
Vapor Density (air = 1)	no data	
Koc	36 (calculated)	Lyman et al. (1990)
Log Kow	0.33	Hansch et al. (1995)
Vapor Pressure	3.53 mm Hg @ 25 °C	Daubert and Danner (1985)
Reactivity	corrodes steel, metal	Weiss (1986)
Flammability	combustible	Lewis (1993)
Flash Point	136 °F (58 °C), open cup	Budavari et al. (1996)
Dissociation Constant	pKa = 4.88	Serjeant and Dempsey (1979)
Molecular Diffusivity Constant	no data	
Air Diffusivity Constant	no data	
Henry's Law Constant	4.45×10^{-7} atm m^3/mole @ 25 °C	Butler and Ramchandani (1935)
Fish Bioconcentration Factor	0.02 (calculated)	Lyman et al. (1990)
Odor Threshold	no data	

II. ENVIRONMENTAL FATE

A. Aquatic Fate

Aerobic biodegradation is likely to be the most important removal mechanism of propionic acid from aquatic systems (Dias and Alexander, 1971, as cited in HSDB, 1998). With a pKa of 4.88 (Serjeant and Dempsey, 1979), propionic acid and its conjugate base will exist in environmental waters in varying proportions that are pH dependent. Under neutral and alkaline conditions, propionic acid is expected to exist predominantly as its conjugate base, the propionate ion (Lyman et al., 1990). In addition, at a pH of 4.88 propionic acid is 50% dissociated; even under mildly acidic conditions, it will exist predominantly as the conjugate base. In general, organic ions are not expected to volatilize from water or adsorb to particulate matter in water to the degree that would be predicted for their neutral counterparts. An estimated Koc of 36, determined from a log Kow of 0.33 (Hansch et al., 1995), indicates propionic acid should not partition from the water column to organic matter contained in sediments and suspended solids. Similarly, the Kow indicates that bioconcentration in fish and aquatic organisms is not an important fate process. Propionic acid's Henry's Law constant of 4.45×10^{-7} atm m^3/mole (Butler and Ramchandani, 1935) indicates that volatilization of propionic acid from environmental waters should be extremely slow (Lyman et al., 1990). Volatilization will be attenuated depending upon pH and the amount of propionic acid that is dissociated. Since carboxylic acids are generally resistant to aqueous hydrolysis (Lyman et al., 1990), it is not expected to be an important fate process for propionic acid. The direct photolysis (Calvert and Pitts, 1966, as cited in HSDB, 1998) and reaction of propionic acid with photochemically-generated hydroxyl radicals in water (Anbar and Neta, 1967, as cited in HSDB, 1998) are also not expected to be important fate processes.

B. Atmospheric Fate

Based on a vapor pressure of 3.53 mm Hg at 25 °C (Daubert and Danner, 1985, as cited in HSDB, 1998), propionic acid is expected to exist almost entirely in the vapor phase in the ambient atmosphere (Bidleman, 1988). The rate constant for the reaction of propionic acid with photochemically-produced hydroxyl radicals in air has been experimentally determined to be 1.22×10^{-12} cm^3/molecule-sec at 25 °C (Daugaut et al., 1988, as cited in HSDB, 1998). This corresponds to an atmospheric half-life of approximately 13 days. Since low molecular weight organic acids have absorption bands at wavelengths well below the environmentally important range of 290 nm, the direct photolysis of propionic acid in air is not expected to be important (Calvert and Pitts, 1966, as cited in HSDB, 1998). Extensive monitoring data (Chapman et al., 1986; Hoffman and Tanner, 1986; Winkeler et al., 1988; Mazurek and Simoneitt, 1986, as cited in HSDB, 1998) has shown that physical removal of propionic acid from the air by wet deposition (rainfall, dissolution in clouds, etc.) may be an important fate process under the appropriate atmospheric conditions.

C. Terrestrial Fate

Biodegradation is likely to be the most important removal mechanism of propionic acid from aerobic soil (Dias and Alexander, 1971, as cited in HSDB, 1998). With a pKa of 4.88 (Serjeant and Dempsey, 1979), propionic acid and its conjugate base will exist in varying proportions that are dependent on the pH of the soil. A Henry's Law Constant of 4.45×10^{-7} atm m^3/mole (Butler and Ramchandani, 1935) indicates that volatilization of propionic acid from moist soil should be extremely slow (Lyman et al., 1990). Yet, propionic acid should volatilize rapidly from dry surfaces based upon a vapor pressure of 3.53 mm Hg at 25 °C (Daubert and Danner, 1985, as cited in HSDB, 1998). Volatilization will be attenuated depending upon pH and the amount of propionic acid dissociated. An estimated Koc of 36, determined from a log Kow of 0.33 (Hansch et al., 1995), indicates that propionic acid may be highly mobile in soil (Swann et al., 1983). In addition, monitoring data has shown that propionic acid can leach to groundwater (Stuermer et al., 1982; Burrows and Rowe, 1975; Lema et al., 1988, as cited in HSDB, 1998). Organic ions generally do not volatilize from moist soil surfaces and do not undergo adsorption to the extent of their neutral counterparts, which is consistent with propionic acid's potential for displaying high mobility through soils under conditions where rapid biodegradation does not occur.

D. Summary

With a pKa of 4.88, propionic acid and its conjugate base will exist in environmental media in varying proportions that are pH dependent; under typical environmental conditions, propionic acid will exist predominantly as its conjugate base. A Henry's Law constant of 4.45×10^{-7} atm m^3/mole at 25 °C indicates that volatilization of propionic acid from environmental waters and moist soil should be extremely slow. Yet, based on a vapor pressure of 3.53 mm Hg, propionic acid should volatilize rapidly from dry surfaces. However, volatilization of propionic acid will be pH dependent; if propionic acid is dissociated, very little (about 1%) will be available for volatilization. A relatively low estimated Koc indicates that propionic acid should not partition from the water column to organic matter contained in sediments and suspended solids; the Koc also indicates that it should be highly mobile in soil. However, monitoring data has shown that propionic acid has the potential to leach to groundwater under the appropriate conditions. Propionic acid is miscible with water and monitoring data has shown that physical removal from air by wet deposition is an important removal mechanism. Biodegradation is likely to be the most important removal mechanism of propionic acid from aerobic soil and water. In the atmosphere, propionic acid is expected to exist almost entirely in the gas phase and oxidative removal by photochemically-produced hydroxyl radicals has a half-life of 13 days. The hydrolysis in water, photolysis in air, and bioconcentration in aquatic organisms are not expected to be important fate processes for propionic acid.

CHEMICAL SUMMARY FOR SILVER NITRATE

This summary is based on information retrieved from a systematic search limited to secondary sources. The only exception is summaries of studies from unpublished TSCA submissions that may have been included. These sources include online databases, unpublished EPA information, government publications, review documents, and standard reference materials. No attempt has been made to verify information in these databases and secondary sources. The search identified sources of information for silver nitrate, other nitrate salts and silver.

I. CHEMICAL IDENTITY AND PHYSICAL/CHEMICAL PROPERTIES

The chemical identity and physical/chemical properties of silver nitrate are summarized in Table 1.

TABLE 1. CHEMICAL IDENTITY AND CHEMICAL/PHYSICAL PROPERTIES OF SILVER NITRATE

Characteristic/Property	Data	Reference
CAS No.	7761-88-8	Lide (1995)
Common Synonyms	silver(I)nitrate	Lide (1995)
Molecular Formula	$AgNO_3$	Budavari et al. (1996)
Chemical Structure	$AgNO_3$	Lide (1995)
Physical State	colorless, rhombohedral crystals	Lide (1995)
Molecular Weight	169.873	Lide (1995)
Melting Point	212 °C	Lide (1995)
Boiling Point	440 °C decomposes	Lide (1995)
Water Solubility	2,500 g/L water	Budavari et al. (1996)
Density	4.35 g/cm^3	Lide (1995)
Vapor Density (air = 1)	no data	
Koc	no data; expected to be < 10	SRC (1998)
Log Kow	no data; expected to be < 1	SRC (1998)
Vapor Pressure	no data; expected to be <10-6 mm Hg at 25 °C	Estimated
Reactivity	can explode on contact with soot, organics	Renner (1993)
Flammability	not flammable	Prager (1995)
Flash Point	no data; expected to be > 350 °C	SRC (1998)
Dissociation Constant	no data	
Molecular Diffusivity Constant	no data	
Air Diffusivity Constant	no data	
Henry's Law Constant	no data; expected to be < 1X10^{-8}	SRC (1998)
Fish Bioconcentration Constant	no data	
Odor Threshold	no data	

II. ENVIRONMENTAL FATE

A. Aquatic Fate

If silver nitrate is released into water, it is expected to dissociate into silver (Ag^+) and nitrate $(NO_3)^-$ ions. The dissociation of silver nitrate into its component ions indicates that silver nitrate is not expected to volatilize from water surfaces or bioconcentrate in aquatic organisms (Bodek et al., 1988). Ionic silver may form complexes with hydroxide, sulfide ligands, halide ligands, and chelating organics (Bodek et al., 1988). Silver-organic complexes may be important (Bodek et al., 1988). In aquatic systems with high halide concentrations, precipitation of insoluble silver halides may occur (Bodek et al., 1988). Silver ions may sorb to organic matter and sediment that has high manganese dioxide, iron oxide, and clay content (Bodek et al., 1988). Nitrate is a minor constituent in natural waters, where its concentration is limited by biological reactions that consume it (Bodek et al., 1988). In aquatic systems where nitrogen is a limiting nutrient, high loadings of nitrate into surface waters can cause algal blooms (Bodek et al., 1988). In natural waters with a low nitrate concentration, complexation with transition metals is not expected to be an important process (Bodek et al., 1988).

B. Atmospheric Fate

If released to the atmosphere, silver nitrate's low vapor pressure indicates that it will exist as a particulate (Bidleman, 1988). Wet and dry deposition of silver nitrate is expected to be the dominant fate process in the atmosphere (Arimoto, 1989). Silver nitrate's high water solubility (Budavari et al., 1996) indicates that it is expected to undergo wet deposition in rain, snow, or fog. The rate of dry deposition will depend on the prevailing winds and particle size (Bodek et al., 1988). Pure silver nitrate is not photosensitive (Cappel, 1997); however, trace amounts of organic material promote its photodegradation (Budavari et al., 1996).

C. Terrestrial Fate

If released to soil, silver nitrate is expected to dissociate into its component ions in the presence of moisture. Silver may adsorb to manganese dioxide, iron oxides, clays, and organic matter (Bodek et al., 1988); therefore, its rate of migration through soil may be slow. The high boiling point, low vapor pressure, and low Henry's Law constant expected for an ionic salt (SRC, 1998) indicates that silver nitrate will not volatilize from either moist or dry soil surfaces. Inoic silver may form complexes with hydroxide, sulfide ligands, halide ligands, and chelating organics (Bodek et al., 1988). Nitrate ions may be converted to gaseous N_2 or nitrous oxide (N_2O) by microorganisms under anaerobic conditions or may be assimilated by plants (Bodek et al., 1988). Sorption of nitrate ions by soils is generally insignificant and therefore nitrate ions are expected to leach into groundwater (Bodek et al., 1988).

D. Summary

If released into water, silver nitrate will dissociate into silver and nitrate ions. Therefore, silver nitrate is not expected to adsorb to suspended solids or sediment in the water column, bioconcentrate in aquatic organisms, or volatilize from water surfaces. In natural waters, the concentration of nitrate is limited by biological reactions that consume it. High loadings of nitrate into surface waters can cause algal blooms if nitrogen is a limiting nutrient. Silver nitrate is expected to dissociate into its component ions in moist soils, and ionic silver may adsorb to manganese dioxide, iron oxides, and clays. Nitrate is highly mobile in soils and therefore may leach into groundwater. Under anaerobic conditions nitrate may be converted to gaseous N_2 or nitrous oxide by microorganisms. Volatilization of silver nitrate from soil surfaces is not expected to occur. If released to the atmosphere, silver nitrate is expected to exist as a particulate. Silver nitrate is expected to be physically removed from the atmosphere by wet and dry deposition. Dry deposition will depend on particle size and prevailing wind patterns. Pure silver nitrate is not photosensitive and will not degrade in sunlight; trace amounts of organic material promote silver nitrate's photodegradation.

CHEMICAL SUMMARY FOR SODIUM HYDROXIDE

This summary is based on information retrieved from a systematic search limited to secondary sources. The only exception is summaries of studies from unpublished TSCA submissions that may have been included. These sources include online databases, unpublished EPA information, government publications, review documents, and standard reference materials. No attempt has been made to verify information in these databases and secondary sources.

I. CHEMICAL IDENTITY AND PHYSICAL/CHEMICAL PROPERTIES

The chemical identity and physical/chemical properties of sodium hydroxide are summarized in Table 1.

TABLE 1. CHEMICAL IDENTITY AND CHEMICAL/PHYSICAL PROPERTIES OF SODIUM HYDROXIDE

Characteristic/Property	Data	Reference
CAS No.	1310-73-2	CAS (1998)
Common Synonyms	Caustic soda	Bodek et al. (1988)
Molecular Formula	HNaO	Budavari et al. (1996)
Chemical Structure	NaOH	Budavari et al . (1996)
Physical State	white orthohombic crystals; hygroscopic	Lide (1995)
Molecular Weight	39.997	Lide (1995)
Melting Point	323 °C	Lide (1995)
Boiling Point	1388 °C	Lide (1995)
Water Solubility	571.9 g/L	Weast et al. (1985)
Density	2.13 g/cm^3	Lide (1995)
Vapor Density (air = 1)	not pertinent	Weiss (1986)
Koc	no data; expected to be <10	SRC (1998)
Log Kow	no data; expected to be <1	SRC (1998)
Vapor Pressure	no data; expected to be <10^{-6} mm Hg	Weiss (1986)
Reactivity	when wet, attacks metals such as aluminum, tin, lead, and zinc to produce flammable hydrogen gas	Weiss (1986)
Flammability	not flammable	Weiss (1986)
Flash Point	not flammable	Weiss (1986)
Dissociation Constant	readily dissociates into Na^+ and OH^-	SRC (1998)
Molecular Diffusivity Constant	no data	
Air Diffusivity Constant	no data	
Henry's Law Constant	no data; expected to be <1X10^{-8}	SRC (1998)
Fish Bioconcentration Constant	no data	
Odor Threshold	not pertinent	Weiss (1986)

II. ENVIRONMENTAL FATE

A. Aquatic Fate

If sodium hydroxide is released into water, it will dissociate into sodium (Na^+) and hydroxide (OH^-) ions (Bodek et al., 1988). The dissociation of sodium hydroxide into its component ions indicates that sodium hydroxide is not expected to volatilize from water surfaces or bioconcentrate in aquatic organisms. Because it is strongly basic, sodium hydroxide will react with any protic acids to form salts. Hydroxide is the conjugate base of water; protonation of hydroxide produces water. The presence of hydroxide in natural waters is entirely dependent on the pH of the water, but massive amounts of sodium hydroxide may raise the pH of the receiving water. Metals present in natural waters may form complexes with the hydroxide ion; complexes with transition metals will result in precipitation of the sparingly soluble metal hydroxides (Bodek et al., 1988). The sodium ion is expected to exist predominately as the free ion in most natural waters (Bodek et al., 1988). Ion exchange processes with suspended solids and sediment in the water column are expected to remove ionic sodium from solution; however, sodium binds weakly to ion exchange sites and is expected to be displaced by other cations present in natural waters (Bodek et al., 1988).

B. Atmospheric Fate

If sodium hydroxide is released to the atmosphere, it is expected to exist as a particulate based upon the low vapor pressure expected for this compound. Wet deposition of sodium hydroxide (Arimoto, 1989) in rain, snow, or fog is expected to be the dominant fate process in the atmosphere based upon its high water solubility (Budavari et al., 1996); however, carbon dioxide dissolved in atmospheric water may react with sodium hydroxide to form sodium carbonate.

C. Terrestrial Fate

If sodium hydroxide is released to soil, it is expected to dissociate into its component ions in moist soils and react with any protic acids present in soil to form the sodium salt and water. The low vapor pressure and low Henry's Law constant expected for an ionic salt indicates that sodium hydroxide will not volatilize from either moist or dry soil surfaces. In soil, ion exchange processes are important in retarding the mobility of sodium ions, however they may be replaced by other soil cations since the sodium ion is held weakly by soils (Evans, 1989).

D. Summary

If released into water, sodium hydroxide will dissociate into sodium and hydroxide ions. The dissociation of sodium hydroxide into its component ions indicates that sodium hydroxide is not expected to volatilize from water surfaces or bioconcentrate in aquatic organisms. The hydroxide ion will react with protic acids to form water. Massive amounts of sodium hydroxide may raise the pH of the water. The sodium ion is expected to participate in ion exchange reactions with charged surfaces of suspended sediments and sediment in the water column. If released to soil, sodium hydroxide is expected to dissociate into its component ions in moist soils and react with protic acids to form water. Sodium hydroxide is not expected to volatilize from moist or dry soil surfaces. The mobility of sodium ions will be retarded by ion exchange processes with charged surfaces of soil particles. However, since the sodium ion is held weakly by ion exchange processes, it may leach into groundwater. If released to the atmosphere, sodium hydroxide is expected to exist as a particulate based upon the low vapor pressure expected for an ionic compound. Sodium hydroxide reacts with carbon dioxide to form sodium carbonate. Wet deposition in rain, snow, or fog is expected to be the dominant fate process in the atmosphere based upon sodium hydroxide's high water solubility.

CHEMICAL SUMMARY FOR SODIUM HYPOPHOSPHITE AND SODIUM HYPOPHOSPHITE MONOHYDRATE

This summary is based on information retrieved from a systematic search limited to secondary sources. The only exception is summaries of studies from unpublished TSCA submissions that may have been included. These sources include online databases, unpublished EPA information, government publications, review documents, and standard reference materials. No attempt has been made to verify information in these databases and secondary sources.

I. CHEMICAL IDENTITY AND PHYSICAL/CHEMICAL PROPERTIES

The chemical identity and physical/chemical properties of sodium hypophosphite and its monohydrate are summarized in Tables 1 and 2, respectively.

TABLE 1. CHEMICAL IDENTITY AND CHEMICAL/PHYSICAL PROPERTIES OF SODIUM HYPOPHOSPHITE

Characteristic/Property	Data	Reference
CAS No.	7681-53-0	CAS (1998)
Common Synonyms	Phosphinic acid, sodium salt	Budavari et al. (1996)
Molecular Formula	H_2NaO_2P	Budavari et al. (1996)
Chemical Structure	NaH_2PO_2	Budavari et al. (1996)
Physical State	colorless, pearly, crystalline plates or white granular powder	Lewis (1993)
Molecular Weight	87.98	Budavari et al. (1996)
Melting Point	no data	
Boiling Point	decomposes	Dean (1985)
Water Solubility	approximately 500 g/L [1]	Estimated
Density	no data	
Vapor Density (air = 1)	no data	
Koc	no data; expected to be <10	Estimated
Log Kow	no data; expected to be <1	Estimated
Vapor Pressure	no data; expected to be $< 10^{-6}$ mm Hg	Estimated
Reactivity	Explosion risk when mixed with strong oxidizing agents.	Lewis (1993)
Flammability	no data	
Flash Point	no data	
Dissociation Constant	2.1 (phosphinic acid)	Fee et al. (1996)
Molecular Diffusivity Constant	no data	
Air Diffusivity Constant	no data	
Henry's Law Constant	no data; expected to be $<1X10^{-8}$	Estimated
Fish Bioconcentration Constant	no data	
Odor Threshold	no data	

[1] Estimated from a reported solubility of 100 parts in 100 parts at 25°C for the monohydrate (Dean 1985).

TABLE 2. CHEMICAL IDENTITY AND CHEMICAL/PHYSICAL PROPERTIES OF SODIUM HYPOPHOSPHITE MONOHYDRATE

Characteristic/Property	**Data**	**Reference**
CAS No.	10039-56-2	CAS (1998)
Molecular Formula	$NaPH_2O_2{\cdot}H_2O$	Dean (1985)
Chemical Structure	$NaPH_2O_2{\cdot}H_2O$	Dean (1985)
Physical State	white, monoclinic	Dean (1985)
Molecular Weight	105.99	Dean (1985)
Melting Point	loses water at 200 °C	Dean (1985)
Boiling Point	decomposes	Dean (1985)
Water Solubility	approximately 500 g/L [1]	Estimated
Density	no data	
Vapor Density (air = 1)	no data	
Koc	no data; expected to be <10	Estimated
Log Kow	no data; expected to be <1	Estimated
Vapor Pressure	no data; expected to be $< 10^{-6}$ mm Hg	Estimated
Reactivity	no data	
Flammability	no data	
Flash Point	no data	
Dissociation Constant	2.1 (phosphinic acid)	Fee et al. (1996)
Molecular Diffusivity Constant	no data	
Air Diffusivity Constant	no data	
Henry's Law Constant	no data; expected to be $<1X10^{-8}$	Estimated
Fish Bioconcentration Constant	no data	
Odor Threshold	no data	

[1] Estimated from a reported solubility of 100 parts in 100 parts at 25 °C (Dean 1985).

II. ENVIRONMENTAL FATE

A. Aquatic Fate

Almost all sodium salts are highly dissociated in natural waters (Bodek et al., 1988). Therefore, if sodium hypophosphite is released into water, it is expected to initially hydrate to form the monohydrate then dissociate into hypophosphite (H_2PO2^-) and sodium (Na^+) ions. The pKa of phosphinic acid indicates that hypophosphite will exist mainly in the dissociated state in the environment. The dissociation of sodium hypophosphite into its component ions indicates sodium hypophosphite will not volatilize from water surfaces or bioconcentrate in aquatic organisms. The sodium ion is expected to exist predominately as the free ion in most natural waters (Bodek et al., 1988). Ion exchange processes with suspended solids and sediment in the water column are expected to remove ionic sodium from solution; however, sodium binds weakly to ion exchange sites and is expected to be displaced by other cations present in natural waters (Bodek et al., 1988). No information specifically regarding the environmental fate of the phosphinic acid or hypophosphite ion in water was located in the available literature. Phosphinic acid and its salts are a strong reducing agents; they are oxidized to phosphonic acid or phosphonate (H_3PO_3 or HPO_3^{2-}) (Fee et al., 1996). It is unclear how rapidly this process will occur in the environment.

B. Atmospheric Fate

If sodium hypophosphite or its monohydrate are released to the atmosphere, it is expected to exist as a particulate based upon the low vapor pressure expected for this compound. Particulates of the unhydrated salt may also hydrate when exposed to moisture in the atmosphere to form the monohydrate. Wet deposition of sodium hypophosphite in rain, snow, or fog is expected to be the dominant fate process in the atmosphere (Arimoto, 1989) based upon its high water solubility (Betterman et al., 1991).

C. Terrestrial Fate

If sodium hypophosphite is released to soil, it is expected to initially hydrate to form the monohydrate then dissociate into its component ions in moist soils. The pKa of phosphinic acid indicates that it will exist mainly in the dissociated state in the environment. The low vapor pressure and low Henry's Law constant expected for an ionic salt indicates that neither sodium hypophosphite nor its hydrate will volatilize from either moist or dry soil surfaces. In soil, ion exchange processes are important in retarding the mobility of sodium ions, however they may be replaced by other soil cations since the sodium ion is held weakly by soils (Evans, 1989). No information specifically regarding the environmental fate of the phosphinic acid or hypophosphite ion in soils was located in the available literature. Phosphinic acid and its salts are a strong reducing agents; they are oxidized to phosphonic acid or phosphonate (H_3PO_3 or HPO_3^{2-}) (Fee et al., 1996). It is unclear how rapidly this process will occur in the environment.

D. Summary

If released into water, sodium hypophosphite and its hydrate are expected to dissociate into sodium and hypophosphite ions. The dissociation of sodium hypophosphite into its component ions indicates that it will not volatilize from water surfaces or bioconcentrate in aquatic organisms. The sodium ion is expected to participate in ion exchange reactions with charged surfaces of suspended sediments and sediment in the water column. If released into soil, sodium hypophosphite and its hydrate are expected to dissociate into its component ions in moist soils. As a result, sodium hypophosphite is not expected to volatilize from moist soil surfaces. The mobility of sodium ions will be retarded by ion exchange processes with charged surfaces of soil particles. However, since the sodium ion is held weakly by ion exchange processes, it may leach into groundwater. Phosphinic acid and its salts are a strong reducing agents; they are oxidized to phosphonic acid or phosphonate (H_3PO_3 or HPO_3^{2-}). It is unclear how rapidly this process will occur in either soil or water environments. The low vapor pressure expected for an ionic salt indicates that neither sodium hypophosphite nor its monohydrate are expected to volatilize from dry soil surfaces. If released to the atmosphere, the low vapor pressure expected for an ionic salt indicates that sodium hypophosphite will exist as a particulate in the ambient atmosphere. Wet and dry deposition will be the dominant fate process in the atmosphere.

CHEMICAL SUMMARY FOR STANNOUS METHANESULFONIC ACID

This summary is based on information retrieved from a systematic search limited to secondary sources. The only exception is summaries of studies from unpublished TSCA submissions that may have been included. These sources include online databases, unpublished EPA information, government publications, review documents, and standard reference materials. No attempt has been made to verify information in these databases and secondary sources.

I. CHEMICAL IDENTITY AND PHYSICAL/CHEMICAL PROPERTIES

The chemical identity and physical/chemical properties of stannous methanesulfonic acid are summarized in Table 1.

TABLE 1. CHEMICAL IDENTITY AND CHEMICAL/PHYSICAL PROPERTIES OF STANNOUS METHANESULFONIC ACID

Characteristic/Property	Data	Reference
CAS No.	53408-94-9	CAS (1998)
Molecular Formula	$C_2H_8O_6S_2Sn$	SRC (1998)
Chemical Structure	$[H_3CS(O)(O)O]Sn[OS(O)(O)CH_3]$	SRC (1998)
Physical State	no data	
Molecular Weight	310.89	SRC (1998)
Melting Point	no data	
Boiling Point	no data	
Water Solubility	no data	
Density	no data	
Vapor Density (air = 1)	no data	
Koc	no data; expected to be <10	Estimated
Log Kow	no data; expected to be <1	Estimated
Vapor Pressure	no data; expected to be $<10^{-6}$ mm Hg at 25°C	Estimated
Reactivity	no data	
Flammability	no data	
Flash Point	no data	
Dissociation Constant	no data	
Molecular Diffusivity Constant	no data	
Air Diffusivity Constant	no data	
Henry's Law Constant	no data; expected to be $<10^{-8}$	Estimated
Fish Bioconcentration Constant	no data	
Odor Threshold	no data	

II. ENVIRONMENTAL FATE

A. Aquatic Fate

If stannous methanesulfonic acid is released into water, it is expected to dissociate into tin (Sn^{2+}) and methanesulfonate ($CH_3SO_3^-$) ions. The dissociation of stannous methanesulfonic acid into its component ions indicates that stannous methanesulfonic acid is not expected to bioconcentrate in aquatic organisms or volatilize from water surfaces. Ionic tin may adsorb to charged surfaces of suspended sediments and humic materials in the water column (Evans, 1989). Methanesulfonic acid has a pKa of -1.86 (Serjeant and Dempsey, 1979 as cited in PHYSPROP, 1998) indicating that it will exist in the ionized at pH values typically encountered in the environment. Therefore, volatilization of methanesulfonate from water surfaces is not expected to be an important fate process. Methanesulfonate ions may adsorb to charged surfaces of suspended solids and sediment in the water column, although the importance of this process in the environment is not known. Limited data indicate that biodegradation of methanesulfonate may be an important fate process (HSDB, 1998). An estimated BCF of 3 for methanesulfonic acid (Meylan et al., 1997) suggests the potential for bioconcentration in aquatic organisms is low (Franke et al., 1994).

B. Atmospheric Fate

If stannous methanesulfonic acid is released to the atmosphere, the low vapor pressure expected for an ionic salt indicates that it will exist as a particulate. Dry deposition of stannous methanesulfonic acid is expected to be the dominant fate process in the atmosphere (Arimoto, 1989). The rate of dry deposition will depend on the prevailing winds and particle size (Bodek et al., 1988). Wet deposition of stannous methanesulfonic acid may occur (Arimoto, 1989) in rain, snow, or fog.

C. Terrestrial Fate

If stannous methanesulfonic acid is released to soil, it is expected to dissociate into its component ions in moist soils. The dissociation of stannous methanesulfonic acid into its component ions in moist soils indicates that stannous methanesulfonic acid is not expected to volatilize from moist soil surfaces. The low vapor pressure expected for an ionic salt indicates that stannous methanesulfonic acid is not expected to volatilize from dry soil surfaces. Ionic tin may adsorb to charged surfaces of soil particles or form inner sphere complexes with variable-charge soil surfaces (Evans, 1989) and therefore its rate of migration through soil may be slow. Methanesulfonic acid has a pKa of -1.86 (Serjeant and Dempsey, 1979 as cited in PHYSPROP, 1998) indicating it will exist in the ionized form in moist soils in the environment. Therefore, volatilization of methanesulfonate from moist soil surfaces will not occur. Methanesulfonate ions may adsorb to charged surfaces of soil particles, however the importance of this process in the environment is unknown. Limited data indicate that biodegradation of methanesulfonate may be an important fate process (HSDB, 1998).

D. Summary

If released into water, stannous methanesulfonic acid is expected to dissociate into tin and methanesulfonate ions. The dissociation of stannous methane sulfonic acid into it component ions indicates that stannous methanesulfonic acid is not expected to bioconcentrate in aquatic organisms nor volatilize from water surfaces. Ionic tin may adsorb to charged surfaces of suspended sediments and humic materials in the water column. Methanesulfonate ions may adsorb to charged surfaces of suspended sediments and humic materials in the water column, however the importance of this process in the environment is unknown. If released to soil, stannous methanesulfonic acid is expected to dissociate into its component ions in moist soils. The dissociation of stannous methanesulfonic acid into its component ions in moist soils indicates that volatilization from soil surfaces is not expected to be an important fate process. Ionic tin may adsorb to charged surfaces of soil particles or form inner sphere complexes with variable-charge soil surfaces and therefore its rate of migration through soil may be slow. Methanesulfonate ions may adsorb to charged surfaces of soil particles, however the importance of this process in the environment is unknown. The low vapor pressure expected for an ionic salt indicates that stannous methanesulfonic acid is not expected to volatilize from dry soil surfaces. Limited data indicate that biodegradation of methanesulfonate may be an important fate process. If released to the atmosphere, stannous methanesulfonic acid is expected to exist as a particulate in the ambient atmosphere based upon the low vapor pressure expected for an ionic salt. Wet and dry deposition will be the dominant fate process in the atmosphere. The rate of dry deposition will depend on the prevailing winds and particle size.

CHEMICAL SUMMARY FOR SULFURIC ACID

This summary is based on information retrieved from a systematic search limited to secondary sources. The only exception is summaries of studies from unpublished TSCA submissions that may have been included. These sources include online databases, unpublished EPA information, government publications, review documents, and standard reference materials. No attempt has been made to verify information in these databases and secondary sources.

I. CHEMICAL IDENTITY AND PHYSICAL/CHEMICAL PROPERTIES

The chemical identity and physical/chemical properties of sulfuric acid are summarized in Table 1.

TABLE 1. CHEMICAL IDENTITY AND CHEMICAL/PHYSICAL PROPERTIES OF SULFURIC ACID

Characteristic/Property	Data	Reference
CAS No.	7664-93-9	CAS (1998)
Common Synonyms	Battery acid	Weiss (1986)
Molecular Formula	H_2O_4S	Budavari et al. (1996)
Chemical Structure	H_2SO_4	Budavari et al. (1996)
Physical State	colorless oily liquid	Lide (1995)
Molecular Weight	98.080	Lide (1995)
Melting Point	10.31°C	Lide (1995)
Boiling Point	337°C	Lide (1995)
Water Solubility	1000 g/L at 25° C	Gunther et al. (1968) as cited in PHYSPROP (1998)
Density	1.8 g/cm^3	Lide (1995)
Vapor Density (air = 1)	not pertinent	Weiss (1986)
Koc	no data; expected to be <10	Estimated
Log Kow	no data; expected to be <1	Estimated
Vapor Pressure	$5.98X10^{-5}$ mm Hg at 25°C	Daubert and Danner (1987)
Reactivity	very reactive, dissolves most metals; concentrated acid oxidizes, dehydrates, or sulfonates most organic compounds, often causes charring.	Lewis (1993)
Flammability	not flammable	Weiss (1986)
Flash Point	not flammable	Weiss (1986)
Dissociation Constant	$pK_{a1} = -3.00$, $pK_{a2} = 1.99$	Bodek et al. (1988)
Molecular Diffusivity Constant	no data	
Air Diffusivity Constant	no data	
Henry's Law Constant	no data; expected to be $<1X10^{-8}$	Estimated
Fish Bioconcentration Constant	no data	
Odor Threshold	greater than 1 mg/m^3	Weiss (1986)

II. ENVIRONMENTAL FATE

A. Aquatic Fate

If sulfuric acid is released into the water column at low concentrations, a pK_{a1} of -3.00 (Bodek et al., 1988) indicates sulfuric acid will dissociate into bisulfate (HSO_4^-) and hydrogen (H^+) ions. In virtually all natural waters, the bisulfate ion will also dissociate into sulfate (SO_4^{2-}) and hydrogen ions based upon a pK_a of 1.99 (Bodek et al., 1988). Sulfuric acid will form salts with basic components in water. The dissociation of sulfuric acid into its component ions indicates that sulfuric acid is not expected to volatilize from water surfaces or bioconcentrate in aquatic organisms. Sulfate ions may participate in oxidation-reduction reactions or react with cations present in the water column to form soluble complexes or insoluble precipitates (Bodek et al., 1988). Sulfate-reducing microorganisms are important mediators in redox reactions involving this ion (Bodek et al., 1988). Large releases of the concentrated acid into water, such as may result from a spill, will result in a lowering of the pH (Bodek et al., 1988).

B. Atmospheric Fate

If sulfuric acid is released to the atmosphere, its vapor pressure (Daubert and Danner, 1987) indicates it will exist as a particulate in the ambient atmosphere. Wet deposition of sulfuric acid in rain, snow, or fog is expected to be the dominant fate process in the atmosphere (Arimoto, 1989) based upon its high water solubility (Gunther et al., 1968 as cited in PHYSPROP, 1998). In the atmosphere, SO_2 is oxidized to sulfuric acid (Graedel et al., 1986).

C. Terrestrial Fate

If sulfuric acid is released to soil, it will dissociate into sulfate and hydrogen ions in moist soils and will form salts with basic soil components. The dissociation of sulfuric acid into its component ions indicates that volatilization from moist soil surfaces is not expected to occur. Sulfate is generally weakly retained by soils (Bodek et al., 1988) and therefore it may leach into groundwater. Adsorption of the sulfate ion may be important in humic soils containing Al and Fe oxides (Bodek et al., 1988). Sulfuric acid's vapor pressure (Daubert and Danner, 1987) indicates that volatilization from dry soil surfaces is not expected to be an important fate process.

D. Summary

If released into water, sulfuric acid will dissociate into sulfate (SO_4^{2-}) and hydrogen (H^+) ions. Therefore, sulfuric acid is not expected to adsorb to suspended solids or sediment in the water column, bioconcentrate in aquatic organisms, nor volatilize from water surfaces. Sulfate ions may participate in redox reactions or react with cations present in the water column. Sulfate-reducing microorganisms have been identified as important mediators in redox reactions involving the sulfate ion. Sulfuric acid will form salts with basic components in water. If released to soil, sulfuric acid is expected to dissociate into its component ions in moist soils and will form salts with basic soil components. The dissociation of sulfuric acid into its component ions indicates that volatilization from moist soil surfaces is not expected to be an important fate process. In general, sulfate is weakly retained by soils and therefore it may leach into groundwater. Adsorption of the sulfate ion may be important in soils with high organic matter content or soils containing Al and Fe oxides. Sulfuric acid's vapor pressure indicates that volatilization from dry soil surfaces is not expected to occur. If released to the atmosphere, sulfuric acid is expected to exist as a particulate. Sulfuric acid is expected to be physically removed from the atmosphere by wet deposition based upon its high water solubility.

CHEMICAL SUMMARY FOR THIOUREA

This summary is based on information retrieved from a systematic search limited to secondary sources. The only exception is summaries of studies from unpublished TSCA submissions that may have been included. These sources include online databases, unpublished EPA information, government publications, review documents, and standard reference materials. No attempt has been made to verify information in these databases and secondary sources.

I. CHEMICAL IDENTITY AND PHYSICAL/CHEMICAL PROPERTIES

The chemical identity and physical/chemical properties of thiourea are summarized in Table 1.

TABLE 1. CHEMICAL IDENTITY AND CHEMICAL/PHYSICAL PROPERTIES OF THIOUREA

Characteristic/Property	Data	Reference
CAS No.	62-56-6	CAS (1998)
Common Synonyms	Thiocarbamide	Lide (1995)
Common Synonyms	Urea, 2-thio	Howard and Neal (1992)
Molecular Formula	CH_4N_2S	Lide (1995)
Chemical Structure	$H_2NC(=S)NH_2$	Budavari et al. (1996)
Physical State	crystals	Budavari et al. (1996)
Molecular Weight	76.12	Lide (1995)
Melting Point	182°C	Lide (1995)
Boiling Point	no data	
Water Solubility	201 g/L at 20°C	Yalkowsky and Dannenfelser (1992)
Density	1.405 g/cm^3 at 25°C	Lide (1995)
Vapor Density (air = 1)	no data	
Koc	no data; estimated to be 2.8	Meylan et al. (1992)
Log Kow	-1.02	Hansch et al. (1995)
Vapor Pressure	3.11×10^{-4} mm Hg at 25°C (extrapolated)	Daubert and Danner (1992)
Reactivity	no data	
Flammability	no data	
Flash Point	no data	
Dissociation Constant	no data	
Molecular Diffusivity Constant	no data	
Air Diffusivity Constant	no data	
Henry's Law Constant	no data; estimated to be 1.6×10^{-7}	Meylan and Howard (1991)
Fish Bioconcentration Constant	<0.2 to <2 in carp	Chemicals Inspection and Testing Institute (1992)
Odor Threshold	no data	

II. ENVIRONMENTAL FATE

A. Aquatic Fate

If thiourea is released into water, an estimated Koc value of 2.8 (Meylan et al., 1992) indicates that thiourea is not expected to adsorb to suspended solids and sediment in the water column (Swann et al., 1983). According to a classification scheme (Franke et al., 1994), BCFs of <0.2 and <2 in carp (Chemicals Inspection and Testing Institute, 1992) indicate that bioconcentration in aquatic organisms is low. An estimated Henry's Law constant of 1.6×10^{-7} atm m^3/mole at 25°C (Meylan and Howard, 1991) indicates that thiourea is expected to be essentially nonvolatile from water surfaces (Lyman et al., 1990). Thiourea has been demonstrated to be resistant to biodegradation in a variety of standard biodegradation tests (HSDB, 1998). Thiourea reached 2.6% of its theoretical biological oxygen demand over 2 weeks in the Japanese MITI test using an activated sludge seed and an initial chemical concentration of 30 mg/L (Chemicals Inspection and Testing Institute, 1992). In the OECD-screening test, 3% degradation was observed (Schmidt-Bleek et al., 1982 as cited in HSDB, 1998) and 17% CO_2 evolution was measured in a 5-day German GSF Biodegradation Test (Rott et al., 1982 as cited in HSDB, 1998). Thiourea is stable to hydrolysis at environmental pHs (Schmidt-Bleek et al., 1982 as cited in HSDB, 1998).

B. Atmospheric Fate

If thiourea is released to the atmosphere, an extrapolated vapor pressure of $3.11X10^{-4}$ mm Hg at 25°C (Daubert and Danner, 1992) indicates that thiourea will exist as a gas in the ambient atmosphere (Bidleman, 1988). The rate constant for the gas-phase reaction of urea with photochemically-produced hydroxyl radicals has been estimated to be $4.2X10^{-11}$ cm^3/molecule-sec at 25° C (Meylan and Howard, 1993); this corresponds to a half-life of 9.2 hours.

C. Terrestrial Fate

If thiourea is released to soil, an estimated Koc value of 2.8 (Meylan et al., 1992) indicates that thiourea is expected to have very high mobility in soils (Swann et al., 1983). Thiourea is not expected to volatilize from moist soil surfaces (Lyman et al., 1990) based upon its estimated Henry's Law constant (Meylan and Howard, 1991) or from dry soils based on its vapor pressure. Biodegradation of thiourea by soil microorganisms may be an important fate process, although microflora activity may be suppressed for extended periods of time by high concentrations of this compound (HSDB, 1998). Degradation of thiourea was also observed in sterilized soils (Kolyada, 1969 as cited in HSDB, 1998) indicating that abiotic degradation may be an important fate process.

D. Summary

If released into water, thiourea is not expected to be adsorb to suspended solids and sediment in the water column. Bioconcentration in aquatic organisms and volatilization from water surfaces are not expected to be important fate processes. Several biodegradation tests indicate that thiourea may be resistant to biodegradation. Thiourea is stable to hydrolysis at environmental pHs. If released to the atmosphere, thiourea is expected to exist as a gas in the ambient atmosphere based upon its extrapolated vapor pressure. Gas-phase thiourea is expected to be degraded in the atmosphere by reaction with photochemically-produced hydroxyl radicals; the half-life for this reaction in air has been estimated to be 9.2 hours. If released to soil, thiourea is expected to have very high mobility and therefore may leach into groundwater. Volatilization from moist or dry soil surfaces is not expected to be an important fate process. Biotic and abiotic degradation of thiourea may be important fate processes, however, no rates were available for these processes. High concentrations of thiourea may suppress the activity of soil microorganisms for extended periods of time.

CHEMICAL SUMMARY FOR TIN

This summary is based on information retrieved from a systematic search limited to secondary sources. The only exception is summaries of studies from unpublished TSCA submissions that may have been included. These sources include online databases, unpublished EPA information, government publications, review documents, and standard reference materials. No attempt has been made to verify information in these databases and secondary sources. The search identified sources of information for Tin.

I. CHEMICAL IDENTITY AND PHYSICAL/CHEMICAL PROPERTIES

The chemical identity and physical/chemical properties of Tin are summarized in Table 1.

TABLE 1. CHEMICAL IDENTITY AND CHEMICAL/PHYSICAL PROPERTIES OF TIN

Characteristic/Property	**Data**	**Reference**
CAS No.	7440-31-5	Howard and Neal (1992)
Common Synonyms	Tin white	Weast (1983)
Molecular Formula	Sn	Howard and Neal (1992)
Chemical Structure		
Physical State	Metal	Budavari et al. (1996)
Molecular Weight	118.69	Budavari et al. (1996)
Melting Point	231.9°C	Weast (1983)
Boiling Point	2260°C	Weast (1983)
Water Solubility	Insoluble	Weast (1983)
Density	7.31g/mL	Weast (1983)
Vapor Density (air = 1)	no data	
Koc	no data	
Log Kow	no data	
Vapor Pressure	no data	
Reactivity	Flammable solid	Budavari et al. (1996)
Flammability	no data	
Flash Point	no data	
Dissociation Constant	no data	
Molecular Diffusivity Constant	no data	
Air Diffusivity Constant	no data	
Henry’s Law Constant	no data	
Fish Bioconcentration Constant	no data	
Odor Threshold	no data	

CHEMICAL SUMMARY FOR TIN CHLORIDE

This summary is based on information retrieved from a systematic search limited to secondary sources. The only exception is summaries of studies from unpublished TSCA submissions that may have been included. These sources include online databases, unpublished EPA information, government publications, review documents, and standard reference materials. No attempt has been made to verify information in these databases and secondary sources.

I. CHEMICAL IDENTITY AND PHYSICAL/CHEMICAL PROPERTIES

The chemical identity and physical/chemical properties of tin chloride are summarized in Table 1.

TABLE 1. CHEMICAL IDENTITY AND CHEMICAL/PHYSICAL PROPERTIES OF TIN CHLORIDE

Characteristic/Property	Data	Reference
CAS No.	7772-99-8	CAS (1998)
Common Synonyms	Tin (II) chloride	Lide (1995)
Common Synonyms	Stannous chloride	Lewis (1993)
Molecular Formula	Cl_2Sn	Sax (1984)
Chemical Structure	$SnCl_2$	Lide (1995)
Physical State	white orthorhombic crystals	Lide (1995)
Molecular Weight	189.615	Lide (1995)
Melting Point	247°C	Lide (1995)
Boiling Point	623°C	Lide (1995)
Water Solubility	approximately 600 g/L [1]	Estimated
Density	3.90 g/cm^3	Lide (1995)
Vapor Density (air = 1)	no data	
Koc	no data; expected to be <10	SRC (1998)
Log Kow	no data; expected to be <1	SRC (1998)
Vapor Pressure	no data; expected to be $< 10^{-6}$ mm Hg	SRC (1998)
Reactivity	violent reactions with BrF_3, CaC_2, ethylene oxide, hydrazine hydrate, nitrates, K, Na, H_2O_2	Sax (1984)
Flammability	no data	
Flash Point	no data	
Dissociation Constant	expected to dissociate into Sn^{2+} and Cl^-	SRC (1998)
Molecular Diffusivity Constant	no data	
Air Diffusivity Constant	no data	
Henry's Law Constant	no data; expected to be $<1X10^{-8}$	SRC (1998)
Fish Bioconcentration Constant	no data	
Odor Threshold	no data	

[1] Estimated from a reported solubility of 84 parts in 100 parts water (Dean, 1985).

II. ENVIRONMENTAL FATE

A. Aquatic Fate

Water hydrolyzes tin halides (Cotton and Wilkinson, 1980). Therefore, if tin chloride is released into water, it is expected to dissociate into tin (Sn^{2+}) and chloride (Cl^-) ions. In waters containing excess chloride ion, tin chloride is expected to dissolve, yielding $SnCl_3^-$ (Cotton and Wilkinson, 1980). As a result, tin chloride is not expected to volatilize from water surfaces or bioconcentrate in aquatic organisms. Ionic tin may adsorb to charged surfaces of suspended sediments and humic materials in the water column (Evans, 1989). The chloride ion may complex with heavy metals, thereby increasing their solubility (Bodek et al., 1988). Adsorption of the chloride ion to suspended solids and sediment in the water column is not expected to be an important fate process.

B. Atmospheric Fate

If tin chloride is released to the atmosphere, the low vapor pressure expected for an ionic salt indicates that it will exist as a particulate. Dry deposition of tin chloride is expected to be the dominant fate process in the atmosphere (Arimoto, 1989). The rate of dry deposition will depend on the prevailing winds and particle size (Bodek et al., 1988). Tin chloride is expected to undergo wet deposition (Arimoto, 1989) in rain, snow, or fog due to its high water solubility (Dean, 1985).

C. Terrestrial Fate

Water hydrolyzes tin halides (Cotton and Wilkinson, 1980). Therefore, if tin chloride is released to soil, it is expected to dissociate into its component ions in moist soils. Ionic tin may adsorb to charged surfaces of soil particles or form inner sphere complexes with variable-charge soil surfaces (Evans, 1989) and therefore its rate of migration through soil may be slow. The dissociation of tin chloride into its component ions in moist soils indicates that tin chloride is not expected to volatilize from moist soil surfaces. The low vapor pressure expected for an ionic salt indicates that tin chloride is not expected to volatilize from dry soil surfaces. Chloride is extremely mobile in soils (Bodek et al., 1988). The chloride ion may complex with heavy metals, thereby increasing their solubility (Bodek et al., 1988) and potential for leaching into groundwater.

D. Summary

If released into water, tin chloride is expected to dissociate into tin and chloride ions. The dissociation of tin chloride into its component ions indicates that tin chloride is not expected to volatilize from water surfaces or bioconcentration in aquatic organisms. Ionic tin may adsorb to charged surfaces of suspended sediments and humic materials in the water column. The chloride ion may complex with heavy metals, thereby increasing their solubility. Adsorption of the chloride ion to suspended solids and sediment in the water column is not expected to be an important fate process. If released to soil, tin chloride is expected to dissociate into its component ions in moist soils. The dissociation of tin chloride into its component ions in moist soils indicates that tin chloride is not expected to volatilize from moist soil surfaces. The low vapor pressure expected for an ionic salt indicates that tin chloride is not expected to volatilize from dry soil surfaces. Ionic tin may adsorb to charged surfaces of soil particles or form inner sphere complexes with variable-charge soil surfaces and therefore its rate of migration through soil may be slow. The chloride ion is extremely mobile in soils; it may complex heavy metals, thereby increasing their solubility and the potential to leach into groundwater. If released to the atmosphere, tin chloride is expected to exist as a particulate in the ambient atmosphere based upon the low vapor pressure expected for an ionic salt. Wet and dry deposition will be the dominant fate process in the atmosphere. The rate of dry deposition will depend on the prevailing winds and particle size.

CHEMICAL SUMMARY FOR UREA

This summary is based on information retrieved from a systematic search limited to secondary sources. The only exception is summaries of studies from unpublished TSCA submissions that may have been included. These sources include online databases, unpublished EPA information, government publications, review documents, and standard reference materials. No attempt has been made to verify information in these databases and secondary sources.

I. CHEMICAL IDENTITY AND PHYSICAL/CHEMICAL PROPERTIES

The chemical identity and physical/chemical properties of urea are summarized in Table 1.

TABLE 1. CHEMICAL IDENTITY AND CHEMICAL/PHYSICAL PROPERTIES OF UREA

Characteristic/Property	Data	Reference
CAS No.	57-13-6	CAS (1998)
Common Synonyms	Carbamide	Lide (1995)
Common Synonyms	Carbonyldiamide	Budavari et al. (1996)
Molecular Formula	CH_4N_2O	Lide (1995)
Chemical Structure	$H_2NC(=O)NH_2$	Budavari et al. (1996)
Physical State	Tetragonal prisms	Budavari et al. (1996)
Molecular Weight	60.06	Lide (1995)
Melting Point	132.7°C	Lide (1995)
Boiling Point	decomposes	Lide (1995)
Water Solubility	545 g/L at 25°C	Yalkowsky and Dannenfelser (1992)
Density	1.3230 g/cm^3 at 20°C	Lide (1995)
Vapor Density (air = 1)	not pertinent	Weiss (1986)
Koc	8	Hance (1965) as cited in HSDB (1998)
Log Kow	-2.11	Hansch et al. (1995)
Vapor Pressure	1.2X10^{-5} mm Hg at 25°C (extrapolated)	Jones (1960) as cited in PHYSPROP (1998)
Reactivity	no reaction with water or common materials	Weiss (1986)
Flammability	not flammable	Weiss (1986)
Flash Point	not flammable	Weiss (1986)
Dissociation Constant	no data	
Molecular Diffusivity Constant	no data	
Air Diffusivity Constant	no data	
Henry's Law Constant	no data; estimated to be less than 1X10^{-8}	PHYSPROP (1998)
Fish Bioconcentration Constant	<10	Freitag et al. (1985) as cited in HSDB (1998)
Odor Threshold	not pertinent	Weiss (1986)

II. ENVIRONMENTAL FATE

A. Aquatic Fate

If urea is released into water, a Koc value of 8 (Hance, 1965 as cited in HSDB, 1998) indicates that urea is not expected to adsorb to suspended solids and sediment in the water column (Swann et al., 1983). According to a classification scheme (Franke et al., 1994), a BCF of <10 in golden ide (Freitag et al., 1985 as cited in HSDB, 1998) indicates that bioconcentration in aquatic organisms is low. An estimated Henry's Law constant of <1X10^{-8} atm m^3/mole at 25°C (PHYSPROP, 1998) indicates that urea is expected to be essentially nonvolatile from water surfaces (Lyman et al., 1990). In natural waters, biodegradation of urea is expected to be an important fate process; ammonia and carbon dioxide have been identified as degradation products (HSDB, 1998). The rate of biodegradation is expected to decrease with decreasing temperatures; at 8°C, negligible degradation was observed after incubation in river water for 14 days, while at 20°C complete degradation was observed after 4 to 6 days incubation (Evans and Patterson, 1973 as cited in HSDB, 1998). The presence of naturally-occurring phytoplankton in water is expected to increase the rate of biodegradation (HSDB, 1998). Urea is used as an agricultural fertilizer (Lewis, 1993) and will be taken up by plants as a source of nitrogen. Abiotic hydrolysis of urea occurs slowly yielding ammonium carbamate (HSDB, 1998). At 5°C, 0.35% of urea hydrolyzed during a 10-day test period in demineralized/distilled water (Atkinson, 1971 as cited in HSDB, 1998).

B. Atmospheric Fate

If urea is released to the atmosphere, a vapor pressure of $1.2X10^{-5}$ mm Hg at 25°C (Jones, 1960 as cited in PHYSPROP, 1998) indicates that urea will exist as both a particulate and a gas in the ambient atmosphere (Bidleman, 1988). The rate constant for the gas-phase reaction of urea with photochemically-produced hydroxyl radicals has been estimated to be $2.0X10^{-12}$ cm^3/molecule-sec at 25° C (Meylan and Howard, 1993); this corresponds to a half-life of 8.0 days. Particulate-phase urea is expected to be physically removed from the atmosphere by wet and dry deposition (Arimoto, 1989).

C. Terrestrial Fate

If urea is released to soil, it is expected to hydrolyze to ammonia through soil urease activity (HSDB, 1998). The rate of hydrolysis can range from 24 hours to weeks depending upon soil type, moisture content, and urea formulation (Malhi and Nyborg, 1979 as cited in HSDB, 1998). Urea is used as an agricultural fertilizer (Lewis, 1993) and will be taken up by plants as a source of nitrogen. While no specific studies were identified in the literature, it is anticipated that urea will biodegrade rapidly in soil as has been reported in water. A Koc value of 8 (Hance, 1965 as cited in HSDB, 1998) indicates that urea is expected to have very high mobility in soils (Swann et al., 1983). Urea is not expected to volatilize from soil surfaces based upon its vapor pressure and estimated Henry's Law constant.

D. Summary

If released into water, urea is expected to be biodegraded yielding ammonia and carbon dioxide. Biodegradation is expected to be more rapid in waters containing phytoplankton and during summer months when warmer water temperatures prevail. Urea will be taken up by plants and used as a source of nitrogen. Bioconcentration in aquatic organisms, adsorption to suspended solids and sediment in the water column, and volatilization from water surfaces are not expected to be important fate processes. If released to the atmosphere, urea is expected to exist as both a particulate and as a gas based upon its vapor pressure. Gas-phase urea is expected to be degraded in the atmosphere by reaction with photochemically-produced hydroxyl radicals; the half-life for this reaction in air has been estimated to be 8.0 days. Particulate-phase urea is expected to be physically removed from the atmosphere by wet and dry deposition. The rate of dry deposition will depend upon particle size and prevailing wind patterns. If released to soil, urea is expected to hydrolyze to ammonia through the activity of soil urease as well as biodegrade as is the case in water. The rate of hydrolysis can range from 24 hours to weeks depending upon soil type, moisture content, and urea formulation. Urea is used an agricultural fertilizer as a source of nitrogen. Urea is expected to have very high mobility in soils and therefore may leach into groundwater. Volatilization from moist and dry soil surfaces is not expected to be an important fate process.

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Appendix D

Supplemental Exposure Assessment Information

Technical Memorandum RE: Modeling Worker Inhalation Exposure

D.1 Technical Memorandum RE: Modeling Worker Inhalation Exposure

TECHNICAL MEMORANDUM

TO: Debbie Boger
PWB Project File, EPA # X823941-01-0

cc: Lori Kincaid, Jack Geibig, Dean Menke, Diane Perhac

FROM: Bruce Robinson, Chris Cox, Nick Jackson, Mary Swanson

DATE: December 22, 1995 (Revised 8/96)

RE: MODELING WORKER INHALATION EXPOSURE

I. INTRODUCTION

This technical memorandum is submitted for review by the RM2 work group. Air transport models to estimate worker inhalation exposure to chemicals from printed wiring board (PWB) making holes conductive (MHC) lines are presented here for review and comment. The purpose is to reach agreement on our technical approach before proceeding with further analysis.

Three air transport models will be required to estimate worker exposure:

- Volatilization of chemicals induced by air sparging.
- Aerosol generation induced by air sparging.
- Volatilization of chemicals from the open surface of MHC tanks.

The total transport of chemicals from the air-sparged baths will be determined by summing the releases calculated using each of the three models described above. Air-sparged baths include the electroless-copper baths and some cleaning tanks. Only the third model will be applied to determine the atmospheric releases of chemicals from unsparged baths. This document includes a review of the relevant literature, descriptions of the models, and examples demonstrating the proposed use of the models. The results of the model calculations will be compared to available occupational monitoring data.

II. VOLATILIZATION OF CHEMICALS FROM AIR-SPARGED PWB MANUFACTURING TANKS

Mixing in plating tanks, e.g., the electroless copper plating tank, is commonly accomplished by sparging the tank with air. This is similar to aeration in wastewater treatment plants, and the volatilization of chemicals from these plants has been the focus of recent research. The volatilization models used in that research are based on well accepted gas transfer theory, discussed below.

Background

Volatilization of chemicals from water to air has been investigated by many researchers (Liss and Slater, 1974; Smith *et al.*, 1980; Roberts, 1983; Peng *et al.*, 1993). In PWB manufacturing, volatilization due to air sparging of process tanks is expected to be one of the main pathways for contaminant transfer to the air. In bubble aeration systems, the volatilization rate is dependent upon the volumetric gas flow rate, partial pressure of the gas, and the mass transfer rate coefficient (Matter-Müller, 1981). The volatilization characteristics for different diffuser types and turbulent conditions were evaluated by Matter-Müller (1981), Peng (1995), and Hsieh (1994).

Volatilization from aerated systems has been mainly quantified using the two-film theory (Cohen *et al.*,1978; Mackay and Leinonen, 1975). This work is discussed below and is used to model chemical transfer rates from air-sparged PWB process tanks. The main assumption of the theory is that the velocity at a fluid interface is zero. Molecular diffusion across the interfacial liquid film is the limiting factor for mass transfer to the air, and it is used to develop a simple equation relating the overall mass transfer coefficient to the diffusion coefficient of the chemical in water.

The two-film model of gas transfer was expanded to include mass transfer in diffused aeration systems (Matter-Müller *et al.*, 1981). Matter-Müller *et al.* assumed that the system was isothermal, hydraulic conditions were steady, and that pressure and volume changes within the bubbles were negligible. Further, an overall mass transfer coefficient was applied to represent transfer of contaminants to the bubble as they rose through the homogeneous liquid volume. Parker (1993) demonstrated that liquid-phase concentration can be assumed constant during the rise time of the bubble. Under these assumptions, Matter-Müller *et al.* derived the following relationship predicting the mass transfer rate from an aerated system:

$$F_{y,s} = Q_G H_y c_{L,y} \left[1 - \exp\left(-\frac{K_{OL,y} a V_L}{H_y Q_G} \right) \right] \qquad (1)$$

where:

$F_{y,s}$ = mass transfer rate of chemical *y* out of the system by sparging (m/t)
Q_G = gas flow rate (l^3/t)
H_y = dimensionless Henry's constant for chemical *y*
$c_{L,y}$ = concentration of chemical *y* in bulk liquid (m/l^3)
$K_{OL,y}$ = overall mass transfer coefficient for chemical *y* (l/t)

a = interfacial area of bubble per unit volume of liquid (l^2/l^3)
V_L = volume of liquid (l^3)

The overall mass-transfer coefficient is defined as the inverse sum of the reciprocals of the liquid and gas-phase mass transfer coefficients; but, because molecular diffusion of oxygen and nonpolar organic substances is 10^3 times greater in air than in water (Matter-Müller *et al.*, 1981), it is set equal to the liquid phase coefficient only. The mass transfer coefficient of a chemical can then be related to oxygen using the following equation:

$$K_{OL,y} = \left(\frac{D_y}{D_{O2}} \right) K_{OL,O2} \tag{2}$$

where:

D_y = molecular diffusion coefficient for chemical *y* in water (l^2/t)
D_{O2} = molecular diffusion coefficient for oxygen in water (l^2/t)
= 2.1×10^{-5} cm^2/cm @ 25° C (Cussler, 1984)
$K_{OL,y}$ = overall mass transfer coefficient for chemical *y* (l/t)
$K_{OL,O2}$ = overall mass transfer coefficient for oxygen in water (l/t)

The value of $K_{OL,O2}$ at 25°C in diffused aeration systems can be estimated using a correlation developed by Bailey and Ollis (1977):

$$K_{OL,O_2} = 0.31 * \left(\frac{d_b^3 (\rho_{H2O} - \rho_{air}) g}{\mu_{H2O} D_{O2}} \right)^{1/3} \frac{D_{O2}}{d_b} \tag{3}$$

where:

d_b = bubble diameter (l)
ρ_{H2O} = density of water (m/l^3)
ρ_{air} = density of air (m/l^3)
g = gravitational constant (l/t^2)
μ_{H2O} = viscosity of water ($m/l \cdot t$)

If a measured value of D_y is not available, then it can be calculated from the Hayduk and Laudie correlation (Lyman *et al.*, 1982):

$$D_y (cm^2/\text{sec}) = \frac{13.26 x 10^{-5}}{\mu_{H2O}^{1.14} \; V_m^{0.589}} \tag{4}$$

where:

V_m = molar volume of solute (cm^3/mol)
μ_{H2O} = viscosity of water (centipoise)

The mass transfer coefficient can be corrected for the bath temperature (°C) as follows (Tschabanoglous, 1991):

$$K_{OL,y,T} = K_{OL,y,25^{o}C}\ 1.024^{(T-25)} \qquad (5)$$

Bailey and Ollis (1977) developed a relationship for the interfacial area per unit volume (a) as a function of the bubble diameter, gas flow rate, and tank geometry:

$$a = \frac{6\ Q_G\ t_b}{V_L\ d_b} \qquad (6)$$

where:

h = tank depth (l); and

$$t_b = \frac{18\ h\ \mu_{H2O}}{d_b^2\ (\rho_{H2O} - \rho_{air}) g} \qquad (7)$$

Values of H_y are often reported at 25°C. The Henry's constant can be corrected to the bath temperature using the van't Hoff equation:

$$H_{y,T} = H_{y,25^{o}C} \exp\left[\frac{\Delta H_{gas} - \Delta H_{aq}}{R}\left(\frac{1}{298.15} - \frac{1}{273.15 + T}\right)\right] \qquad (8)$$

where:

$\Delta\eta_{gas}$ = enthalpy of the chemical in the gas phase (cal/mol)
ΔH_{aq} = enthalpy of the chemical in the aqueous phase (cal/mol)
R = gas constant (1.987 cal/mol·K)

Matter-Müller (1981) concluded that surfactants do not significantly alter the rate of volatilization from the water. Some agents did lower the overall mass transfer coefficient, but most showed no appreciable difference. This was attributed to an increase in the specific interfacial area, *a*, when the interfacial energy, or mass transfer coefficient, was decreased. The transfer rate of volatile organic compounds (VOCs) was found to depend heavily upon the type of aerators used, and the degree of saturation of the bubbles rising through the liquid.

III. AEROSOL GENERATION FROM BATHS MIXED BY SPARGING WITH AIR

Aerosols or mists have been identified as a major source of contaminants released by electroplating baths to the atmosphere (Burgess, 1981) and should be investigated as a potential source of contaminants from electroless baths. At least two sources of aerosols exist in electroplating baths: 1) aerosols generated due to liquid dripping from parts as they are removed from the bath (drag-out drips); and 2) aerosols generated due to bursting of the bubbles at the surface. Drag-out drips are insignificant compared to other sources of aerosols (Berglund and Lindh, 1987; Cooper et al., 1993).

Bubbles in electroplating baths can originate from the dissociation of water at the electrode, or mixing of the bath via air sparging. Bubbles in other plating baths (e.g., electroless plating baths) can originate from reactions in the bath or mixing of the bath via air sparging. The rate of aerosol generation per unit bubble volume decreases with increasing bubble size. Bubbles generated by water dissociation are typically smaller than those generated by air sparging; therefore, aerosol generation in electroless plating processes may be less significant than in electroplating operations. The focus of this memo is aerosols generated by air sparging. Except for the conductive polymer and non-formaldehyde electroless alternatives, MHC processes in PWB manufacturing do not use electroplating and therefore would not dissociate water to form gas bubbles. Information collection is continuing to allow prediction of aerosol formation in MHC processes that do have an electroplating step. Importantly, Berglund and Lindh (1987) report that aerosol generation from electroplating tanks is greatly reduced by sparging; the relatively large air bubbles formed during air sparging coalesce the smaller bubbles formed by hydrolysis and electroless plating reactions.

To estimate the emission of contaminants resulting from aerosols, the rate of aerosol generation and the concentration of contaminant in the aerosol are required. Limited information concerning the rate of aerosol formation was found in the literature. The following sources were consulted:

! U.S. EPA (1991). *Chemical Engineering Branch Manual for the Preparation of Engineering Assessments*.

! Chemical Abstracts, 1986 to date.

! Current and past text books in air pollution, chemical engineering, and water and wastewater treatment.

! Perry's Handbook (1984) related to entrainment in distillation trays.

! The last five years of *Water Environment Research* and *ASCE Journal of the Environmental Engineering Division*.

! A title key-word search of holdings in the library of the University of Tennessee.

! The ASPEN model commonly used for modeling chemical manufacturing processes. (It was found that any aerosol formation routines within ASPEN would be relevant to entrainment in devices such as distillation trays and not relevant to sparging of tanks.)

! The manager of the US EPA Center for Environmental Assessment Modeling in Athens, Georgia, as well as an expert in the Air and Energy Lab - Emission Modeling Branch in North Carolina.

In this work, the aerosol formation rates will be predicted based upon limited measurements of aerosol generation in electroplating (Berglund and Lindh, 1987) and other air-sparged baths (Wangwongwatana et al., 1988; Wangwongwatana et al., 1990) found in the literature.

Berglund and Lindh (1987) developed several graphs relating aerosol generation to air sparging rate (Figure 1a), bath temperature (Figure 1b), air flow rate above the bath (Figure 1c), and distance between bath surface and the tank rim (Figure 1d). Using Figures 1a-1d, the following relationship may be developed:

$$R_A = \left[5.5x10^{-5}\left(Q_G \ / \ A\right) + 0.01\right] \ F_T \ F_A \ F_D \tag{9}$$

where:

R_A = aerosol generation rate (ml/min/m^2)
Q_G/A = air sparging rate per unit bath area (l/min/m^2)
F_T = temperature correction factor
F_A = air velocity correction factor
F_D = distance between the bath surface and tank rim correction factor

Wangwongwatana et al. (1988) presented figures relating the number of aerosol droplets generated as a function of air flow rate, bubble rise distance, bubble size, and colloid concentration (Figure 2). Droplet size distribution measurements by these researchers indicate volume mean diameters of 5 to 10 µm. The aerosol generation rate can be calculated using the following equation:

$$R_A = \frac{Q_G C_d V_d}{A} \tag{10}$$

where:

C_d = droplet concentration (l^{-3})
V_d = droplet volume (l)
A = bath area (l^2)

Contaminants may be present in aerosols at elevated concentration relative to the bath concentration. Colloidal contaminants may be collected on the bubble surface as it rises through the bath. As the bubble bursts, the contaminants on the bubble surface are incorporated into aerosols. Wangwongwatana et al. (1990) report that in their experiments about one in two aerosols contain polystyrene latex spheres, compared to about one in 250 expected based upon the concentration of latex sphere in the bath. Organic contaminants may also partition at the air-water interface. A correlation for the water-interface partitioning coefficient for nonpolar compounds, k_{IW}, defined as the ratio of the mass of contaminant per unit area of interface to the mass of contaminant per unit volume of water is given by Hoff et al. (1993):

$$\log \ k_{IW} = -8.58 \ - 0.769 \ \log \ C_W^S \tag{11}$$

where:

C^S_W = saturated aqueous solubility of the contaminant.

For more polar compounds a more complicated relationship is required:

$$\log\ k_{IW} = -7.508 + \log\ \gamma_w + a_s(\sigma_{wa} - \sigma_{sa} - 1.35\sigma_{sw})/2.303RT \tag{12}$$

where:

$(_w$ = activity coefficient of the contaminant in water (dimensionless)
a_s = molar area of the solute (cm^2/mol)
R = gas constant ($8.314x10^7$ erg/mol K)
F_{WA} = surface tension of the water-air interface (dyne/cm)
F_{SA} = surface tension of the solute-air interface (dyne/cm)
F_{SW} = surface tension of the solute-water interface (dyne/cm)

Hoff et al. (1993) also present a relationship for the ratio of the mass of contaminant sorbed at the air-water interface to the mass of contaminant in the gas volume of the bubble:

$$\frac{M_I}{M_b} = \frac{k_{IW}}{H_y(d_b\ /\ 6)} \tag{13}$$

where:

M_I = mass of contaminant at the interface
M_b = mass of contaminant in gas bubble

Only a small fraction of the bubble interface will be ejected as aerosols. It may be calculated from the following equation:

$$f_{IE} = \frac{R_A\ \ A\ d_b}{6\ Q_G\ l_b} \tag{14}$$

where:

f_{IE} = fraction of bubble interface ejected as aerosols (dimensionless)
l_b = thickness of bubble film (l)

The rate of mass transfer from the tank to the atmosphere by aerosols, $F_{y,a}$ (m/t) is given by:

$$F_{y,a} = \frac{M_I}{M_b}\ f_{IE}\ F_{y,s} \tag{15}$$

IV. VOLATILIZATION OF CHEMICALS FROM THE OPEN SURFACE OF MHC TANKS

Most plating tanks have a free liquid surface from which chemicals can volatilize into the workplace air. Air currents across the tank will accelerate the rate of volatilization. The model presented in the Chemical Engineering Branch Manual for the Preparation of Engineering Assessments (CEBMPEA) (US EPA, 1991) has potential application in this case. Some limitations of the model should be pointed out. The model was developed to predict the rate of volatilization of pure chemicals, not aqueous solutions. The model was also validated using pure chemicals. As a result, the model implicitly assumes that mass transfer resistance on the gas side is limiting. The model may fail in describing volatilization of chemicals from solutions when liquid-side mass transfer controls.

CEBMPEA models the evaporation of chemicals from open surfaces using the following model:

$$F_{y,o} = 2\, c_{L,y}\, H_y\, A\, [D_{y,air} v_z/(\pi z)]^{0.5} \tag{16}$$

where:

$F_{y,o}$ = volatilization rate of chemical *y* from open tanks (m/t)
$D_{y,air}$ = molecular diffusion coefficient of chemical *y* in air (l^2/t)
v_z = air velocity (l/t)
z = distance along the pool surface (l)

The value of v_z recommended by CEBMPEA is 100 $ft\cdot min^{-1}$. The value of $D_{y,air}$ can be estimated by the following formula (US EPA, 1991):

$$D_{y,air} = 4.09\text{x}10^{-5}\, T^{1.9}\, (1/29 + 1/M)^{0.5}\, M^{-0.33}/P_t \tag{17}$$

where:

$D_{y,air}$ = molecular diffusion coefficient of chemical *y* in air (cm^2/s)
T = air temperature (K)
M = molecular weight (g/mol)
P_t = total pressure (atm)

This equation is based on kinetic theory and generally gives values of $D_{y,air}$ that agree closely with experimental data.

V. CALCULATION OF CHEMICAL CONCENTRATION IN WORKPLACE AIR FROM EMISSION RATES

The indoor air concentration will be estimated from the following equation (US EPA, 1991):

$$C_y = F_{y,T}/(V_R\, R_V\, k) \tag{18}$$

where:

C_y = workplace contaminant concentration (m/l^3)
$F_{y,T}$ = total emission rate of chemical from all sources (m/t)
V_R = room volume (l^3/t)
R_V = room ventilation rate (t^{-1})
k = dimensionless mixing factor

The mixing factor accounts for slow and incomplete mixing of ventilation air with room air. CEBMPEA sets this factor to 0.5 for the typical case and 0.1 for the worst case. CEBMPEA commonly uses values of the ventilation rate Q from 500 ft^3/min to 3,500 ft^3/min. Appropriate ventilation rates for MHC lines will be chosen from facility data and typical industrial recommendations.

VI. EXAMPLE MODELING OF FORMALDEHYDE RELEASE TO ATMOSPHERE FROM AIR-SPARGED ELECTROLESS COPPER BATH

In the examples below, the values of some parameters are based upon a site visit to SM Corporation in Asheville, NC. Except where stated otherwise, final values of the various parameters used in the models will be chosen based on the results of the Workplace Practices Questionnaire, chemical suppliers information, site visits, and performance demonstrations. All parameter values are based on preliminary information and are subject to change.

Values of site-specific parameters assumed in the example

Tank volume = 242 L	Site visit to SM Co., Asheville, NC
Tank depth = 71 cm	Assumed
Tank width = 48 cm	Assumed
Tank length = 71 cm	Assumed
Air sparging rate = 53.80 L/min	Midpoint of values given in Perry's Handbook, 1985, pg 19.13
Tank temperature = 51.67°C	Site visit to SM Co., Asheville, NC
H2CO Concentration in tank = 7,000 mg/L	Product data sheets
Bubble diameter at tank surface = 2.00 mm	Assumed
Room length = 20 m	Assumed
Room width = 20 m	Assumed
Room height = 5 m	Assumed
Air turnovers/hour = 4 hr^{-1}	Assumed
Air velocity across tank surface = 0.508 m/s	Default recommended by US EPA, 1991
Dimensionless mixing factor = 0.5	Default recommended by US EPA, 1991

Volatilization induced by air sparging

Calculating overall mass transfer coefficient for oxygen in water:

$$K_{OL,O_2} = 0.31 * \left(\frac{d_b^3(\rho_{H2O} - \rho_{air})g}{\mu_{H2O} D_{O2}} \right)^{1/3} \frac{D_{O2}}{d_b}$$

= 0.0113 cm/sec
= 0.678 cm/min

where:

d_b = 0.2 cm
ρ_{H2O} = 0.997 g/cm^3 (Dean, 1985)
ρ_{gas} = 0.00118 g/cm^3 (Dean, 1985)
g = 980 cm/sec^2
μ_{H2O} = 0.0089 (g/cm·sec) (Dean, 1985)
D_{O2} = 2.1x10^{-5} cm^2/sec (Cussler, 1984)

Calculating molecular diffusion coefficient of formaldehyde in water:

$$D_y = \frac{13.26x10^{-5}}{\mu_{H2O}^{1.14} \; V_m^{0.589}}$$

= 1.81x10^{-5} cm^2/sec

where:

V_m = 36.8 cm^3/mol
μ_{H2O} = 0.89 centipoise

Calculating mass transfer coefficient of formaldehyde in water:

$$K_{OL,y} = \left(\frac{D_y}{D_{O2}} \right) K_{OL,O2} = \left(\frac{1.81x10^{-5}}{2.10x10^{-5}} \right) * 0.678$$

= 0.584 cm/min

Correcting mass transfer coefficient for temperature:

$K_{OL,y,\ 51.67} = K_{OL,y,25^{o}C}\ 1.024^{(T-25)} = 0.584*1.024^{(51.67-25)} = 1.10$ cm/min

Calculating t_b:

$$t_b = \frac{18 \quad h \; \mu_{H2O}}{d_b^2 \; (\rho_{H2O} - \rho_{air})g}$$

= 0.291 sec
= 4.85x10^{-3} min

where:

h = 71 cm

Calculating interfacial area per unit volume:

$$a = \frac{6\ Q_G\ t_b}{V_L\ d_b}$$

= 0.0323 cm^2/cm^3

where:

Q_G = 53,800 cm^3/min
V_L = 242,000 cm^3

Correcting Henry's constant for temperature:

$$H_{y,51.67} = H_{y,25^oC} \exp\left[\frac{\Delta H_{gas} - \Delta H_{aq}}{R}\left(\frac{1}{298.15} - \frac{1}{273.15 + T}\right)\right]$$

= $1.99\text{x}10^{-5}$ (dimensionless)

where:

$H_{y,25}{}^oC$ = $1.7\text{x}10^{-7}$ atm·m^3/mol (Risk Assistant, 1995)
= $6.38\text{x}10^{-6}$ (dimensionless)
DH_{gas} = -27,700 cal/mol
DH_{aq} = -35,900 cal/mol
R = 1.987 cal/mol·K

Calculating mass transfer rate of formaldehyde by air sparging:

$$F_{y,v} = Q_G\ H_y\ c_{L,y} \left[1 - \exp\left(-\frac{K_{OL,y} a V_L}{H_y Q_G}\right)\right]$$

= 7.49 mg/min

The argument of the exponential function is -8031. This indicates that the formaldehyde concentration in the air bubbles is essentially in equilibrium with the bath concentration.

Transport in aerosols

The aerosol generation rate will be estimated using data presented by both Berglund and Lindh (1987) and Wangwongwatana et al. (1988).

Calculating aerosol generation rate using Berglund and Lindh (1987) data:

$$R_A = \left[5.5x10^{-5}\left(Q_G/A\right)+0.01\right] F_T\ F_A\ F_D$$

$$= 0.0187 \text{ mL/min/m}^2$$

where:

Q_G/A = (53.8*10,000)/(71*48) = 158 (L/min/m^2)
F_T = 0.95 @ 51.67ºC (Figure 1b)
F_A = 1.2 @ 0.508 m/s (Figure 1c)
F_D = 1.0 assumed (Figure 1d)

Calculating aerosol generation rate using Wangwongwatana et al. (1988) data:

The air sparging rate used in the example (53.8 L/min) must be converted to an equivalent rate in the experimental apparatus using the ratio of the area of the example bath (0.341 m^2) to the area of the experimental apparatus (0.123 m^2). The equivalent rate is 19.4 L/min. The bubble rise distance would be approximately 0.6 m. From Figure 2, it can be inferred that the droplet concentration is not much greater than 100 droplets/cm^3. The aerosol generation rate can now be calculated:

$$R_A = \frac{Q_G C_d V_d}{A}$$

$$= 8.27x10^{-3} \text{ ml/m}^2\text{/min}$$

where:

Q_G = 53800 cm^3/min
C_d = 100 droplets/cm^3
V_d = (p/6) d_d^3 = 5.24x10^{-10} cm^3
d_d = 0.001 cm (upper end of range reported by Wangwongwatana et al., 1988)
A = 0.341 m^2

The aerosol generation rates calculated by the two methods agree quite well. The model of Berglund and Lindh (1987) will be used because it gives a slightly greater generation rate and is easier to use.

<u>Emission rate from bath</u>. If it is assumed that the formaldehyde concentration in the aerosols is equal to the bath concentration (7 mg/mL) then the formaldehyde emission rate is:

$$F_{y,a} = (7 \text{ mg/mL}) \cdot (0.0187 \text{ mL/m}^2\text{/min}) \cdot (0.341 \text{ m}^2) = 4.46x10^{-2} \text{ mg/min}$$

To determine if accumulation of the contaminant at the air-water interface is significant, k_{IW} must be estimated using Equation 11. Since formaldehyde is a gas at the temperatures of interest, interfacial tension data are not available; however, average values of other aldehydes may be used (Hoff et al., 1993). Calculation of k_{IW} @25ºC is summarized below; information was not available for calculating k_{IW} at other temperatures.

$$\log\ k_{IW} = -7.508 + \log\ \gamma_w + a_s(\sigma_{wa} - \sigma_{sa} - 1.35\sigma_{sw})\ /\ 2.303RT$$

$$= -6.848$$

where:

γ_w = 1.452 Method 1, page 11-10 in Lyman et al. (1982)

a_s = $9.35\text{x}10^8$ cm^2/mol Calculated from: $a_s = 8.45\text{x}10^7\ V_m^{2/3}$

R = $8.314\text{x}10^7$ erg/mol K

σ_{WA} = 72 dyne/cm Hoff et al. (1993)

σ_{SA} = 21.9 dyne/cm Value for acetaldehyde, Weast, 1980

σ_{SW} = 14.6 dyne/cm Average value for n-heptaldehyde and benzaldehyde, Girfalco and Good, 1957

k_{IW} = $1.418\text{x}10^{-7}$ cm

Formaldehyde emissions due to aerosols can now be calculated:

Calculating the ratio of contaminant mass sorbed at the air-water interface to mass in gas volume of bubble:

$$\frac{M_I}{M_b} = \frac{k_{IW}}{H_y(d_b/6)}$$

$$= 0.2138$$

Calculating fraction of bubble interface ejected as aerosols:

$$f_{IE} = \frac{R_A\ \ A\ \ d_b}{6\ \ Q_G\ \ l_b}$$

$$= 4.35\text{x}10^{-3}$$

where:

l_b = $5\text{x}10^{-7}$ cm (Rosen, 1978)

Calculating formaldehyde mass transfer rate via aerosols from tank to the atmosphere:

$$F_{y,a} = \frac{M_I}{M_b} f_{IE} F_{y,s}$$

$$= 0.00697 \text{ mg/min}$$

Volatilization from open tanks

Calculating molecular diffusion coefficient of formaldehyde in air:

$$D_{y,air} = 4.09\text{x}10^{-5}\ T^{1.9}\ (1/29 + 1/M)^{0.5}\ M^{-0.33}\ /\ P_t$$

$= 0.174\ cm^2/sec$

where:

T = 298.15 K

M = 30.03 g/mol

P_t = 1 atm

Calculating volatilization rate of formaldehyde from open tanks:

$$F_{y,o} = 2\ c_{L,y}\ H_y\ A\ [D_{y,air} v_z/(pz)]^{0.5}$$

$$= 13.8\ mg/min$$

where:

$D_{y,air}$ = molecular diffusion coefficient of chemical in air (l^2/t)

V_z = 0.508 m/sec

z = 0.48 m (shortest tank dimension gives highest mass transfer rate)

The gas side mass transfer coefficient (k_g) in the above model is:

$$k_g = 2[D_{y,air} v_z/(pz)]^{0.5}$$

$$= 0.484\ cm/sec$$

Thibodeaux (1979) reports a value of the liquid side mass transfer coefficient (k_l) in large water bodies of about $6x10^{-4}$ cm/sec for wind speeds of 0.5 m/sec. Although not directly applicable to the current situation, it can be used as a first estimate to determine the potential for liquid film resistance to control the mass transfer rate.

Liquid side resistance = $H_y / k_l = 3.3x10^{-2}$ sec/cm

Gas side resistance = $1/k_g$ = 2.1 sec/cm

It can be concluded that formaldehyde volatilization from open tanks is controlled by gas-side mass transfer resistance; therefore, the CEBMPEA equation appears to be valid. It should be noted that it may be necessary to consider liquid-side mass transfer resistance for chemicals with larger Henry's constants. In this case the CEBMPEA model would not be valid.

Surprisingly, volatilization due to air sparging is less significant than that from open tanks. Although the concentration of formaldehyde in the bubbles is high (virtually at equilibrium with the formaldehyde concentration in the bath), the volume of air sparged is small compared to the volume of room air flowing over the top of the tanks.

Concentration of formaldehyde in workplace air

C_y = $F_{y,T}/(V_R\ R_V\ k)$
= 0.326 mg/m^3
= 0.265 ppmv

where: $F_{y,T}$ = 7.49 mg/min + 0.421 mg/min + 13.8 mg/min = 21.71 mg/min
V_R = 20 m · 20 m · 5 m = 2000 m^3
R_V = 4 hr-1 = 0.0667 min^{-1}
k = 0.5

VII. COMPARISON OF PREDICTED FORMALDEHYDE CONCENTRATIONS IN WORKPLACE AIR TO MONITORING DATA

In this section, the concentrations of formaldehyde in the workplace air predicted by the model are compared to available monitoring data. The purpose of the comparison is not to validate the model but to determine if the modeling approach gives reasonable values of formaldehyde concentration. Model validation would require calculation of formaldehyde concentrations using the conditions specific to the monitoring sites. Such data are not available.

The results of an OSHA database (OCIS) search of monitoring data for formaldehyde (provided by OPPT) include 43 measured air concentrations for 10 facilities in Standard Industrial Classification (SIC) 3672 (printed circuit boards). The concentrations range from not detected to 4.65 ppmv. Most of the concentrations (37/42) range from $\leq$ 0.04 to 0.6 ppmv, with all but one less than 1.55 ppmv. Cooper et al. reports formaldehyde concentrations from three electroless plating operations measured over a two day period. The mean concentrations ranged from 0.088 to 0.199 ppmv. The predicted concentration of formaldehyde in the workplace air was 0.263 ppmv. Thus the predicted value is within the range of concentrations determined by monitoring, and less than the OSHA time-weighted-average concentration of 0.75 ppmv. The authors conclude that the results are reasonable.

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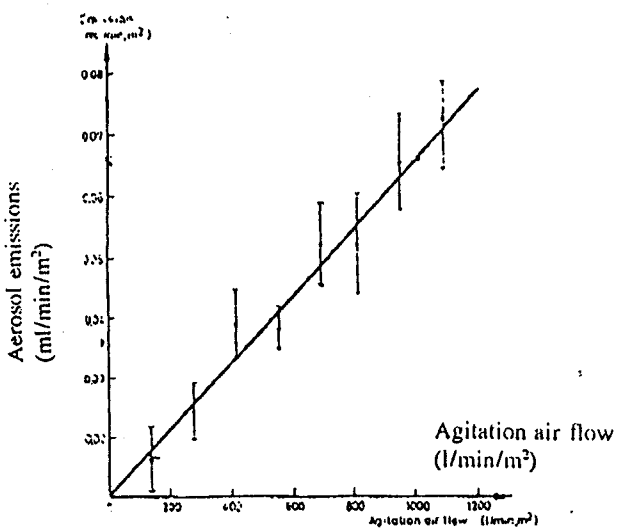

Figure 1a. Mist generation caused by air agitation.

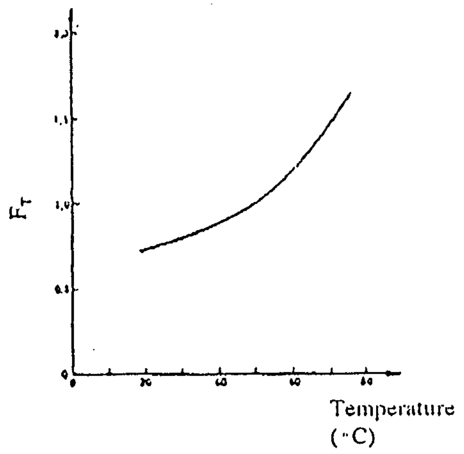

Figure 1b. Influence of bath temperature.

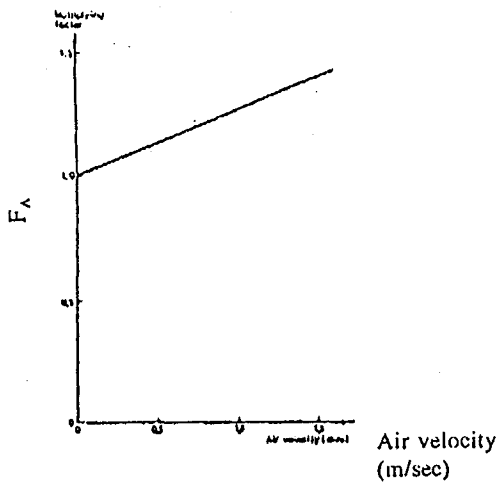

Figure 1c. Influence of air velocity across the bath surface.

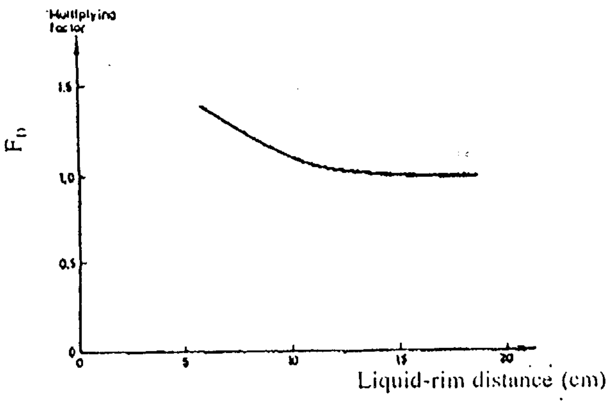

Figure 1d. Influence of the distance from the liquid to the bath rim.

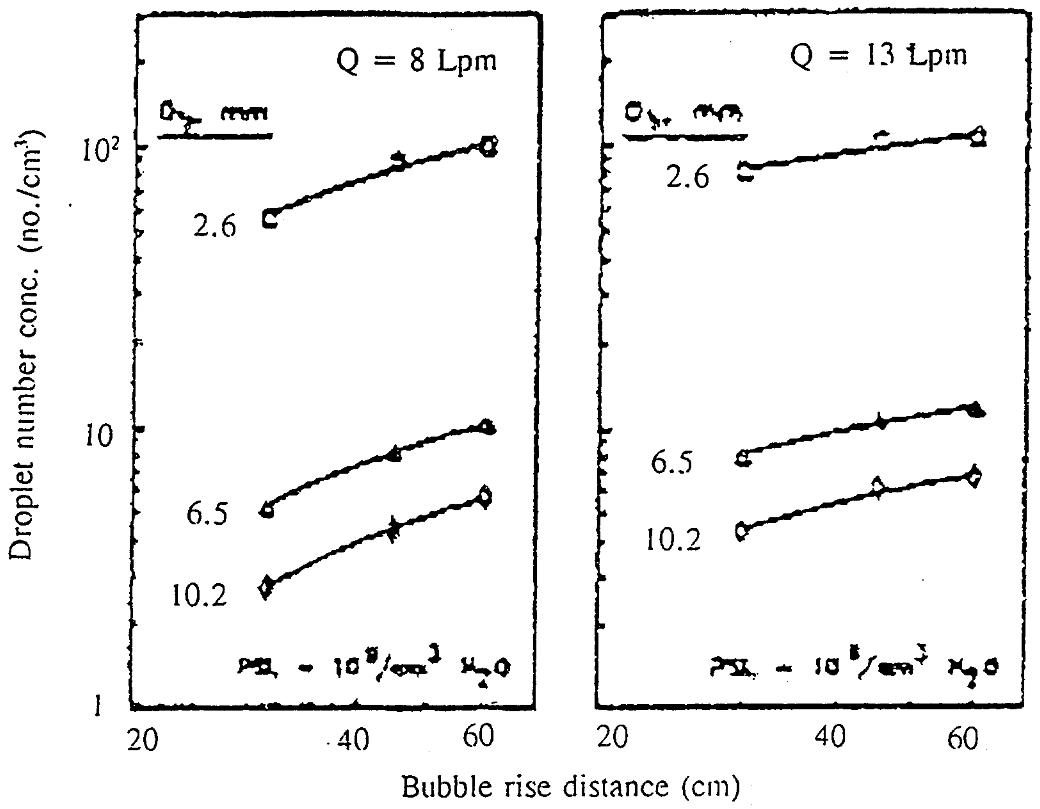

Figure 2. Effect of bubble rise distance on droplets number concentration. (From Wangwongwatana et al., 1990)

Appendix E

Drag-Out Model

Contents

Estimates of Drag-out, Wastewater and Surface Water Concentrations

Process Name:	Non-conveyorized HASL
Production Rate, sq.m./d:	553
Number of Process Tanks:	2
Plant WW Flowrate, L/d:	27911
Stream Flow rate, L/d:	13,300,000

Summary of all Chemicals in Process Wastewater

Chemical Name	Drag-out, g/d	Bath Replacement, g/d	Total in Wastewater, g/d	Concentration in Wastewater, mg/L	Stream Concentration w/o Treatment, mg/L [a]	Treatment Efficiency, %	Stream Concentration Following POTW Treatment, mg/L
1,4-Butenediol	861	507	1368	49	**0.10**	90	0.010
Alkylakyne diol	8.4	4.7	13	0.47	0.00098		
Alkylaryl sulfonate	42	23	65	2.3	**0.0049**	0	0.0049
Alkylphenol ethoxylate	106	59	165	5.9	0.012		
Alkylphenolpolyethoxyethanol	999	558	1557	56	0.12		
Aryl phenol	2.9	1.7	4.6	0.16	0.00034		
Citric acid	1679	937	2616	94	**0.20**	93	0.014
Copper sulfate pentahydrate	3046	1792	4838	173	**0.36**	86	0.051
Ethoxylated alkylphenol	144	80	224	*	0.02		
Ethylene glycol	3087	1731	4818	173	0.36		
Ethylene glycol monobutyl ether	1271	709	1980	71	**0.15**	90	0.015
Fluoboric acid	684	382	1066	38	0.080		
Gum	12	6.8	18	0.66	0.0014		
Hydrochloric acid	1157	646	1802	65	0.14		
Hydrogen peroxide	3434	2021	5454	195	**0.41**	90	0.041
Hydroxyaryl acid	16	10	26	0.92	0.0019		
Hydroxyaryl sulfonate	28	17	45	1.6	0.0034		
Phosphoric acid	3391	1893	5285	189	0.40		
Potassium peroxymonosulfate	6883	4051	10934	392	**0.82**	90	0.082
Sodium benzene sulfonate	8.3	4.6	13	0.46	0.00097		
Sodium hydroxide	12	6.8	18	0.65	0.0014		
Sulfuric acid	13132	7543	20675	741	1.6		

[a] Numbers in bold indicate the estimated stream concentration (without wastewater treatment) that exceeds the aquatic toxicity concern concentration.

Estimates of Wastewater and Surface Water Concentrations

Process Name:	Conveyorized HASL
Production Rate, sq.m./d:	1108
Number of Process Tanks:	2
Plant WW Flowrate, L/d	44829
Stream Flow rate, L/d:	13,300,000

Summary of all Chemicals in Process Wastewater

Chemical Name	Bath Replacement, g/d	Concentration in Wastewater, mg/L	Stream Concentration w/o Treatment, mg/L [a]	Treatment Efficiency, %	Stream Concentration Following POTW Treatment, mg/L
1,4-Butenediol	1016	23	**0.076**	90	0.0076
Alkylakyne diol	9.4	0.21	0.00070		
Alkylaryl sulfonate	47	1.0	**0.0035**	0	0.0035
Alkylphenol ethoxylate	119	2.6	0.0089		
Alkylphenolpolyethoxyethanol	1118	25	0.084		
Aryl phenol	3.4	0.076	0.00025		
Citric acid	1879	42	**0.14**	93	0.0099
Copper sulfate pentahydrate	3593	80	**0.27**	86	0.038
Ethoxylated alkyphenol	161	3.6	0.0121		
Ethylene glycol	3470	77	0.26		
Ethylene glycol monobutyl ether	1422	32	**0.11**	90	0.011
Fluoboric acid	766	17	0.057		
Gum	14	0.30	0.0010		
Hydrochloric acid	1294	29	0.097		
Hydrogen peroxide	4050	90	**0.30**	90	0.030
Hydroxyaryl acid	19	0.43	0.0014		
Hydroxyaryl sulfonate	33	0.75	0.0025		
Phosphoric acid	3795	85	0.28		
Potassium peroxymonosulfate	8120	181	**0.61**	90	0.061
Sodium benzene sulfonate	9.3	0.21	0.00070		
Sodium hydroxide	14	0.30	0.0010		
Sulfuric acid	15120	337	1.1		

[a] Numbers in bold indicate the estimated stream concentration (without wastewater treatment) that exceeds the aquatic toxicity concern concentration.

Estimates of Drag-out, Wastewater and Surface Water Concentrations

Process Name: Non-conveyorized Nickel/Gold
Production Rate, sq.m./d: 113.9
Number of Process Tanks: 6
Plant WW Flowrate, L/d 9595
Stream Flow rate, L/d: 13,300,000

Summary of all Chemicals in Process Wastewater

Chemical Name	Drag-out, g/d	Bath Replacement, g/d	Total in Wastewater, g/d	Concentration in Wastewater, mg/L	Stream Concentration w/o Treatment, mg/L [a]	Treatment Efficiency, %	Stream Concentration Following POTW Treatment, mg/L
Aliphatic acid A	136	82	219	23	0.016		
Aliphatic acid B	20	12	32	3.4	0.0024		
Aliphatic acid E	306	184	491	51	0.037		
Aliphatic dicarboxylic acid A	96	58	154	16	0.012		
Aliphatic dicarboxylic acid C	45	27	73	7.6	0.0055		
Alkylamino acid B	337	45	383	40	0.029		
Alkyl diol	581	93	673	70	0.051		
Alkylphenolpolyethoxyethanol	206	33	239	25	0.018		
Ammonia compound B	1.0	0.57	1.5	0.16	0.00011		
Ammonium chloride	745	100	845	88	0.064		
Ammonium hydroxide	480	65	545	57	0.041		
Citric acid	134	16	150	16	0.011		
Copper sulfate pentahydrate	627	123	750	78	**0.056**	86	0.0079
Ethoxylated alkylphenol	12	2.0	14	1.5	0.0011		
Hydrochloric acid	7601	569	8170	851	0.61		
Hydrogen peroxide	500	98	598	62	**0.045**	90	0.0045
Hydroxyaryl acid	3.3	0.66	4.0	0.42	0.00030		
Inorganic metallic salt A	0.029	0.017	0.046	0.0048	0.0000035		
Inorganic metallic salt B	1.9	1.1	3.1	0.32	0.00023		
Inorganic metallic salt C	0.020	0.012	0.032	0.0033	0.0000024		
Malic acid	205	123	328	34	0.025		
Nickel sulfate	508	306	814	85	**0.061**	24	0.051
Palladium chloride	18	2.4	20	2.1	0.0015		
Phosphoric acid	581	93	673	70	0.051		
Potassium compound	959	577	1535	160	0.12		
Potassium gold cyanide	41	5.5	46	4.8	**0.0035**	66	0.0045
Sodium hydroxide	2.4	0.47	2.8	0.30	0.00021		
Sodium hypophosphite mono hydrate	585	352	936	98	0.070		
Sodium salt	1229	164	1393	145	0.10		
Substituted amine hydroxhloride	818	109	928	97	**0.070**	80	0.014
Sulfuric acid	2796	491	3287	343	0.25		
Transition metal salt	8.2	1.1	9.3	1.0	0.00070		
Urea compound B	0.7	0.4	1.1	0.1	0.00008		

[a] Numbers in bold indicate the estimated stream concentration (without wastewater treatment) that exceeds the aquatic toxicity concern concentration.

Estimates of Drag-out, Wastewater and Surface Water Concentrations

Process Name:	Non-conveyorized Nickel/Palladium/Gold
Production Rate, sq.m./d:	86
Number of Process Tanks:	8
Plant WW Flowrate, L/d	12703
Stream Flow rate, L/d:	13,300,000

Summary of all Chemicals in Process Wastewater

Chemical Name	Drag-out, g/d	Bath Replacement, g/d	Total in Wastewater, g/d	Concentration in Wastewater, mg/L	Stream Concentration w/o Treatment, mg/L [a]	Treatment Efficiency, %	Stream Concentration Following POTW Treatment, mg/L
Aliphatic acid B	15	9.2	24	1.9	0.0018		
Aliphatic acid E	308	186	494	39	0.037		
Aliphatic dicarboxylic acid A	72	44	116	9.1	0.0087		
Aliphatic dicarboxylic acid C	34	21	55	4.3	0.0041		
Alkylamino acid B	451	61	512	40	0.038		
Alkyldiol	438	70	509	40	0.038		
Alkylpolyol	389	892	1282	101	0.096		
Amino acid salt	21	1.4	22	1.7	0.0017		
Amino carboxylic acid	10	23	34	2.7	0.0025		
Ammonia compound A	513	69	582	46	0.044		
Ammonia compound B	0.72	0.44	1.2	0.091	0.000087		
Ammonium hydroxide	615	83	698	55	0.052		
Citric acid	124	15	139	11	0.010		
Copper sulfate pentahydrate	474	93	567	45	**0.043**	86	0.0060
Ethoxylated alkylphenol	9.3	1.5	11	0.85	0.00081		
Ethylenediamine	46	105	150	12	0.011		
Hydrochloric acid	1268	159	1427	112	0.11		
Hydrogen peroxide	378	74	452	36	**0.034**	90	0.0034
Hydroxyaryl acid	2.5	0.50	3.0	0.24	0.00023		
Inorganic metallic salt B	6.6	13	19	1.5	**0.0015**	82	0.00026
Maleic acid	20	47	67	5.3	0.0051		
Malic acid	155	93	248	20	0.019		
Nickel sulfate	604	365	969	76	**0.073**	24	0.055
Palladium salt	33	74	107	8.4	0.0080		
Phosphoric acid	438	70	509	40	0.038		
Potassium compound	724	437	1160	91	0.087		
Potassium gold cyanide	31	4.1	35	2.7	0.0026		
Propionic acid	75	171	246	19	0.018		
Sodium hydroxide	1.8	0.35	2.1	0.17	0.00016		
Sodium hypophosphite mono hydrate	625	463	1088	86	0.082		
Sodium salt	1548	166	1714	135	0.13		
Substituted amine hydrochloride	618	83	701	55	**0.053**	80	0.011
Sulfuric acid	1646	324	1970	155	0.15		
Surfactant	1.0	2.3	3.4	0.27	0.00025		
Transition metal salt	6.2	0.83	7.0	0.55	0.00053		
Urea compound B	1.0	0.62	1.7	0.13	0.00120		

[a] Numbers in bold indicate the estimated stream concentration (without wastewater treatment) that exceeds the aquatic concern concentration.

Process Name:	Non-Conveyorized OSP
Production Rate, sq.m./d:	686
Number of Process Tanks:	3
Plant WW Flowrate, L/d	21631
Stream Flow rate, L/d:	13,300,000

Summary of all Chemicals in Process Wastewater

Chemical Name	Drag-out, g/d	Bath Replacement, g/d	Total in Wastewater, g/d	Concentration in Wastewater, mg/L	Stream Concentration w/o Treatment, mg/L [a]	Treatment Efficiency, %	Stream Concentration Following POTW Treatment, mg/L
Acetic acid	4951	339	5289	245	0.40		
Alkylaryl imidazole	4054	277	4332	200	**0.33**	90	0.033
Aromatic imidizole product [b]	519	35	554	26	0.042		
Arylphenol	3.6	2.1	5.7	0.26	0.00430		
Copper ion	4054	277	4332	200	**0.33**	86	0.046
Copper salt C	112	8	119	5.5	**0.0089**	86	0.00130
Copper sulfate pentahydrate	3778	2225	6003	278	**0.45**	86	0.063
Ethoxylated alkyphenol	74	42	116	5.4	0.0087		
Ethylene glycol	3829	2149	5978	276	0.45		
Gum	14	8	23	1.1	0.0017		
Hydrochloric acid	1639	916	2555	118	0.19		
Hydrogen peroxide	1525	898	2423	112	**0.18**	90	0.018
Hydroxyaryl acid	20	12	32	1.50	0.0024		
Hydroxyaryl sulfonate	35	21	56	2.6	0.0042		
Phosphoric acid	3497	1954	5451	252	0.41		
Sodium hydroxide	14	8	23	1.10	0.0017		
Sulfuric acid	21683	12751	34433	1592	2.6		

[a] Numbers in bold indicate the estimated stream concentration (without wastewater treatment) that exceeds the aquatic toxicity concern concentration.

[b] This ingredient not evaluated further as there was not enough information provided to identify a specific chemical.

Process Name:	Conveyorized OSP
Production Rate, sq.m./d:	1500
Number of Process Tanks:	3
Plant WW Flowrate, L/d	32232
Stream Flow rate, L/d:	13,300,000

Summary of all Chemicals in Process Wastewater

Chemical Name	Bath Replacement, g/d	Concentration in Wastewater, mg/L	Stream Concentration w/o Treatment, mg/L [a]	Treatment Efficiency, %	Stream Concentration Following POTW Treatment, mg/L
Acetic acid	2963	92	0.22		
Alkylaryl imidazole	2427	75	**0.18**	90	0.018
Aromatic imidizole product [b]	310	10	0.023		
Arylphenol	4.6	0.14	0.00034		
Copper ion	2427	75	**0.18**	86	0.025
Copper salt C	67	2.1	**0.0050**	86	0.00070
Copper sulfate pentahydrate	4865	151	**0.36**	86	0.051
Ethoxylated alkyphenol	91	2.8	0.0068		
Ethylene glycol	4699	146	0.35		
Gum	18	0.6	0.0014		
Hydrochloric acid	2002	62	0.15		
Hydrogen peroxide	1964	61	**0.15**	90	0.015
Hydroxyaryl acid	26	0.81	0.0019		
Hydroxyaryl sulfonate	45	1.4	0.0034		
Phosphoric acid	4272	133	0.32		
Sodium hydroxide	18	0.57	0.0014		
Sulfuric acid	27877	865	2.1		

[a] Numbers in bold indicate the estimated stream concentration (without wastewater treatment) that exceeds the aquatic toxicity concern concentration.

[b] This ingredient not evaluated further as there was not enough information provided to identify a specific chemical.

Estimates of Wastewater and Surface Water Concentrations

Process Name:	Conveyorized Immersion Silver
Production Rate, sq.m./d:	376
Number of Process Tanks	4
Plant WW Flowrate, L/d	8083
Stream Flow rate, L/d:	13,300,000

Summary of all Chemicals in Process Wastewater

Chemical Name	Bath Replacement, g/d	Concentration in Wastewater, mg/L	Stream Concentration w/o Treatment, mg/L [a]	Treatment Efficiency, %	Stream Concentration Following POTW Treatment, mg/L
1,4-Butenediol	390	48	**0.029**	90	0.0029
Alkylamino acid A	1603	198	0.12		
Fatty amine	62	7.7	**0.0047**	95	0.00023
Hydrogen Peroxide	3462	428	**0.26**	90	0.026
Nitrogen acid	281	35	0.021		
Nonionic Surfactant [b]	345	43	0.026		
Phosphoric acid	2891	358	0.22		
Silver Nitrate	8.4	1.0	**0.00063**	96	0.000025
Sodium hydroxide	621	77	0.047		
Sulfuric acid	141	17	0.011		

[a] Numbers in bold indicate the estimated stream concentration (without wastewater treatment) that exceeds the aquatic toxicity concern concentration.

[b] This ingredient not evaluated further as there was not enough information provided to identify a specific chemical.

Estimates of Drag-out, Wastewater and Surface Water Concentrations

Process Name:	Non-conveyorized Immersion Tin
Production Rate, sq.m./d:	321
Number of Process Tanks:	4
Plant WW Flowrate, L/d	23624
Stream Flow rate, L/d:	13,300,000

Summary of all Chemicals in Process Wastewater

Chemical Name	Drag-out, g/d	Bath Replacement, g/d	Total in Wastewater, g/d	Concentration in Wastewater, mg/L	Concentration in Stream, mg/L [a]	Treatment Efficiency, %	Concentration in Stream following POTW Treatment, mg/L
Aliphatic acid D	493	33	526	22	0.039		
Alkylalkyne diol	4.9	0.78	5.7	0.24	0.00042		
Alkylamino acid B	779	51	830	35	0.062		
Alkylaryl sulfonate	24	3.9	28	1.2	**0.0021**	0	0.0021
Alkylimine dialkanol	26	1.7	28	1.2	0.0021		
Alkylphenol ethoxylate	61	9.8	71	3.0	0.0054		
Bismuth compound	1.0	0.066	1.1	0.045	0.000080		
Citric acid	14599	1056	15655	663	**1.2**	93	0.082
Cyclic amide	1983	131	2115	90	0.16		
Ethoxylated alkylphenol	49	7.8	57	2.4	0.0042		
Ethylene glycol monobutyl ether	738	118	856	36	**0.064**	90	0.0064
Fluoboric acid	397	63	461	19	0.035		
Hydrochloric acid	279	18	298	13	0.022		
Hydroxy carboxylic acid	1633	108	1741	74	0.13		
Methane sulfonic acid	15636	1046	16682	706	1.3		
Phosphoric acid	974	156	1130	48	0.085		
Potassium peroxymonosulfate	3996	785	4780	202	**0.36**	90	0.036
Quantenary alkylammonium chlorides	922	61	983	42	**0.074**	90	0.0074
Silver salt	0.15	0.010	0.16	0.0067	0.000012		
Sodium benzene sulfonate	4.8	0.77	5.6	0.24	0.00042		
Sodium phosphorus salt	3475	231	3706	157	0.28		
Stannous methane sulfonic acid	4352	288	4640	196	**0.35**	40	0.21
Sulfuric acid	10239	1325	11564	490	0.87		
Thiourea	3799	251	4050	171	**0.30**	90	0.030
Tin chloride	544	36	580	25	**0.044**	40	0.026
Unspecified tartrate	973	64	1037	44	0.078		
Urea	3503	231	3735	158	0.28		
Urea compound C	779	51	830	35	**0.062**	90	0.0062
Vinyl polymer	493	33	526	22	0.039		

[a] Numbers in bold indicate the estimated stream concentration (without wastewater treatment) that exceeds the aquatic toxicity concern concentration.

Estimates of Wastewater and Surface Water Concentrations

Process Name: Conveyorized Immersion Tin
Production Rate, sq.m./d: 226
Number of Process Tanks: 4
Plant WW Flowrate, L/d 8106
Stream Flow rate, L/d: 13,300,000

Summary of all Chemicals in Process Wastewater

Chemical Name	Bath Replacement, g/d	Concentration in Wastewater, mg/L	Stream Concentration w/o Treatment, mg/L [a]	Treatment Efficiency, %	Stream Concentration Following POTW Treatment, mg/L
Aliphatic acid D	23	2.8	0.0017		
Alkylalkyne diol	0.55	0.067	0.000041		
Alkylamino acid B	36	4.5	0.0027		
Alkylaryl sulfonate	2.7	0.34	0.00021		
Alkylimine dialkanol	1.2	0.15	0.000092		
Alkylphenol ethoxylate	6.9	0.85	0.00052		
Bismuth compound	0.046	0.0057	0.0000035		
Citric acid	742	92	0.056		
Cyclic amide	92	11	0.0069		
Ethoxylated alkylphenol	5.5	0.67	0.00041		
Ethylene glycol monobutyl ether	83	10	0.0062		
Fluoboric acid	45	5.5	0.0033		
Hydrochloric acid	13	1.6	0.0010		
Hydroxy carboxylic acid	76	9.4	0.0057		
Methane sulfonic acid	735	91	0.055		
Phosphoric acid	109	13	0.0082		
Potassium peroxymonosulfate	551	68	**0.041**	90	0.0041
Quantenary alkylammonium chlorides	43	5.3	0.0032		
Silver salt	0.0069	0.00086	0.00000052		
Sodium benzene sulfonate	0.54	0.067	0.000041		
Sodium phosphorus salt	163	20	0.012		
Stannous methane sulfonic acid	202	25	0.015		
Sulfuric acid	932	115	0.070		
Thiourea	176	22	0.013		
Tin chloride	25	3.1	0.0019		
Unspecified tartrate	45	5.6	0.0034		
Urea	163	20	0.012		
Urea compound C	36	4.5	0.0027		
Vinyl polymer	23	2.8	0.0017		

Numbers in bold indicate the estimated stream concentration (without wastewater treatment) that exceeds the aquatic toxicity concern concentration.

PREDICTION OF WATER QUALITY FROM PRINTED WIRING BOARD PROCESSES

Final Report to the University of Tennessee Center for Clean Products and Clean Technologies and to the U.S. Environmental Protection Agency

Part of the Verification of Finishing Technologies Project
EPA Grant X825373-01-2 (Amendment No. 2)

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August 6, 1999

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REFERENCES

LIST OF SYMBOLS

INTRODUCTION

The Design for the Environment (DFE) Project Printed Wiring Boards (PWB) Cleaner Technologies Substitutes Assessment: Making Holes Conductive (MHC) was performed by the Center for Clean Products and Clean Technologies (CCPCT) at the University of Tennessee. The project and results were well received by industry and the U.S. Environmental Protection Agency. However, all parties agreed that one weakness in the project was the evaluation of impacts of chemicals in the wastewater discharges of bath solutions from the MHC plating lines. Evaluation of these impacts was more difficult than anticipated partly because of insufficient information from surveyed facilities on the water quality of their discharges. Attempts at a mass balance to predict chemical discharges were also unsatisfactory due to insufficient data on chemical use and ultimate fate.

An estimate of the pollutants in the raw wastewater from PWB plating processes is needed in order to evaluate health risks, impacts on the environment, impacts on municipal wastewater plants, and overall manufacturing costs which includes treatment/disposal costs. The main source of pollutants in the raw wastewater is the drag-out from the baths. Hence, drag-out is the key variable for determining pollutant mass.

PWB facilities analyze at most only a couple of chemicals in their wastewater, and the facilities generally have insufficient data to calculate chemical mass balances. Therefore, a different approach is required to estimate the pollutant loads and wastewater quality of the PWB wastewater discharges. This report discusses the development, validation, and use of predictive tools to satisfy this need.

Objectives:

The objectives of this research were:

- Develop tools and methodologies to predict, but more importantly to compare the mass of pollutants in the raw wastewater discharges from PWB plating processes.
- Validate these tools and methodologies against data available in the literature and against samples collected at PWB facilities.

LITERATURE REVIEW

Literature was identified through a computerized search on several key words. Additional papers were found from the references in papers and from a manual search of recent *Chemical Abstracts* (1998).

Pollutant Generation Rate and Waste Generation Volume

The sources of the pollutants in the wastewater generated in the MHC and surface finishing processes for PWB manufacturing are the chemicals that escape from the process baths and from other processes such as stripping racks of plating deposits. Our assumption for estimating the pollutant mass generation rate, e.g., kg Cu/day, is that the source of the pollutants is predominantly the drag-out from the process baths. Whatever chemicals are drug out of the process tanks by solution adhering to the surface of the boards and racks will be removed in the rinse tanks and ultimately end up in the raw wastewater discharge before any treatment or metals recovery. This is consistent with the literature (Mooney 1991) and is expressed in a simple mass balance:

$$\begin{pmatrix}\text{mass of pollutants}\\ \text{in drag-out}\end{pmatrix} = \begin{pmatrix}\text{mass of pollutants}\\ \text{in rinse discharge}\end{pmatrix} \qquad \text{Eqn 1}$$

As discussed later, the etchant process baths themselves are generally not dumped into the wastewater at the end of their useful life, but are typically sent off-site for processing. Other process baths are apparently not sent off-site and do need to be accounted for in the waste generation. Although pollutants from the stripping of racks may be significant at times, the average mass pollutants originating from this process should be less than that contributed by drag-out. Therefore, an estimate of the expected drag-out from various process tanks under differing conditions is critical for estimating the waste mass generation rate. The arrangement of the rinse tanks and the rinse flow rates will not change the total mass of contaminants released, only the concentration and the volume of wastes. The waste generation volume primarily depends on the rinse flow rates since this is the main source of wastewater discharge. If certain assumptions are made, then conventional rinsing theory may be used to estimate the volume of waste based on the drag-out and needed final rinse water quality. Importantly, the primary goal of this work is a methodology that can be used to compare the relative amounts of wastes generated from alternative PWB surface finishing manufacturing processes.

There are many references giving advice on minimizing drag-out and rinse water. Factors that will reduce the drag-out include slow withdrawal from the process tank, longer drainage times, tilting the boards so that the liquid drains to a corner, using drip shields, using drag-out/drag-in tanks, as well as others. Solution density, viscosity, which depends on the bath chemistry and temperature, and surface tension also affect how well the liquid drains off the boards, and hence affects drag-out. Because of the number of variables which have complex relationships with drag-out, estimating drag-out for a series of baths is a difficult, unsolved problem. The following sections review what is known about estimating drag-out, including several references that include predictive equations and experimental measurements.

Drag-Out Tests at Micom, Inc.

The MnTAP/EPA Write study (Pagel 1992) at Micom, Inc. evaluated the ability of two modifications to reduce waste from PWB surface finishing processes. At the time of the study, Micom produced 92 - 111 m^2/day of double-sided and multilayered PWBs with the average board being 0.46 m by 0.53 m and having 8000 holes. Micom had already implemented several waste reduction measures, including countercurrent rinses, flow restrictors, softened water in the rinses (softened water improved the rinsing and increased the efficiency of the ion exchange waste treatment system), and air and mechanical agitation. However, Micom evaluated whether changes to the way PWBs were transferred from process baths to the rinse tanks could further reduce the amount of waste by reducing the drag-out.

Two processes were tested at Micom, Inc. in their MHC line: 1) a micro-etch bath and the countercurrent rinse tanks following it; and 2) an electroless copper bath and the countercurrent rinse tanks following it. The PWBs were moved from tank to tank in racks. The racks were 0.86 m high by 0.50 m wide by 0.33 m deep and could hold 24 boards. Typically, the operator controlled a hoist and allowed the rack to drain for 3-5 seconds before going into the next tank. The residence time was about 75 seconds in the micro-etch tank, 30 minutes in the electroless copper tank, which held two racks at a time, and 2-3 minutes in each rinse tank.

The modifications evaluated at Micom were: 1) slowing the withdrawal rate of the racks from the process bath; and 2) using an intermediate rack withdrawal rate combined with a longer drain time over the process bath before going into the rinse tanks. Slowing the withdrawal rate was achieved by lowering the speed of the motor on the mechanical hoist used to move the racks. Installation of new equipment prohibited matching the withdrawal rates used in the first modification with tests on the second modification, hence the designation of “intermediate” withdrawal rate. Withdrawal time was defined as the time it took to raise the boards from the bath to a height needed to clear the tank walls, a total of 0.91 m. Increasing the drain time was achieved by the operator simply waiting longer before placing the boards in the next bath. Drain time was defined from the moment that the rack cleared the water surface until half of the rack was over the adjacent rinse tank. Measurement of drag-out was accomplished by shutting off the rinse water and then measuring the increase in copper concentration after a known quantity of boards had been rinsed. Copper was measured by atomic absorption spectrophotometry. The electroless copper samples were preserved with a hydrochloric/nitric acid mixture rather than just nitric, because copper precipitated out of solution as the solution cooled when nitric acid alone was used. There were some analytical difficulties of unknown origin in that the copper measurements done by an outside laboratory showed about 1800-2200 mg/L of copper whereas Micom’s laboratory analyses showed about 2400 mg/L.

Baseline drag-out measurements were made over a twelve day period using 136 samples for 12 pairs of racks. The first modification experiments were also made using 136 samples for 12 pairs of racks, and the second modification experiments used 109 samples for 9 pairs of racks.

The results of the experiments are summarized in Tables 1 and 2. It should be noted that the values for drag-out, withdraw rate, and drain time are averages of a rather broad range of values grouped by relative magnitude by Page l.

Table 1. Drag-Out Test Results on the Microetch Bath at Micom, Inc.

Parameter	Baseline	Slow Withdrawal Rate	Intermediate Withdrawal Rate & Longer Drain Time
Drag-out, mL/m^2	129	72.1	76.4
Withdrawal time, sec	1.7	14.9	4.3
Withdrawal rate, m/sec	0.51	0.056	0.20
Drain time, sec	3.4	2.5	12.1
Total time, sec	5.1	17.4	16.4
Surface area/rack, m^2	8.2	7.7	8.6
Water flow rate, lpm	9.8	---	---

Table 2. Drag-Out Test Results on the Electroless Bath at Micom, Inc.

Parameter	Baseline	Slow Withdrawal Rate	Intermediate Withdrawal Rate & Longer Drain Time
Drag-out, mL/m^2	64.6	32.3	31.4
Withdrawal time, sec	1.8	13.9	4.3
Withdrawal rate, m/min	0.48	0.061	0.175
Drain time, sec	5.2	3.2	11.9
Total time, sec	7.0	17.1	16.3
Surface area/rack, m^2	15.7	15.0	16.3
Water flow rate, lpm	12.5	---	—

For the micro-etch bath, the first modification reduced the drag-out by 45% while the second modification reduced drag-out by 41%. For the electroless copper bath, the reductions were 50% and 52%, respectively. Because it was easier for Micom to control the drain time than the withdrawal rate, they implemented a longer drain time.

It should be noted that reducing the drag-out from the micro-etch affects the bath. This bath removes copper until the etchants are exhausted. Make-up chemicals may be added to replace etchant solution is lost in drag-out. Reducing drag-out may mean that the entire bath must be replaced more frequently, because of increased copper build-up in the bath. However, Micom preferred to retain the copper in the bath and replace the bath, because there is greater opportunity to recover metals in the etchant bath than in the rinses. For the electroless bath, drag-out reduction helps retain the chemicals in the bath and increase its life, providing that build-up of impurities does not offset this advantage. Reduction of drag-out from upstream baths would help in this regard.

Other Published Drag-Out Estimates

Süβ (1990) evaluated several ways to minimize drag-out, including the effect of the inclination angle during drainage, the withdrawal rate, and the drainage time. Several experiments focused on the inclination angle in the design of electroplating product holders and its effect on drag-out. The holders were not for PWBs but apparently for a variety of electroplated products. The holders typically had horizontal cross-braces or struts. Süβ noted that the drag-out from the holder could be as much as 50% of the total drag-out in these cases. Süβ experimented with holder designs that had struts of different angles and showed that drag-out could be reduced significantly. The effect of the inclination angle of the struts on drag-out is shown in Table 3. Struts tilted at a 45^o angle to horizontal had only 36% of the drag-out as a horizontal one.

Table 3. Effect of Inclination Angle of the Product Holder Strut on Drag-Out

Angle to Horizontal	Drag-Out mL/m^2	% of Maximum
0^o	44	100
15^o	35	80
30^o	25	57
45^o	16	36
90^o	22	50

Süβ (1990) also experimented with chromium plated sheets suspended from the holders to determine the effect of drainage time and inclination angle of the sheet. The experiments used either 19-20 g/L or 240-250 g/L CrO_3 electrolytes. The effect of drainage time and inclination angle is shown in Table 4. (Note: the data reported in Table 4 were read from two graphs in Süβ (1990) and include representative data, but not all the data.). As seen in the table, a 45^o inclination angle had about 33% less drag-out at short drainage times compared to a horizontal angle and nearly 50% less drag-out at long drainage times. An increase in the drainage time greatly reduced drag-out up to about 20-30 seconds, but had a relatively small effect for longer times. Further experiments were conducted on the effect of withdrawal rate and inclination angle of the sheet. The effect of withdrawal rate is shown in Table 5. Slower withdrawal rates reduced the drag-out, but not as much as inclination angle. A plate withdrawn at 60 m/min had roughly 25-30% more drag-out volume than a plate withdrawn at 6 m/min. The drag-out volumes reported by Süβ are approximately a factor of two less than the drag-out volumes reported in the Micom study (Pagel 1992) discussed above. One explanation for the difference may be that the boards in the Süβ study did not contain holes but the boards used in the Micom study did. It should be noted that Süβ was not clear how the drag-out was calculated. It appears to be American practice to report the drag-out in terms of the area of one side of the board. It is possible that Süβ calculated his drag-out based on the area of both sides of the board, leading to numbers which are half as large. If this were the case, then to be comparable to American practice, his drag-out volumes should be doubled. However, in a later paper, Süβ (1992) used an equation which was developed for drag-out on the basis of one side of the board. It is likely that he was aware of the assumptions built into the equation, and considering that his values are comparable to the Micom study, we will assume that Süβ's drag-out volumes are directly comparable to other values. In either case, the trends are the same.

Table 4. Effect of Drainage Time and Inclination Angle on Drag-Out.

Drainage Time, s	Drag-Out, mL/m^2			
	280-320 g/L CrO_3, 0° angle, 40°C	280-320 g/L CrO_3, 45^0 angle, 40°C	20 g/L CrO_3, 0^0 angle, 20°C	20 g/L CrO_3, 45^0 angle, 20°C
0	57	--	64	--
10	28	21	33	24
20	22	13	28	19
30	20	11	25	15
45	19	--	21	13
60	19	10	19	11

Table 5. Effect of Withdrawal Rate on Drag-Out.

Withdrawal Rate, m/min	Drag-Out	
	240-250 g/L CrO_3 (40±1°C)	19-20 g/L CrO_3 (20±1°C)
	mL/m^2	mL/m^2
3.6	17	21
6	22	26
9	24.5	29
18	26.5	32
36	27	33
60	28	33

In a second paper, Süβ (1992) evaluated two drag-out prediction equations by comparing measured volumes of drag-out to predicted values. The first equation was from Kushner (1951):

$$f = 0.02\sqrt{\frac{m \cdot h}{r \cdot t_w}} \qquad \text{Eqn 2}$$

or:

$$f = 0.02\sqrt{n \cdot v_A} \qquad \text{Eqn 3}$$

where:

f = film thickness, cm
μ = dynamic viscosity of electrolyte, g/(cm·s)
h = height of metal sheet
ρ = density of electrolyte, gm/cm^3
t_w = withdrawal time, s
ν = kinematic viscosity, cm^2/s
v_A = withdrawal rate of metal sheet, cm/s

The second equation was:

$$f = \sqrt{\frac{2n \cdot h \cdot v_A}{9g(h + 4v_A t_{dr})}} \qquad \text{Eqn 4}$$

where:

g = gravity, 981 cm/s^2
t_{dr} = drainage time, s

Experiments were conducted on 21.0 x 21.4 cm metal sheets which had no holes. The sheets were withdrawn from the bath at 20 cm/s and allowed to drain for 10 seconds.

Neither of the two equations predicted the measured values very well. Sixteen different electrolytes were tested with concentrations ranging from 17 to 300 gm/L of material, densities ranging from 1.015 to 1.562 g/cm^3, dynamic viscosities ranging from 0.713 to 8.6 cP, and temperatures ranging from 18 to 59.5^{o}C. The average measured drag-out was 47.4 mL/m^2 with a standard deviation of 16.3 mL/m^2. The average predicted drag-out and standard deviation predicted by equation 3 were 96.8 and 17.8 mL/m^2, respectively, while equation 4 had average predicted drag-out and standard deviation of 15.6 and 2.06 mL/m^2, respectively. A linear regression of measured versus predicted drag-out volumes gave an r^2 of 0.021 and 0.012 for equations 3 and 4, respectively. Taking an average of the two equations yielded no better results. A scatter plot of the measured drag-out and the predicted drag-out is shown in Figure 1.

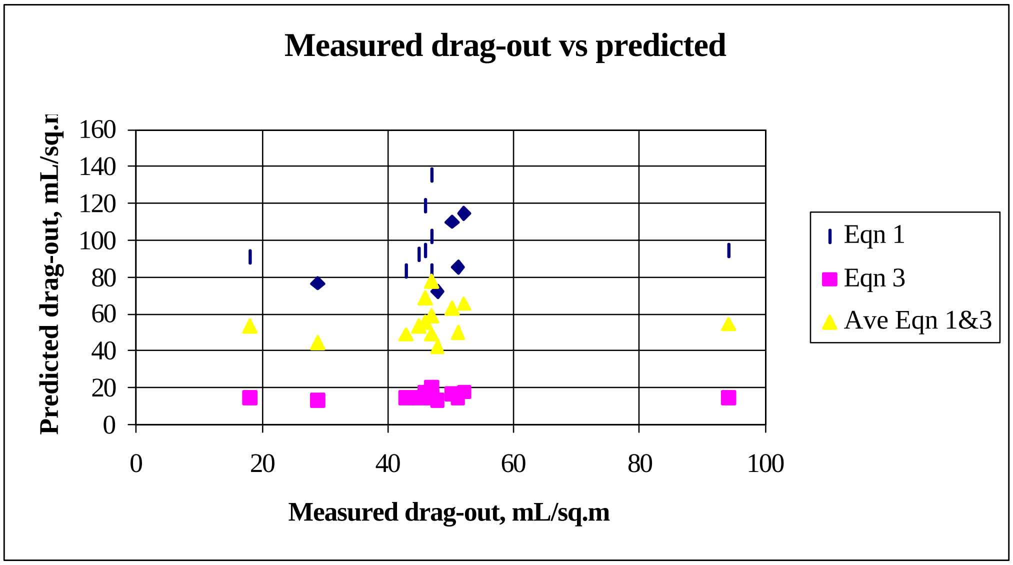

Figure 1. Measured Versus Predicted Drag-Out for Results by Süβ (1992).

Süβ commented that the equations do not account for electrolyte that adheres to the surface and bottom edge even after long drain times, i.e., there is a minimal film thickness left. This becomes increasingly important for rougher surfaces. Süβ recommended that drag-out estimations for use in recycling procedures and wastewater treatment should be based on measurements rather than calculations. Part of the reason that poor correlation was found between Süβ's measured drag-out and the predictive equations is that Süβ's drag-out showed little variation with viscosity as shown in Figure 2.

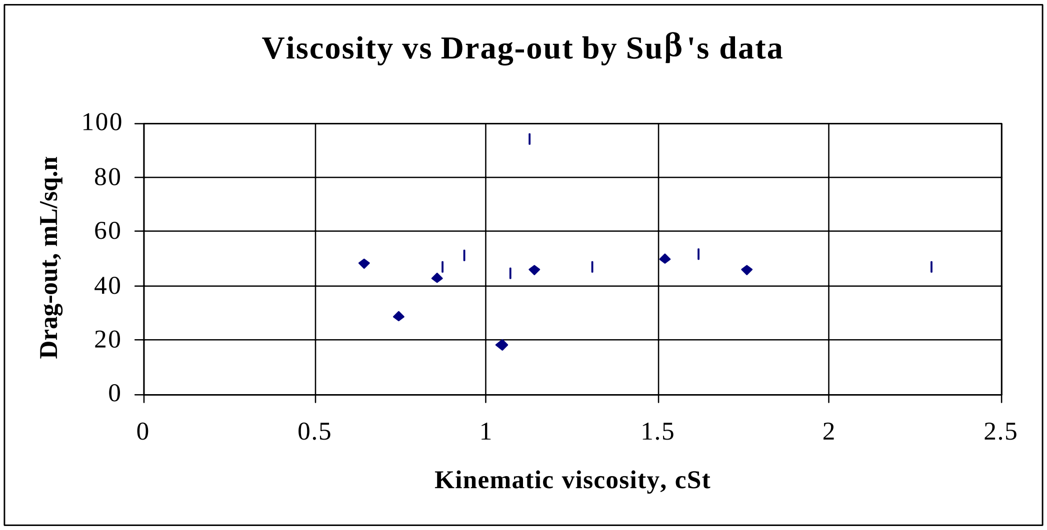

Figure 2. Measured Drag-out as a Function of Kinematic Viscosity for Results of Süβ (1992).

McKesson and Wegener (1998) at RD Chemical Company experimentally measured the amount of drainage from PWBs as a function of time. They pointed out that longer “hang” or drainage times allows more liquid to drain from the PWB with consequently less drag-in into the rinse tanks and thus more efficient rinsing. However, too long of a drainage time may result in lower PWB quality due to drying and tarnishing. McKesson and Wegener tested two outer layer boards with solder mask and solder plated and one inner layer board with no holes. A typical result is shown in Figure 3. (This figure is reconstructed from a figure in McKesson and Wegener.)

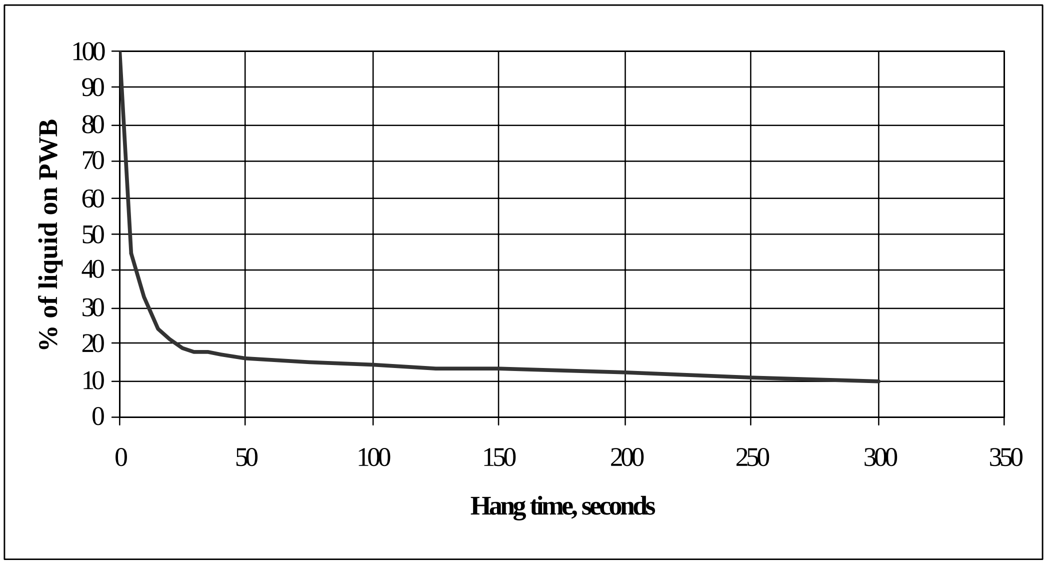

Figure 3. Drainage vs Hang Time (McKesson and Wegener 1998).

The results for all three PWBs lay virtually on top of each other in Figure 3. The authors chose to report just the percentage of liquid that remains on the board rather than mass or volume. This allowed the authors to see the great similarities in drainage among varying conditions. The figure shows two drainage phases. For short times, the liquid drains very quickly followed at longer times by a much slower drainage rate. The authors concluded that 30 seconds appeared to be an optimal drain time. The authors also studied the effect of surfactants and found very little difference. They also tested canting the boards at about a 15-20^{o} angle and saw only minor differences.

It appears that the most influential reference for typical drag-out volumes is the *Electroplating Engineering Handbook* (Pinkerton 1984). These values seem to go back to work by Soderberg published in 1936. Typical drag-out volumes are given in Table 6 as reported by Pinkerton.

Table 6. Drag-Out per Unit Area (Pinkerton 1984).

Condition	Drag-Out mL/m^2
Vertical parts, well drained	16.2[1]
Vertical parts, poorly drained	82
Vertical parts, very poorly drained	160
Horizontal parts, well drained	32
Horizontal parts, very poorly drained	410
Cup shaped parts, very poorly drained	320-980

[1] Suggested by Pinkerton as being the absolute minimum for drag-out on a vertical sheet.

Hanson and Zabban (1959) discussed the design of a wastewater treatment plant at an IBM plant. To design the plant, an estimate of the wastewater quality was needed. Because a primary source of the contaminants was the plating lines, the drag-out was estimated based on information published by Graham in the *Electroplating Engineering Handbook*. (Note: the data given are the same as that in a more recent version of the *Handbook* given by Pinkerton [1984] and experimental data from another IBM plant which showed drag-out volumes ranging from 100 to 160 mL/m^2.) For design, a drag-out value of 200 mL/m^2 was used.

Yost (1991) studied the effect of various rinsing arrangements on the costs of cadmium electroplating wastewater costs. In doing the calculations, Yost arbitrarily assumed drag-out of 200 mL/m^2 with no reference for the value.

Chang and McCoy (1990) used a drag-out value of 160 mL/ft^2 to evaluate waste minimization for PWB manufacture. No source was given for their drag-out value, but this value appears to be commonly used by several researchers.

Discussions with Experts in the Surface Finishing Industry

Contacts were made with several experts in the surface finishing industry. One expert source (Sharp 1998) had the following comments on drag-out:

- CH_2M-Hill did a drag-out study for Merix Corporation sometime in the mid-80s (our efforts to obtain the report from Merix were unsuccessful). CH_2M-Hill used a bath tank and one rinse tank and dipped the boards in the bath and rinsed them sequentially and monitored the conductivity of the rinse tank. The boards were vertical and had **no** holes (interlayer boards about 20 mils thick), but the hang time and other variables can only be found in the original report. The amount of drag-out was 7½ gallons of process bath liquid per 3,000 ft^2 (102 mL/m^2) of board area (one side only).
- Holes make a difference for drag-out since the holes are small enough that the liquid does not drain out of them very well. “Hang time” also affects the drag-out.

- Horizontal lines have drag-out of about 2-5 gallons per 3,000 ft^2 (39-66 mL/m^2) of board area (one side only) for boards with no holes. The drag-out is lower for horizontal lines compared to vertical lines because of the rollers used to squeegee the water off. Vertical boards are the older process, and the trend is to go to horizontal boards. Currently, the industry is about ½ vertical and ½ horizontal.
- One vendor has suggested that the drag-out is about 15 gallons per 3,000 ft^2 (200 mL/m^2) of board area (one side only). However, this appears too high because the experts's mass balances on his own plating line didn't work out using this number.
- Based on the mass balances on the expert's surface finishing line, i.e., accounting for the amount of chemicals added, consumed, and those in the waste, etc., the drag-out ought to be about 7 gallons per 3,000 ft^2 (95 mL/m^2) of board area (one side only) for circuit boards with holes, and about 3 gallons per 3,000 ft^2 (41 mL/ft^2) for interlayer boards.
- There are not any available computer models that could be used to predict wastewater concentrations, flows, etc. for plating lines.

Most of the baths used at the expert's facility (Sharp 1998) have a specific gravity of about 1.08, but the the viscosity and surface tension are unknown. The expert thought that chemical supply companies know the viscosity or surface tension of the process baths, but it is nearly impossible to get those data from the suppliers.

Summary of Drag-Out Studies

Table 7 summarizes the reported drag-out quantities from researchers and practitioners.

Table 7. Summary of Reported Drag-Out Volumes in the Literature.

Board Orientation	Bath	Conditions/Description	Drag-Out, mL/m^2	Reference
Vertical	Microetch	Baseline	130	Pagel 1992
"	"	Slow withdrawal rate	72	"
"	"	Intermediate withdrawal rate & longer drain time	76	"
"	Electroless	Baseline	65	"
"	"	Slow withdrawal rate	32	"
"	"	Intermediate withdrawal rate & longer drain time	31	"
Vertical	Not specified	CH_2M-Hill study	103	Sharp 1998
Horizontal	"	Based on experience	27 - 67	"
Vertical	"	Boards with holes	95	"
"	"	Interlayer boards without holes	41	"
"	"	Vertical parts, well drained	16[1]	Pinkerton 1984
"	"	Vertical parts, poorly drained	82	"
"	"	Vertical parts, very poorly drained	160	"
"	"	Rack plating (used to estimate metals in wastewater for design of wastewater treatment system)	203	Hansan & Zabban 1959
Not specified	Not specified	Drag-out value assumed in order to compare costs of rinsing alternatives	162	Yost
"	"	Drag-out value assumed to evaluate waste minimization	160	Chang & McCoy 1990
Vertical	19-20 g/L & 240-250 g/L CrO_3	Studies at varying drainage angles, drainage times, and withdrawal rates	12 - 65	Süβ 1990
Vertical	Various electrolytes	Experimental determinations to test theoretical equations	18 - 94	Süβ 1992

[1] Suggested by Pinkerton as being the absolute minimum for drag-out on a vertical sheet.

Drag-Out Prediction Equations

Kushner (1951a) was one of the first researchers to study drag-out in detail. Kushner distinguished two stages in the generation of drag-out. The first stage is the “withdrawal” stage in which the work piece is moving out of the liquid but is still in contact with it. The second stage is “drainage” in which the work piece is completely out of the liquid, but is still over the bath and liquid is still running off the piece. Kushner considered the withdrawal stage the more important, because the withdrawal determined the thickness of the adhering liquid film. The factors that control the film thickness are the velocity of withdrawal, viscosity of the liquid, density of the liquid, and surface tension of the liquid although he believed surface tension was a minor factor. Using dimensional analysis, Kushner derived the following equation:

$$f = K\left(\frac{Vm}{pg}\right)^{m} \qquad \text{Eqn 5}$$

where:
f = film thickness
K = unknown constant determined by experiments
V = velocity of withdrawal
µ = viscosity
ρ = density
g = acceleration of gravity
m = unknown exponent determined by experiments

Based on experimental work of others, Kushner concluded that the best fit equation was equation 3 presented earlier:

$$f = 0.02\sqrt{n \cdot v_A} \qquad \text{Eqn 3}$$

Note that although equation 3 was derived by dimensional analysis, it does not appear dimensionally consistent, because the acceleration of gravity is dropped as a term. This is also the equation referenced by Pinkerton and Graham in the *Electroplating Engineering Handbook* (1984). Importantly, this equation is for work pieces with smooth surfaces, unlike PWBs which have many small holes. This equation will tend to underestimate drag-out for PWBs. Notably, this is one of two equations tested by Süβ (1992) and discussed above. The equation performed poorly in predicting drag-out for a variety of electrolytes.

Kushner (1951b) argued that equation 3 gives good drag-out predictions for short drainage times, but increasingly overestimates the drag-out with longer drainage times, because it does not allow for the liquid that drains off the work piece. Conceptually for a rectangular sheet, the volume of liquid that drains off the sheet is:

$$\Delta V = A \cdot f_{dr} = A \cdot F_{dr}(f, r, g, m, s, t_{dr}) \qquad \text{Eqn 6}$$

where:
ΔV = volume of liquid that drains from the rectangular sheet
A = area of the sheet
f_{dr} = thickness of the film that drains off the sheet
F_{dr} = function describing a relationship between the independent variables and thickness of the film that drains from the sheet
σ_{dr} = surface tension of the liquid
t_{dr} = drainage time

Hence, the net film thickness or the drag-out volume per unit area after any drainage time, t_{dr}, is:

$$f = 0.02\sqrt{n \cdot v_A} - F_{dr}(f, r, g, m, s, t_{dr}) \qquad \text{Eqn 7}$$

The volume of liquid that drains from the board is a complex process and Kushner was not able to develop a predictive equation. He did, however, make qualitative statements about the effect of several variables. Kushner believed that viscosity was the most important property of the plating solution. Higher viscosities tend to increase the liquid adhering to the sheet as it is withdrawn from the bath and tend to decrease the liquid that drains. Some chemicals in particular are surface active and have molecular structures that increase viscosity. These chemicals may cause a “surface viscosity” that give higher drag-out. Higher densities tend to decrease the liquid adhering to the sheet and increase the drainage. However, the increase in density due to a higher concentration of chemicals in solution is usually outweighed by the increase in viscosity. Kushner gave an example of increasing a sucrose solution from 20% to 60%. This increases the density by 18% while the viscosity increases by 2700%. Lower surface tension will thin the film thickness as the sheet is withdrawn and also increase the drainage as well as reducing the volume of the bead of liquid along the bottom edge of the sheet. Of course, wetting agents are surface active and will concentrate in the drag-out, and hence will be removed at a higher rate than other chemicals. Longer withdrawal times and drain times will reduce drag-out, but Kushner believed that it is better to have a longer withdrawal time than a longer drain time. His rationale was to start with the smallest volume on the work piece to begin with. He also referenced work by Soderberg that drainage times beyond 60 seconds have little effect. Finally, Kushner recommended that work pieces be oriented to minimize the drainage distance and that the pieces be tilted.

Rinsing Theory

The primary source of the quantity of wastewater generated is rinse water. Most process baths are followed by two rinses, but sometimes just one rinse and sometimes three rinses. The development of rinsing theory can be traced at least as far back as Kushner (1949). Pinkerton and Graham (1984) summarized some of the fundamental mathematical relationships for rinsing. For a non-running rinse tank and assuming that ideal, instantaneous mixing occurs, the concentration of a contaminant in the rinse tank is given by:

$$C_t = C_o \cdot \left[1 - \left(\frac{V_t}{V_t + D} \right)^n \right] \qquad \text{Eqn 8}$$

where:
C_t = concentration of contaminant in rinse tank after t min
C_o = concentration of contaminant solution being drug into rinse tank
V_t = volume of rinse tank
D = volume of drag-over or drag-out on rack and work rinsing operation
n = number of rinsing operations in t min

Most rinse operations at larger facilities use multiple countercurrent cascade rinses. In this case, the concentration in the effluent from the rth rinse tank is:

$$C_r = \left[\frac{(Q \cdot t/D) - 1}{(Q \cdot t/D)^{r+1} - 1} \right] \cdot C_0$$

Eqn 9

where:

C_r = concentration of contaminant in the effluent of the rth rinse tank

Q = rate of fresh water flow

t = time interval between rinsing operations

r = number of rinse tanks in series

Talmadge (1968) presents equations similar to the above but with an extra term to account for imperfect mixing, i.e., imperfect removal of the contaminant from the work piece.

An approximate equation for multiple, countercurrent rinses has apparently been used by some (Hanson and Zabban 1959; Mohler 1984):

$$Q = \frac{D}{t} \left(\frac{C_o}{C_r} \right)^{1/r}$$

Eqn 10

Mohler (1984) discussed how rinsing equations can be used in practice. In general the rinse must not cause a loss in product quality. There is, then, a maximum allowable concentration in the final rinse called the “contamination limit.” The ratio of the concentration in the drag-in, C_o, into the first rinse tank (or drag-out from the process bath) to the concentration in the final rinse, C_r, is the dilution factor or “rinsing ratio,” C_o/C_r. Either the contamination limit or rinsing ratio can be used to calculate the required rinse flow rate if the other parameters are known. For example, assume that the rinsing ratio is 5,000, there are two countercurrent rinse tanks, the drag-out volume is 100 mL/m^2 of PWB, each rinse cycle rinses 15 m^2 of PWBs, and the time interval between operations is 3 minutes. Then:

C_o/C_r = 5000

D = (100 mL/m^2)(15 m^2) = 1.5 L

t = 3 minutes

r = 2 tanks

Solution of equation 10 yields the required rinse flow rate, Q = 35.4 lpm.

The approach above is consistent with Kushner (1949). Kushner observed that the purpose of the rinse tanks are to "stand guard between baths to keep one solution from mixing with another and contaminating it." The rinse water flow rate partially determines the concentration of carryover into the next plating tank and thus the plating quality. Kushner believed that each rinse system in a facility would have its own unique rinsing ratio, C_o/C_r. Kushner suggested several values for the rinsing ratio as listed in Table 8. These values would not be valid to use for PWB manufacturing because it is a different system than what Kushner dealt with and Kushner gave these criteria as approximations based on only limited data, but probably on the conservative side.

Table 8. Kushner's (1949) Suggested Rinsing Ratios.

Type of Rinse Tank	Rinsing Ratio
Rinse after alkaline cleaner	5000 - 7000
Rinse after acid dip	2000 - 3000
Rinse after cyanide dip	3000 - 5000
Rinse after cyanide copper	1500 - 2500
Rinse before drying (better work)	10,000
Rinse before drying (cheaper work)	5,000

Kushner (1979) observed that the theoretical rinsing equations as discussed above assume ideal mixing. Kushner cited work by Talmadge showing that if mixing is very poor so that mixing is by diffusion only, then the equations based on ideal mixing can not be used. However, Kushner stated that experience had shown for most practical applications that the ideal mixing equations were more accurate than equations based on diffusion as the dominant mixing mechanism. Indeed, Talmadge and Buffham (1961) stated that if the primary concern is to estimate the amount of contaminants that enter the wastewater, then rinsing equations based on complete mixing would be adequate and provide conservative answers.

Although using rinsing ratios and the rinsing equations is an interesting approach to calculating the volume of rinse water, it is apparently difficult to do this in practice. The contamination limits are apparently not readily known and are influenced by upstream processes. This was also pointed out by McKesson and Wegener (1998) who stated that there is not standard for rinsing that can be used to determine "manageable" concentrations of contaminants remaining on the work. What is manageable would need to be determined for each specific process and would depend on:

- "The type of contaminant."
- "The tolerance of the following process step for the particular contaminant in question."
- "The effect the residual contaminants have on the work."

Other Rinsing Theory Studies

Several other rinsing theory studies have been conducted by various researches. Some of these have focused on how well the drag-out is dispersed into the rinsing tank. While interesting, these studies are not applicable to this project, because sufficient rinsing is used in practice such that most of the drag-out ends up in the rinse water and thence the wastewater. For example, Talmadge and Sik (1969) developed equations to describe the dispersing of the bead of liquid at the bottom of a plate into the rinse water. They extended previous work that used diffusion theory to predict the residual contaminant on a plate in a rinse tank. Talmadge and Buffham (1961) and Talmadge et al. (1962) made detailed investigations of rinsing effectiveness in the absence of mixing or agitation other than the flow of rinse water in the tank, i.e., molecular diffusion is the dominant mass transfer mechanism. They found in such cases that about 10% of the contaminant is left in the film a flat sheet as compared to typically less than 0.1% when using ideal mixing rinse equations. However, the situation is not typical of practice, and as mentioned above, using the ideal complete mixing equations gives a conservative estimate of contaminant in the wastewater, i.e., less contaminant is left on the board.

PWB Pollution Prevention and Control Technology: Analysis of Updated Survey Results

As part of an EPA funded project, a questionnaire survey form on pollution prevention was sent to 400 PWB shops in 1995 and 40 shops responded. A shortened survey was sent in 1997 to 250 PWB shops in California and 45 responded for a total of 85 between the two surveys. A summary of information relevant to this project follows (U.S. EPA 1998).

Wastewater generation. Most of the wastewater generated is from rinsing. The best estimate of water usage is 10 gallons/(layer-ft^2 of production) or 410 l/m^2 which is the "wetted" surface area and was "calculated based on the total surface area of all layers of boards manufactured." This value is the mean of the 20 largest shops. Large shops had the most reliable data. Smaller shops were encouraged to estimate their data if they did not know, and this made their data suspect.

Recycle, recovery, and bath maintenance. The survey revealed several practices for recycle, recovery, and bath maintenance:

- Nearly all shops responding to the survey reported using off-site recycling for one or more of their spent process baths although the percentage recycled for each bath type was not reported. The most common bath sent for recycle was spent etching because the baths have high copper concentrations of about 150 g/L. About 80-85% of the responders used an ammoniacal etchant and most of the rest used cupric chloride. The volume of spent ammoniacal etchant solutions generated was 1 gallon per 30 ft^2 (1.4 l/m^2) of inner- and outer-layer panels. Other types of spent baths were far less likely to be sent off-site for recycle. Tin and/or tin-lead stripping solutions were the next most common spent bath sent off-site and was reported by 20% of the survey responders. Approximately 50% of the responders used a tin outer-layer etch resist and 50% used a tin-lead etch resist. Only 10% of responders indicated that spent rack stripping solutions are sent off-site.

This stripping solution results from removing plating deposits from racks used to hold the PWBs. This solution can be a significant waste. Based on the survey report, we will assume that only spent etchant baths are sent off-site for recycle.

- The use of various technologies to recycle and recover baths and waste streams on-site varied. Ion exchange was used by 45% of the responders to treat and recover discharges, but many times this was part of their waste treatment system.
- The volume of wastes generated from spent baths was estimated as shown in Table 9.

Wastewater treatment. Wastewater treatment systems removed the metals by conventional precipitation systems, ion exchange, or a combination of the two. Wastewater treatment sludges generated are typically (88% of responders) sent off-site for recycle rather than disposed of in a landfill. Sludge generation data were few. The three largest facilities reporting data had sludge generation rates of 0.02, 0.31, and 0.24 kg/m^2. The smallest number, 0.02 kg/m^2, came from a facility making only single sided boards whereas the other two had a larger mix of products which generated more waste.

Drag-out reduction practices. Table 10 shows the drag-out reduction or recovery practices used by the responders.

Drag-out reduction can reduce pollution, but it can cause problems for the process baths due to greater build-up of contaminants in the bath. One or more bath maintenance techniques may be required.

Water Use Rates from Survey of MHC Facilities

As part of a U.S. EPA sponsored research project, the University of Tennessee CCPCT (1997) surveyed MHC PWB plating facilities. Part of the survey addressed water use for various MHC process alternatives. Table 11 shows the estimated water consumption for MHC alternatives based on the survey data and normalizing assumptions.

These water consumption rates are of the same order of magnitude as those from the U.S. EPA (1998) survey discussed earlier which estimated water usage to be 10 gallons/(layer-ft^2 of production) as the mean of the 20 largest shops.

Table 9. Selected Waste Volume Estimates From Spent Baths.

Process	Waste	Volume[1] (per 1,000 ft^2 of 4 layer boards)	Volume[1] (per m^2 of 4 layer boards)
Etching, inner and outer layers	Spent etchant	140 gallons	5.7 liters
Dry film resist developer	Spent developer	200 gallons	8.1 liters
Dry film resist stripper	Spent stripping solution	6 gallons	0.24 liters
Tin-lead stripper	Spent stripping solution	17 gallons	0.69 liters
Soldermask developer	Spend developer	60 gallons	2.4 liters
Microetch; inner and outer layers	Spent micro-etchant	16 gallons	0.65 liters
Sulfuric acid dips	Spent sulfuric acid baths	12 gallons	0.48 liters
Electroless copper	Waste electroless Cu bath	26 gallons	1.1 liters
Board trim	Waste copper-clad material	187.5 ft^2, 42.9 lbs Cu	0.1875 m^2, 19.6 kg

[1] Assumptions:

a) Ammoniacal etchant used for both inner- and outer-layers, 70% of copper foils etched, 1 oz. copper used on all layers, and 20 oz/gal carrying capacity of etchant.

b) 50% of film developed (30% outer, 70% inner), developer carrying of 3 mil-ft^2/gal, and 1 mil film is used throughout.

c) 50% of film stripped (70% outer, 30% inner), stripper carrying capacity of 100 mil-ft^2/gal, and 1 mil film is used throughout.

d) 30% metal area, tin-lead resist is 0.3 mil thick and stripper capacity of 15 oz/gal of metal.

e) 30% of mask developed, 1 mil thickness, 10 mil-ft^2/gal carrying capacity.

f) Oxide, electroless Cu, and pre-pattern plate microetches (50%, 100%, and 30% of surface area etched, respectively) considered. Many facilities may employ additional baths.

g) Microetches average etch and 4 oz/gal carrying capacity.

h) Bath life of 1 gallon/500 ssf, 3 sulfuric dips (oxide, electroless copper, and pattern plate lines).

I) 18x24 panels with 0.75 inch thief area and 0.25 inch spacing of 6 step-and-repeats, outer layer 2 oz copper (80% trim area), inner layer 1 oz copper (50% trim area).

Table 10. Drag-out Reduction or Recovery Practices Used by the Responders.

Drag-Out Reduction or Recovery Practice	PWB Responders Using, %[1]	Plating Shops Using, %[2]
Allow for long drip times over process tanks	76.3	60.4[3]
Have drip shields between process and rinse tanks	60.5	56.9
Practice slow rack withdrawal from process tanks	52.6	38.1[3]
Use drag-in/drag-out rinse tank arrangements	34.2	20.8[3]
Use drag-out tanks and return contents to process baths	34.2	61.0[3]
Use wetting agents to lower viscosity	31.6	32.4
Use air knives to remove drag-out	26.3	2.2[3]
Use drip tanks and return contents to process baths	10.5	27.0[3]
Use fog or spray rinses over heated process baths	10.5	18.9[3]
Operate at lowest permissible chemical concentrations	7.9	34.6
Operate at highest permissible temperatures	5.2	17.9

[1] Data from PWB survey.

[2] Data from 1993-1994 survey of for the metal finishing industry.

[3] Data are for manually operated methods, which are the predominant type for the plating operations surveyed during the NCMS/NAMF project.

Table 11. Water Consumption Rates of PWB MHC Alternatives.

Process Type	Water Consumption[1]	
	(gal/ft^2)	(l/m^2)
Electroless copper, non-conveyorized	11.7	476
Electroless copper, conveyorized	1.15	46.8
Carbon, conveyorized	1.29	52.5
Conductive polymer, conveyorized	0.73	30
Graphite, conveyorized	0.45	18
Non-formaldehyde electroless copper, non-conveyorized	3.74	152
Organic-palladium, non-conveyorized	1.35	54.9
Organic-palladium, conveyorized	1.13	46.0
Tin-palladium, non-conveyorized	1.80	73.2
Tin-palladium, conveyorized	0.57	23

[1] Based on wetted board surface area.

RESEARCH APPROACH

The objective of this study was to develop and validate methods to predict the quality of waste water generated from PWB manufacturing processes. The methods can then be used to compare alternative manufacturing processes in the PWB industry. In the DFE studies, industrial and environmental exposure and risk are evaluated on a chemical-specific basis for individual manufacturing operations. Wastewater data collected during routine regulatory sampling are inadequate for these purposes because data are collected for only a few specific pollutants and the samples contain wastewater from the entire plant rather than an individual process line. For these reasons, a mass-balance calculation is the most suitable approach to estimating the load of each pollutant emanating from a given process line.

The literature review revealed that drag-out was the source of most of the contaminants in the wastewater from a given process. Process-specific waste loads originating from drag-out can be estimated by the product of the drag-out volume and the chemical concentration in the process baths. The latter are determined as an existing component of the DFE process. However, according to the literature review, drag-out volume from PWBs and other flat, vertical pieces can vary between about 10 and 120 mL/m^2. Drag-out was affected by variables such as bath chemistry, board withdraw rate, drain time, and orientation of the boards during withdraw. Board surface characteristics and the number and geometry of holes drilled in the board may also be significant, but these variables have not been systematically investigated to date. Equations presently available in the literature fail to accurately predict the volume of drag-out from vertical plates (Süβ 1992).

The MHC process was selected as the basis of the research because a significant data base already existed for this process as a result of the previously concluded DFE project. Also, the research team was most experienced and familiar with this process line. The results of this work apply to other PWB processes that employ process baths in which the boards are vertically oriented.

The specific steps in the research plan were:

- To conduct limited laboratory drag-out experiments for the purpose of supplementing existing data in the literature.
- To identify or develop an accurate and comprehensive drag-out model for PWB using a data-base that includes data developed in this study and by others.
- To develop a computer model to predict wastewater quality and quantity from a PWB processes that incorporates the new drag-out model.
- To validate the model using data from process bath and rinse water samples collected from three MHC process lines.

LABORATORY DRAG-OUT EXPERIMENTS

Laboratory drag-out experiments were conducted to supplement existing drag-out data in the literature. Existing drag-out equations do not accurately predict the effect of fluid properties on drag-out from vertical flat pieces such as PWBs (Süβ 1992). While some studies have investigated the effect of viscosity, another parameter that may exert significant influence, surface tension, has received virtually no attention. The scope of this study did not allow a comprehensive evaluation of the effect of these parameters. Instead, an alkaline cleaner bath was selected as a bath that was more difficult to drain and a microetch bath was selected as one that would be relatively easy to drain. During the study, viscosity and surface tension would be measured to gain an indication of the relative influence of these parameters on drag-out.

The procedures for the laboratory drag-out experiments were devised to simulate conditions occurring in the PWB manufacturing process. The drag-out volume was measured gravimetrically as the boards were withdrawn from the process tanks. Experiments were conducted using two heated process baths to determine the range of expected drag-out volumes under various conditions. Because the alkaline cleaner/condition and microeth baths have significantly different chemical compositions and properties, these baths were chosen for the experiments to provide a realistic range of drag-out volumes. The board size was 0.457 m by 0.610 m. Experimental conditions that were studied were the orientation of the board during the drain time, the length of the drain time, the board withdraw rate from the bath, and shaking the board at the beginning of the drain period. Withdraw rates of 0.076 m/sec and 0.305 m/sec were tested, and the boards were drained with the long edge horizontally, vertically, or at a 45° angle. Drain periods of 10 seconds, 20 seconds, and 30 seconds were studied. The basic operating conditions (BOC) for the majority of the tests were: 0.076 m/sec withdraw rate, 10 second drain time, no shaking after board withdraw, 45° drain angle, and the board oriented with the long edge horizontal. Nine sets of experiments were conducted on each bath for a total of eighteen drag-out experiments. Several additional experiments were conducted with the microetch bath for a drilled board with a different hole density and design. The matrix of experimental conditions that were tested for each of the two baths is presented in Table 12.

For the alkaline cleaner/conditioner experiments, generally five repetitions were made for each condition, with the circuit board remaining submersed in the bath for one minute on each test. Since the etching process changed both the properties of the circuit board and the chemical composition of the bath, only three repetitions for each condition were performed and the boards were only allowed to remain submersed for 30 seconds. These conditions were taken into account by assuming that the copper etch rate would remain constant over the duration of the experiments. This assumption was verified by weighing the boards before and after the tests to determine the mass of copper etched from the board.

Table 12. Experimental Matrix for Laboratory Study of Drag-out Volumes for Each Bath Type.

Experimental Conditions	Drilled Board	Undrilled Board	Drilled, Etched Board
0.076 m/sec withdraw 45° drain angle 10 sec drip time no shaking	!	!	!
0.076 m/sec withdraw long edge horizontal 10 sec drip time no shaking	!		
0.076 m/sec withdraw long edge vertical 10 sec drip time no shaking	!		
0.076 m/sec withdraw 45° drain angle 20 sec drip time no shaking	!		
0.305 m/sec withdraw 45° drain angle 30 sec drip time no shaking	!		
1.0 fps withdraw 45° drain angle 10 sec drip time no shaking	!		
0.076 m/sec withdraw 45° drain angle 10 sec drip time shake board	!		

Apparatus

- 10 cm by 61 cm by 76 cm high density polyethylene (HDPE) tank, supported and stabilized to prevent tipping.
- Magna-Whirl Constant Temperature Water Bath, Model MW-1140A-1.
- Pump, ITT Jabsco Self-Priming, Model 12290-0001, 115 volt, 3.3 amp, with thermal overload protection.
- 6 m of 1.3 cm diameter stainless steel tubing, coiled to fit inside bottom of HDPE tank.
- 1.3 cm I.D. Nalgene tubing, lab/food grade, with connection clamps.
- 48 liters bath solution (Alkaline Cleaner/Conditioner or Microetch).
- Mettler Toledo Electronic Analytical Balance, Model PR5002, Maximum 5100 grams, with cardboard air current shield.

- 0.457 m by 0.610 m circuit boards (copper clad with holes; copper clad without holes; etched, with holes).
- Plastic bags, 0.50 mil, 110 l capacity.
- Whittner Taktell Super-Mini Metronom, Model 886051, set at 120 beats per minute.
- Laboratory clamps and clips.

Procedure

1. For the first set of experiments, the Alkaline Cleaner/Conditioner bath was prepared according to the manufacturer's specifications by filling the HDPE tank with 24 L of deionized water. Next, 2.88 L of Electro-Brite ML-371 were added, and the tank was brought to a volume of 48 L with deionized water to produce a 6% (by volume) concentration. The solution was gently mixed. For the second set of experiments, the Microetch bath was prepared according to the manufacturer's specifications by filling the HDPE process tank with 24 L of tap water and adding 720 g of copper sulfate pentahydrate ($CuSO_45H_2O$) and 8.64 L of 66° Baume sulfuric acid (H_2SO_4). The acid was added very slowly, taking care that the temperature of the mixture remained below 54° C. A laboratory thermometer was inserted into the mixture to monitor temperature. Next, 3.34 L of Co-Bra Etch Inhibitor Makeup were added, and the mixture was brought to a volume of 48 L with tap water.
2. The stainless steel heating coil was placed into the HDPE tank containing the simulated bath. The coil inlet was connected to tubing from the water bath (with the in-line pump), and the coil outlet connected to tubing discharging back to the water bath. The experimental set up is presented as Figure 4.
3. The Magna-Whirl water bath was filled with approximately 95 liters of hot tap water. The water bath heater and pump were turned on, allowing the bath to equilibrate to 57° C for the alkaline cleaner/conditioner, and 52° C for the microetch bath. The water bath thermostat was set, and a thermometer was placed in the bath to monitor the bath temperature.
4. The bath temperature, pH, and density were measured *in-situ* in the tank. Conductivity, viscosity, and surface tension were measured on a sample collected from the tank. Analyses were performed as described later in the section entitled: **COLLECTION AND ANALYSIS OF FIELD SAMPLES.**
5. The circuit board was cleaned with tap water and detergent, and thoroughly rinsed with deionized water. The board was dried using compressed air to ensure no moisture remained entrapped in the holes.
6. The board was centered on the analytical balance, and the weight was recorded to the nearest 0.01 g.
7. A clean new plastic bag was weighed on the analytical balance, and the results recorded to the nearest 0.01 g.
8. The plastic bag was opened, and carefully attached to the outside of the HDPE tank using small laboratory clips.

9. The metronome was turned on, and two laboratory clamps were attached to the circuit board to serve as handles. The circuit board was slowly lowered into the tank so the entire surface was completely submerged in the bath. The board was agitated slightly to remove entrapped air bubbles, and then allowed to remain submerged for approximately one minute in the alkaline cleaner/conditioner bath or 30 seconds in the microetch bath. The process was timed by counting ticks on the metronome.
10. The board was removed vertically at the appropriate withdraw rate, stopping several inches above the bath surface. Depending on the experiment, the board was then either held steady or given one quick shake, and the board held so that its edge was either level or at a 45° angle during the allotted drain time. The appropriate withdraw rates, drain positions, and drain times were specified in the Table 12. Both the withdraw rate and drip time were timed by ticks of the metronome.
11. The board was immediately placed into the plastic bag attached to the tank. Extra care was taken to ensure that any drips after the specified drain period fell into the bag, and that the sharp corners of the board did not puncture the bag.
12. The clamps were removed from the board, along with the clips holding the bag to the tank. The bag was carefully sealed, removing as much air as possible.
13. The sealed bag containing the circuit board and drag-out was centered on the analytical balance and weighed, the results were recorded to the nearest 0.01 g.
14. The circuit board was carefully removed from the bag, and the process was repeated, beginning with weighing a clean new plastic bag.
15. After the specified number of runs were completed for each set of conditions, the bath temperature, pH, and density were again measured *in-situ* in the tank. Conductivity, viscosity, and surface tension were measured on a sample collected from the tank. Analyses were performed immediately after collecting the sample, and the results were recorded.
16. The drag-out volumes were calculated.

Before the actual drag-out experiments were conducted using PWB bath chemicals, a series of four preliminary tests were conducted to validate the proposed methodology and to verify that the drag-out could be measured accurately and precisely. The preliminary tests also served as practice runs, and allowed for any necessary adjustments to the procedure and apparatus. The coefficients of variation for the first two tests were 0.039 and 0.056, for eleven and nine trials, respectively. The coefficients of variation in the third and fourth tests improved to 0.007 and 0.008, respectively, for series of seven trials each. Since preliminary tests were not designed to cover the full range of operating variables, the following representative variables were selected: 1) ambient temperature tap water was used to simulate bath chemicals; 2) a 0.265 m x 0.457 m drilled etched board was used in the first two preliminary tests, and a 0.457 m by 0.610 m drilled copper clad board was used for the third and fourth tests; and (3) the circuit board was withdrawn at 0.15 m/sec, given one quick shake after removal, and allowed to drip for 10 seconds.

Quality Assurance and Quality Control (QA/QC)

Prior to the experiments, all laboratory equipment was thoroughly cleaned with detergent followed by a thorough deionized water rinse. The analytical balance used for weighing the boards was allowed to warm up for at least 30 minutes before any measurements were made. The balance was calibrated using calibration weights at the beginning and end of each laboratory session, to ensure the instrument had not drifted. A large shield was placed around the balance to decrease the effects of drafts while weighing the board.

Prior to mixing the actual baths, 500 ml batches of the solution were prepared per the manufacturers' product information sheets. Measurements of viscosity, specific gravity, surface tension, conductivity and pH were compared between the 500 ml batches and the full bath volume. Temperature was monitored continuously during the drag-out experiments in the baths by suspending a laboratory thermometer in the tank. Before the tests, the timing of the metronome was checked with a clock to ensure proper timing. The tank was positioned in front of a fume hood for adequate ventilation, and a large strip of tape was affixed to the fume hood shield at a 45° angle from the horizontal to use as a guide during drain periods. Personal protection equipment such as safety goggles, gloves, and aprons were used whenever feasible. All waste material including plastic bags contaminated with the drag-out chemicals and the used bath solutions were stored for proper disposal. All laboratory experimental information and data were recorded in a laboratory notebook, with carbon copies given to the principal investigators upon test completion.

Results and Discussion

Results of the laboratory drag-out volume experiments are presented in Tables 13 and 14 for the alkaline cleaner/conditioner and microeth baths, respectively.

Table 13. Drag-Out Results for Alkaline Cleaner/Conditioner Bath.

Test	Board Type	Drag-Out (ml/sq.m)	Coeff. of Variation
BOC	drilled, design 2	77.8	0.032
BOC, board edge horizontal	drilled, design 2	75.6	0.015
BOC, board edge vertical	drilled, design 2	81.3	0.021
BOC, 20 sec. drip time	drilled, design 2	68.2	0.040
BOC, 30 sec. drip time	drilled, design 2	64.5	0.047
BOC, 1 fps withdraw	drilled, design 2	98.7	0.013
BOC, with shake	drilled, design 2	77.8	0.032
BOC	undrilled	38.6	0.016
BOC	drilled, etched	89.2	0.038

Note: Design 1, 5619 holes; Design 2, 7824 holes.

Table 14. Drag-Out Results for Microetch Bath.

Test	Board Type	Drag-Out, ml/sq m	Coeff. of Variation
BOC (2/2/99)	drilled, design 2	108.9	0.043
BOC (2/13/99)	drilled, design 2	107.8	0.023
BOC (2/13/99)	drilled, design 2	93.4	0.038
BOC, board edge horizontal	drilled, design 2	120.9	0.006
BOC, board edge vertical	drilled, design 2	113.0	0.006
BOC, 20 sec. drip time	drilled, design 2	98.1	0.015
BOC, 30 sec. drip time	drilled, design 2	94.4	0.007
BOC, 1 fps withdraw	drilled, design 2	133.1	0.016
BOC, with shake	drilled, design 2	111.9	0.021
BOC	drilled, design 2	69.8	0.038
BOC, etched board	drilled, design 2	112.3	0.022
BOC, etched board	drilled, design 2	118.3	0.021

Note: Design 1, 5619 holes; Design 2, 7824 holes.

The drag-out volume for each experimental condition was calculated using the mean drag-out weight from the group of tests for the specific condition. This was generally five runs for the alkaline cleaner/conditioner, and three runs for the microetch. In addition to calculating the mean drag-out weight (in grams), the standard deviation and the coefficient of variation of the measurements were checked for each condition. The coefficient of variation was less than 0.05 for all experiments.

The mean drag-out volume for all experimental conditions for the alkaline cleaner/conditioner was 74.7 ml/m^2, which is approximately 30% less than the mean drag-out volume of 108 ml/m^2 for the microetch bath. The mean drag-out for all experimental conditions for both baths combined was 91.1 ml/m^2, and was calculated using only data from the same board hole design so as not to skew the results. It appears that drain time has an affect on drag-out volume, as reflected in the decreasing drag-out volumes as drain time increased. It also appears that the drag-out volume increases as the board withdraw rate decreases. Board tilt and orientation did not appear to affect the drag-out volume; however, drilled boards had more drag-out than undrilled boards, as expected.

Results from the microetch experiments compare favorably to those performed at Micom, Inc. (Pagel 1992), although a direct comparison was difficult since operating conditions were different. Board hole density for both tests were similar, with Micom boards having 33,000 holes/m^2 compared to 28,000 holes/m^2 for the boards used in the microetch experiments in this study. Pagel's drag-out volumes appear to be less than those measured in this study. At a withdraw rate of 0.20 m/sec and drain time of 12.1 sec, Pagel reported a drag-out volume of 76.4 mL/m^2. Under similar conditions, specifically a withdraw rate of 0.305 m/sec and a drain time of 10 seconds, this study resulted in a drag-out of 130 mL/m^2. Other differences in experimental procedures that could affect drag-out volumes include: 1) a 45° drain angle used in this study, compared to a 0° angle used by Pagel; 2) Pagel's experiments included drag-out associated with the racks; and 3) drag-out was measured by completely different approaches; specifically, Pagel used a concentration approach whereas this study used a weight approach.

Analyses of parameters for the alkaline cleaner/conditioner and microetch simulated baths were performed before the drag-out tests were run, and again after the tests were completed. Results of the tests are presented in Tables 15 and 16.

Table 15. Alkaline Cleaner/Conditioner Bath Properties.

Parameter	Before Experiments	After Experiments
pH	8.65 @ 58°C	8.47 @ 57°C
Conductivity mS/cm	0.21 @ 35°C	0.23 @ 35°C
Specific Gravity	8.65 @ 57°C	0.995 @ 57°C
Surface Tension, dynes/cm	34.7	34.7
Viscosity, cP	0.85	0.87

Table 16. Microetch Bath Analyses.

Parameter	Before Experiments	After Experiments
pH	-0.42 @ 53°C	-0.62 @ 55°C
Conductivity mS/cm	1374 @ 22°C	1562 @ 22°C
Specific Gravity	1.175 @ 53°C	1.205 @ 57°C
Surface Tension, dynes/cm	71	60
Viscosity, cP	1.44 @ 49°C	0.87 @ 50°C

As expected, there was no significant variation in the bath parameters for the alkaline cleaner/condition bath comparing values before and after the drag-out tests. There were, however, significant variations in the microetch bath characteristics, as expected. Conductivity, specific gravity, hydrogen ion concentration and viscosity all increased, possibly due to the increase in copper in the bath as a result of etching from the PWBs during the drag-out tests.

DRAG-OUT MODEL DEVELOPMENT

As stated previously the goal of this project was to develop and validate methods for predicting the quality of wastewater generated during PWB manufacturing. Drag-out and bath dumps are the two major sources of process wastewater. The literature reports drag-out rates for flat panels and PWBs ranging from 10 to 160 ml/m^2. Currently-available models utilize solution viscosity and withdraw rate as the primary independent variables. Süβ (1992) has demonstrated that drag-out rates predicted using these models are poorly correlated with results from experiments. Clearly there is a need for a more a more accurate means of predicting drag-out for PWB manufacturing.

In addition to the drag-out data collected as part of this study, three data sets containing extensive drag-out data for PWBs or flat panels were available in the literature (Süβ 1990; Süβ 1992; Pagel 1992; Ducker). An attempt was made to develop regression models to predict drag-out volumes as a function of PWB manufacturing practices. Possible model variables that were either recorded or varied in each study are summarized in Table 17.

Table 17. Potential Variables for PWB Drag-Out Prediction Model.

	Süβ 1990	Süβ 1992	Pagel 1992	This Study
Board Size	·	·	·	·
Withdraw Rate	·	·	·	·
Drain Time	·	·	·	·
Board Orientation	·			·
Board Angle	·			·
Board Surface				·
Holes	·	·	·	·
Shaking or Vibration				·
Bath Type	·	·	·	·
Kinematic Viscosity		·		·
Surface Tension				·

Of the variables listed in the table above, not all were evaluated for inclusion in the model. Board surface (etched or unetched) and shaking were not included in the parameters to be evaluated because the little data that were available for these parameters indicated they have a minor effect on drag-out volumes. Board orientation during draining was also not considered because relatively few data were available and it is not one of the waste minimization practices commonly practiced. We hypothesized that kinematic viscosity and surface tension were two fluid properties that may be most significant in determining drag-out volumes. However, Süβ (1992) showed that drag-out volume was poorly correlated with kinematic viscosity. Furthermore, Pagel's data set did not include data for either kinematic viscosity or surface tension of the baths and Süβ's data did not include any surface tension data. It was judged that the quantity of data and range of values for these two variables were insufficient to justify their inclusion in the model.

In the data base used to develop the model, board size (m^2), withdraw rate (m/sec), and drain time (sec) were treated quantitatively by using the numerical value of the variable. Three other variables were treated qualitatively using indicator variables having values of 1 or 0. The indicator variable for board angle was assigned a value of 1 if the board was angled and a value of 0 if the board edge was kept horizontal. Similarly, the indicator variable for holes was assigned a value of 1 if it contained holes and a value of 0 if the board did not contain holes. The hole density for the drilled boards in the data base ranged from 20,000 to 33,000 holes/m^2; however, data needed to further quantify the effect of drilled holes, such as hole diameter and aspect ratio, were not available. Three different indicator variables were included to specify bath type: alkaline cleaner, micro-etch and electroless copper. The obvious disadvantage of this approach is that the model can make bath-specific predictions only for these three bath types, but insufficient viscosity and surface tension data are available to make the model more general.

The data set was not ideal for development of the model. The work of Süβ (1990, 1992) was not specific to the PWB industry; therefore, he did not use standard PWB process baths, his boards were smaller than those often used in the PWB industry, and his boards did not contain drilled holes. As a result, variables describing board size and holes were strongly correlated (0.904), making it difficult to distinguish between the effects of these two parameters. Also, Süβ did not use actual PWB process baths, thus bath type and board size were also correlated. During model development, it was necessary to be aware of the effects that these peculiarities may have on the developed model.

Both a linear regression model and a multiplicative regression model were tested. The linear model was:

$$\begin{aligned} DO = {} & a_0 + a_1 SIZE + a_2 WR + a_3 DT + a_4 \frac{WR}{DT} + a_5 WR \cdot DT + \\ & a_6 HOLES + a_7 ANGLE + a_8 ALK + a_9 MICRO + a_{10} ELCTRS \end{aligned}$$

where:

DO = drag-out volume, mL/m^2

SIZE = board area, m^2

WR = withdraw rate, m/sec

DT = drain time, sec

HOLES = 1 if the board is drilled and = 0 for undrilled boards

ANGLE = 1 of the board is tilted during draining and = 0 if the board is kept horizontal

ALK = 1 if the bath is an alkaline cleaner bath and = 0 otherwise

MICRO = 1 if the bath is a micro-etch bath and = 0 otherwise

ELCTRLS = 1 if the bath is an electroless copper bath and = 0 otherwise

The multiplicative model was:

$$DO = a_0 \cdot SIZE^{a_1} \cdot WR^{a_2} \cdot DT^{a_3} \cdot a_6{}^{HOLES} \cdot a_7{}^{ANGLE} \cdot a_8{}^{ALK} \cdot a_9{}^{MICRO} \cdot a_{10}{}^{ELCTRLS} \qquad \text{Eqn 12}$$

which was rewritten in linear form for analysis by linear regression:

$$\log DO = \log a_0 + a_1 \log SIZE + a_2 \log WR + a_3 \log DT + HOLES \log a_6 + ANGLE \log a_7 + ALK \log a_8 + MICRO \log a_9 + ELCTRLS \log a_{10} \qquad \text{Eqn 13}$$

Both models were evaluated using stepwise regression (SSPS ver. 9). This procedure adds or removes independent variables to the model based on criteria related to the reduction in the sum of squares achieved by inclusion of the variable. The final model includes only the variables that result in a statistically significant reduction in the sum of squares error. The stepwise regression procedure yielded an $r^2 = 0.883$ for the linear model and 0.814 for the multiplicative model. The linear model was:

$$DO = 3.63 + 694 \cdot SIZE - 180 \cdot ELCTRLS + 89.6 \cdot \frac{WR}{DT} - 155 \cdot ALK + 38.6 \cdot HOLES + 29.9 \cdot WR - 0.443 \cdot DT - 127 \cdot MICRO \qquad \text{Eqn 14}$$

The statistical package did not include the variables of ANGLE and WR·DT in the model because they were not statistically significant. Inspection of this equation reveals that all three bath-type coefficients are relatively large negative numbers, which would cause it to predict an erroneously large drag-out for large boards (ca. 0.25 m^2) with bath-types not explicitly accounted for in the model. For small boards (ca. 0.05 m^2) used with the bath-types accounted for in the model, it could predict negative drag-out values. These anomalies were the result of correlation of the independent variables, as described earlier. To correct this problem it was necessary to eliminate one of the three bath types as a variable in the model. Each of the three bath types was evaluated for elimination, the best fit was given by eliminating MICRO as a variable ($R^2 = 0.852$). The final drag-out model was:

$$DO = 18 + 201 \cdot SIZE - 60.1 \cdot ELCTRLS + 73 \cdot \frac{WR}{DT} - 20.9 \cdot ALK + 26.0 \cdot HOLES + 26.1 \cdot WR - 0.355 \cdot DT \qquad \text{Eqn 15}$$

A comparison of predicted and measured drag-out volumes is shown in Figure 5. The groups of vertically-aligned data points occur when the model predicts a near-constant drag-our for conditions in which the measured drag-out is variable. While some of the variability is random error, some is also the result of variation of the independent variables, indicating that the model is not able to accurately account for all the variables that affect drag-out. A more comprehensive data base in which the independent variables are systematically varied is needed if more accurate predictions of drag-out from PWB manufacturing processes are desired.

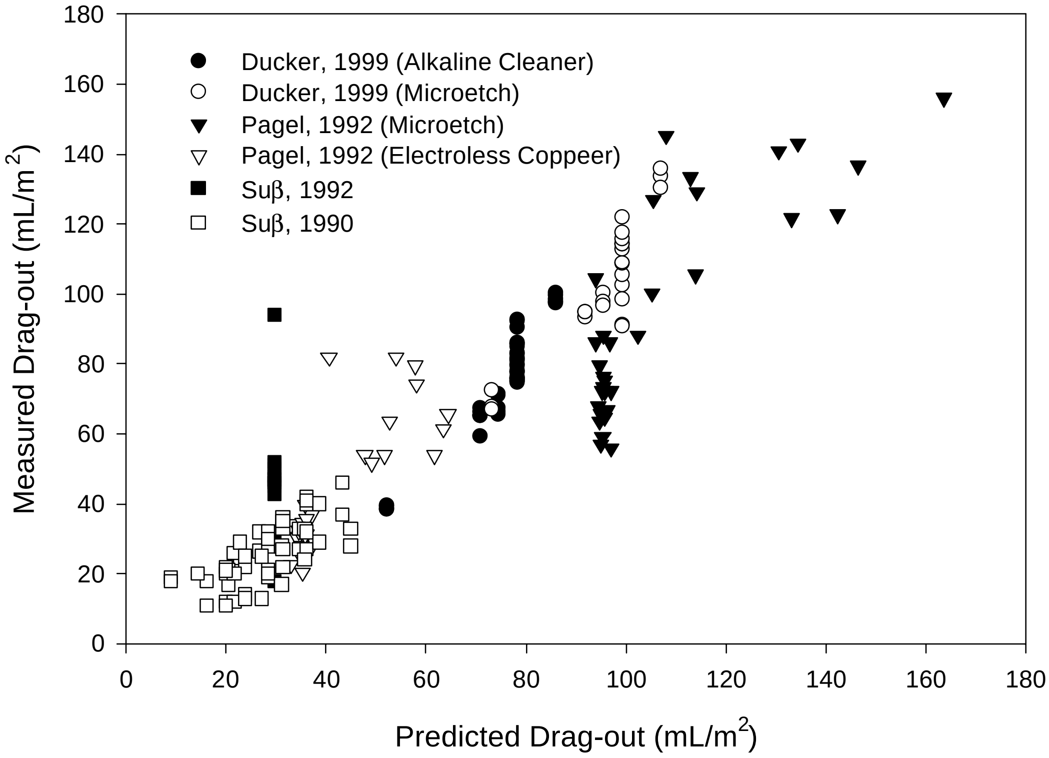

Figure 5. Comparison of Measured and Predicted Drag-Out Volumes.

PWB WASTEWATER MODEL

Given the volume of drag-out from and chemical composition of each bath, it is possible to calculate the mass of each contaminant that would enter the waste stream for a given PWB process line. A computer model was developed to facilitate such calculations. The model was based on the following assumptions:

1. Contaminants in wastewater are from drag-out from process baths and from dumping of some baths at the end of their useful life. Contaminants from the stripping of racks from deposits are ignored.
2. Essentially 100% of the drag-out ends up in the wastewater, i.e., very efficient rinsing.
3. Predictions are for vertical boards only.
4. Various predictive equations reported in literature are of limited value for estimating absolute values of drag-out as evidenced by the results of Süβ's work comparing predicted versus measured drag-out. Equation 15 was used to estimate drag-out in the model here.
5. Insufficient information exists to include surface tension as a variable although the authors recognize that it may be an important variable.
6. The estimate of drag-out of contaminants in g/d is based on the PWB production rate, chemical composition of each bath, and the estimated drag-out from each bath, according to the following equation:

$$\begin{pmatrix}\text{kg / d of}\\ \text{contaminant i}\\ \text{from bath j}\end{pmatrix} = \begin{pmatrix}\text{PWB production}\\ \text{rate, m}^2\text{ / d}\end{pmatrix}\cdot\begin{pmatrix}\text{Concentration of}\\ \text{i in bath j, mg / L}\end{pmatrix}\cdot\begin{pmatrix}\text{drag-out from}\\ \text{bath j, mL / m}^2\end{pmatrix} \qquad \text{Eqn 16}$$

The model is coded in an Excel Spreadsheet and utilizes a Visual Basic Macro. The user is required to enter information in a separate spreadsheet defining the operating conditions of the process line and the chemical composition of the baths. The effect of bath dumps on the overall pollutant load can be included by specifying their frequency. The model calculates the mass of contaminants coming from each process tank, together with the contaminant mass and concentration for the entire process line. A user's manual is included in the Appendix.

COLLECTION AND ANALYSIS OF FIELD SAMPLES

Samples of plating baths and rinse waters were collected from the MHC process line from three different PWB facilities for the purpose of verifying the drag-out model. Three process baths at each plant were selected for sampling: microetch, electroless copper, and Anti-Tarnish. Sodium or potassium were selected as tracers for each bath because they are common ions in PWB baths, and they tend to be relatively stable in solution. The relative amount of sodium and potassium in the bath and downstream rinses can be used to estimate the drag-out from each tank and to verify the overall mass balance approach to modeling wastewater quality from PWB facilities. In addition to sodium and potassium, fluid properties (viscosity, surface tension and specific gravity) that might effect the quantity of drag-out were measured. Routine measurements of conductivity and pH were taken too. The project QA/QC plan (Robinson and Cox 1998), submitted to and approved by EPA, was followed except where field conditions necessitated minor changes.

Process Characterization

Operating practices affect the amount of drag-out and the concentration of contaminants in the rinse-tank effluent. Extensive data characterizing the operating practices used at each site were collected during the site visits. Operating practices potentially affecting the amount of drag-out or the rinsing process are summarized in Tables 18 - 20. These data were later used to predict the drag-out from each process bath using equation 15 and to independently calculate the drag-out via a dynamic mass balance approach described later.

Table 18. Summary of MHC Operating Practices for the Field Sites.

	Cycle Time, min	Withdraw Rate, m/sec	Board Tilt, degrees	Hole Density, #/m^2
Plant 1	30	0.173	5	100,000 to 570,000
Plant 2	37	0.163	0	NA
Plant 3	27	0.234	0	50,000

Table 19. Summary of Drip Times for Process Baths at Field Sites.

Bath	Drip Time, sec
Plant 1 ME	5
Plant 1 EC	25
Plant 1 AT	5
Plant 2 ME	10
Plant 2 EC	15
Plant 2 AT	10
Plant 3 ME	5
Plant 3 EC	10
Plant 3 AT	5

Table 20. Summary of Rinsing Practices Used at Field Sites.

	Rinse Time (min:sec)	Rinse Tank Vol (l)	Rinse Flow Rate (l/min)	Rinse Water Source	Mixing[1]
Plant 1 ME Rinse 1	1:20	832	7.6	ME Rinse 2	1,2
Plant 1 ME Rinse 2	1:00	832	7.6	city	1,2
Plant 1 EC Rinse 1	2:10	832	7.6	EC Rinse 2	1,2
Plant 1 EC Rinse 2	1:00	832	7.6	city	1,2
Plant 1 AT Rinse 1	3:20	832	7.6	AT Rinse 2	1,2
Plant 1 AT Rinse 2	2:00	832	7.6	city	1,2
Plant 2 ME Rinse 1	2:05	415	3.8	city	1,2
Plant 2 EC Rinse 1	8:00	415	3.8	AT Rinse 1	1,2
Plant 2 AT Rinse 1	3:55	415	3.8	city	1,2
Plant 3 ME Rinse 1	1:15	892	9.8	H_2SO_4 rinse	1,2
Plant 3 EC Rinse 1	2:00	892	7.6	EC Rinse 2	1,2
Plant 3 EC Rinse 2	4:20	892	7.6	AT Rinse 1	1,2
Plant 3 AT Rinse 1	6:04	892	7.6	city	1

[1] Mixing: 1 = Board Agitation; 2 = Aeration.

Sample Collection

Samples were collected for analyses from the laboratory drag-out study tanks in the UT laboratory and from actual process baths and rinse tanks during the PWB industry site visits. For the laboratory drag-out study in the UT laboratory, grab samples were collected for surface tension and viscosity. The samples were collected directly from the experiment tank in a clean beaker, and the analyses were immediately performed.

Samples were collected during the PWB site visits from the microetch (ME), electroless copper (EC), and anti-tarnish (AT) process baths and their succeeding rinse tanks in the MHC process line. Grab samples were collected using either a plastic measuring cup or a sampling beaker, which consisted of a plastic beaker with a long handle attached. The sampling container was thoroughly rinsed with the sampling fluid prior to sample collection. The grab sample was then immediately transferred from the sampling cup or beaker into a clean 500 ml HPDE sample bottle and capped. Before the sampling event, pre-printed labels were prepared in duplicate, with one label pre-attached to the sample bottle. After the sample was collected, the remaining label was attached to the Sub-Unit Data Collection Log, and the sample description, person taking the sample, time of sample, sample volume, and method of preservation was recorded in ink. Duplicate samples taken in identical manner were collected at plants 1 and 2. At plant 3, the two samples were taken at different times in the board cycle. The first sample was taken just prior to the boards entering the rinse tank while the second was taken just after the boards were removed. Replicates were taken for approximately 20% of the samples. The sample bottles were sealed with color-coded tamper-proof tape (to identify the sampler and establish chain-of-custody), and placed in plastic lined containers for transport to the UT laboratory.

Temperature

Temperature was measured *in-situ* in the laboratory drag-out tanks. In the field, temperature was measured on grab samples collected from the process and rinse tanks. Measurements were made immediately after collection.

pH

pH was measured *in-situ* in the laboratory drag-out tanks. In the field, pH was measured on grab samples collected from the process and rinse tanks. Measurements were made immediately after collection.

Apparatus

- Orion Digital Portable pH Meter, Model 250A.
- Orion Triode^{TM} pH Electrode, Model 91-57BN.

Procedure for pH Measurements

1. After the meter was calibrated, the electrode was placed into the laboratory drag-out tank or sample and agitated slightly.
2. When the pH display was stable, the pH was recorded on the Sub-Unit Data Collection Log.
3. The electrode was rinsed with deionized water, and the process repeated.

The pH meter was calibrated prior to taking measurements for each sub unit. A two buffer calibration was performed using the 4.01 and 7.00 buffers for the acid sub units, and 7.00 and 10.01 buffers for the alkaline sub units. The first measurement in a sub unit was made in the samples from the last rinse tank, and the measurements progressed up-line, with the last measurement made on the process bath sample.

Conductivity

Conductivity measurements were performed both in the UT laboratory and at the PWB site visits. The instrument automatically compensates for temperature effects to a certain degree, except for acids. Since many of the PWB baths and rinses were acids, and temperature could have a significant effect on the conductance of these solutions, it was determined that all conductivity measurements should be made at the reference temperature of 25° C. The conductivity measurements originally made in the field at the PWB sites were re-analyzed on samples in the UT laboratory at a controlled temperature of approximately 25° C. At the beginning of each lab session, the conductivity meter was checked against a solution of known conductance to verify accuracy.

The conductivity measurements of the rinse tanks were within the meter range of 0.0 to 199.9 mS/cm; however, as anticipated, the values of some of the process baths were higher. Since conductivity is a nearly linear function of total dissolved solids (Snoeyink and Jenkins 1980), a 1:10 or 1:100 dilution with deionized water was performed on the sample if the initial reading was above the highest range on the meter. The measurement was then taken on the diluted sample, and the meter reading multiplied by the dilution factor.

Two temperature and conductivity readings were taken on each sample, with the mean values reported.

Apparatus

- Orion Conductivity/Temperature Meter, Model 122.

Viscosity

Viscosity was measured on site from grab samples collected from the rinse tanks, process baths, and laboratory drag-out tanks.

Apparatus

- Gilmont Falling Ball Viscometer, size 1, with stainless steel ball, range 1 to 10 centipoise.

Procedure

1. The temperature of the rinse tank or process bath was taken using the laboratory thermometer.
2. A grab sample was collected from the tank using a 2000 ml beaker. The viscometer, stainless steel ball, and thermometer were immediately submerged into the sample for approximately one minute to allow the laboratory equipment to equilibrate to the liquid temperature.
3. The inside of the viscometer was rinsed with the sample, then slowly filled with rinse or process bath liquid, making sure no air bubbles adhered to the sides of the viscometer.
4. The temperature of the liquid in the beaker was checked and compared with the tank temperature. In general, if the temperature difference was more than approximately 5°C, the beaker was emptied and a new sample collected.
5. The viscometer was held vertical in the center of the 2000 ml beaker. (The beaker still contained the rinse or process liquid, which acted as a temperature bath for the viscometer.) The stainless steel ball was carefully placed by hand into the filled viscometer, making sure no air bubbles stuck to the ball.
6. A stopwatch was used to time the descent of the ball between the fiducial lines on the viscometer. The time was recorded on the Sub-Unit Data Collection Log.
7. The viscometer and beaker were emptied, and the process repeated.

Using the mean descent time, the viscosity was calculated as follows:

$$m = K\left(r_f - r\right)t \qquad \text{Eqn 17}$$

where:

m = viscosity, centipoise

K = viscometer constant (0.257 with stainless steel ball, based on laboratory calibration tests using deionized water and sucrose solutions, described below)

r_f = density of ball, mg/l (8.02 for stainless steel ball)

r = density of liquid, mg/l

t = time of descent, minutes

The viscosity was recorded on the Sub-Unit Data Collection Log.

The viscometer, stainless steel ball, and beaker were thoroughly rinsed with deionized water prior to the next test.

Before viscosity measurements were made in the field and on the laboratory drag-out tanks, a series of tests were performed to establish the viscometer constant, K, for the falling ball viscometer. The constant was obtained by measuring the time of descent of the stainless steel ball in standard solutions of known viscosity, and was calculated using the following relationship:

$$K = \frac{m}{\left(r_f - r\right)t} \qquad \text{Eqn 18}$$

Three solutions were used in the investigation: 30 percent sucrose (by weight), 40 percent sucrose (by weight), and deionized water. Before the sucrose solutions were prepared, the sucrose was dried in a desiccator, and all glassware was cleaned and completely air dried. A 1000 ml volumetric flask was weighed on an electronic analytical balance, and the weight recorded to the nearest 0.01 gram. The appropriate amount of sucrose was weighed on the analytical balance (338.10 g and 470.60 g for the 30 percent and 40 percent solutions, respectively), and added to the clean, dry volumetric flask. Approximately 500 ml of deionized water was added to the flask, and the mixture agitated by swirling. Additional deionized water was added slowly, while being swirled, until the sucrose was completely dissolved and the bottom of the meniscus reached the 1000 ml reference line on the volumetric flask. The solution was allowed to rest to allow any entrapped air bubbles to rise. The volumetric flask containing the solution was weighed on the analytical balance, and the temperature was measured with a laboratory thermometer; both measurements were recorded in a laboratory research notebook.

The density of the sucrose solutions and the deionized water was calculated using the following relationship:

$$D = \frac{m}{v} \qquad \text{Eqn 19}$$

where:

D = density, g/ml

m = mass of solution = mass of flask and solution - mass of flask, g/L

v = volume of solution, ml

Prior to the experiments to determine the viscometer constant, the sucrose solutions were gently stirred to ensure a homogeneous mixture. A laboratory thermometer was used to measure the temperatures of the sucrose solutions and deionized water, and the results were recorded in a laboratory research notebook. The same procedure as described above was used except the constant temperature bath was not needed because the experiments were done at ambient temperature. Instead, the filled viscometer was held vertical in a 50 ml glass cylinder. The viscometer constant, K, was determined to be 0.257 by fitting equation 17 to the experimental time and literature values of viscosity.

Specific Gravity

Specific gravity was measured *in-situ* in the laboratory drag-out tanks. In the field, specific gravity was measured on grab samples collected from the process and rinse tanks. Measurements were made immediately after collection.

Apparatus

- Hydrometer, Fisherbrand, range 0.890 to 1.000.
- Hydrometer, Fisherbrand, range 1.000 to 1.600.
- 500 ml glass cylinder (optional).

Before the hydrometers were used for measurements for the rinse tanks, process baths and laboratory drag-out tests, the accuracy of the instruments was verified. Hydrometer readings were taken on deionized water and a 40 percent (by weight) sucrose solution. The temperature of the water and sucrose solution was measured with a laboratory thermometer, and the specific gravity measurements were compared with published values. Results of the verification for deionized water resulted in a value 0.15% higher than the expected published value of 1.000 at 20° C, and 0.5% less than the published value of 1.176 for the 40 percent sucrose solution at 20° C.

Surface Tension

Surface tension was measured in the UT laboratory on grab samples collected from the rinse tanks, process baths, and laboratory drag-out tanks.

Apparatus

- Fisher Surface Tensiomat, Model 21, with platinum-iridium ring.
- 5 cm inch diameter glass vessel, approximately 1.3 cm deep.
- Magna-Whirl water bath.

Procedure

1. A water bath was prepared to simulate the temperature of the rinse tank or process bath as measured in the field and recorded on the Sub-Unit Data Collection Log.
2. The rinse tank or process bath sample bottles were placed in the water bath, and allowed to equilibrate to the bath temperature. The water bath and sample temperatures were intermittently monitored using the thermometer. The sample bottles remained in the water bath until used for the surface tension measurement.
3. The clean platinum-iridium ring was placed on the hook on the lever arm of the tensiomat.
4. A clean 5 cm diameter glass vessel was filled with a portion of the sample (transferred immediately from the water bath) and placed on the sample table inside the tensiomat.
5. The sample table was raised until the ring was immersed in the liquid to a depth of approximately 3 mm.
6. The torsion arm on the tensiomat was released, and the instrument was adjusted to a zero reading by turning the knob on the right side of the case until the index and its image were in line with the mark on the mirror. Care was taken to ensure the ring remained in the liquid by adjusting the height of the sample table. The knob on the front of the case beneath the main dial was adjusted until the vernier read zero on the outer scale of the dial.

7. The sample table was lowered until the ring was at the surface of the liquid. At the same time, the knob on the right side of the case was adjusted to keep the index in line with the mark on the mirror. The two simultaneous adjustments were continued until the distended film at the surface of the liquid broke.
8. The reading on the scale at the breaking point (surface tension in dynes per centimeter) was recorded on the Sub-Unit Data Collection Log.
9. The liquid was emptied from the glass vessel, and the process was repeated.
10. Both the platinum-iridium ring and glass vessel were rinsed with deionized water prior to the next test.

Prior to the surface tension tests, the calibration of the tensiomat was checked and the platinum-iridium ring was thoroughly cleaned.

To verify the calibration according to the instrument's instruction manual, the ring was placed on the lever arm and the instrument was adjusted to a zero reading. A 600 mg piece of aluminum foil was placed on the ring, and the knob on the right side of the case was adjusted until the index and its image were in line with the mark on the mirror. The dial reading was recorded, and compared with the calculated surface tension:

$$S = \frac{Mg}{2L} \qquad \text{Eqn 20}$$

where:

S = dial reading = apparent surface tension in dynes/cm
M = weight (0.6 grams)
g = acceleration of gravity (980 cm/sec^2)
L = mean circumference of ring (6.00 cm)

The platinum-iridium ring was cleaned per the manufacturer's instructions: the ring was: 1) soaked in concentrated nitric acid for approximately 2 minutes, then rinsed with deionized water; 2) rinsed with acetone, followed by deionized water; and 3) flamed with a Bunsen burner.

Before surface tension measurements were made, the surface tension of deionized water was checked at 20°C to verify accuracy. Seven measurements were made, with a mean value of 74.96 dynes/cm, a standard deviation of 2.03 dynes/cm. This mean value is 4.2 percent higher than the expected value of 72 dynes/cm for the deionized water.

Metals Analysis

Sodium and/or Potassium analyses were conducted in the UT laboratory on grab samples collected from the process baths and rinse tanks.

Apparatus

- Allied Analytical Systems Atomic Absorption Spectrophotometer, IL Video 12, Serial Number 1857.
- Sartorius Analytical Balance, Model AC 120S, UT ID Number 427286.

Reagents

- Sodium calibration standard, Fisher Scientific, 1000 mg/L.
- Potassium calibration standard, Fisher Scientific, 1000 mg/L.
- Potassium chloride (KCl), Fisher Scientific, certified grade.
- Lanthanum chloride (LaCl $6H_2O$), Fisher Scientific, certified grade.

Procedure

1. Stock potassium chloride solution was prepared by dissolving 23.84 g. of potassium chloride in 250 ml of deionized water in a volumetric flask. This produced a solution of 50,000 mg/L as K, which was used as an ionization suppressant for the sodium samples. A stock solution of lanthanum chloride was prepared by dissolving 12.72 g. of lanthanum chloride in 100 ml of deionized water in a volumetric flask. This produced a solution of 50,000 mg/L as La, which was used as an ionization suppressant for the potassium samples.
2. Sodium and potassium standards were prepared by diluting the Fisher Scientific calibration standards with deionized water to achieve the desired standards concentrations.
3. The samples were prepared by performing dilutions with deionized water to get the anticipated analyte concentrations within the linear range of the instrument. Volumetric pipettes and volumetric flasks were used, and the samples were transferred to new, clean 125 ml HDPE sample bottles. Samples were acidified with ultrapure nitric acid, and ionization suppressants were added to achieve a concentration of 2000 mg/L as K for the sodium samples, and 1000 mg/L as La for the potassium samples.
4. The appropriate lamp was inserted in the atomic absorption spectrophotometer, and a safety check of all settings was performed. The instrument electronics were turned on and allowed to warm up for approximately 30 minutes.
5. The instrument printer, compressed air, and acetylene were turned on. The pilot was lit, the flame adjusted, and the sampling tube was placed in a fresh beaker of deionized water.
6. The instrument was calibrated with the appropriate sodium or potassium standards. A standards curve was printed, and a linear regression performed to check linearity of the curve. If the value of r^2 value was below 0.9950, the instrument was re-calibrated with fresh standards.
7. The prepared samples were analyzed, beginning with the rinse samples and progressing up-line to the process tank. Approximately ten analyses were run per sample, each lasting approximately eight seconds. Results were printed and transferred to an Excel spreadsheet.
8. The method of standard additions was performed on process bath samples to reduce matrix effects. The samples were diluted 1:1 with known standards and analyzed in the absorption mode. Generally, 0, 50, 100 and 200 mg/L standards were used for potassium analyses, and 0, 20, 50 and 100 mg/L standards were used for sodium analyses; however there was some variation since it was necessary to keep concentrations within the instrument’s linear range. A plot of absorption verses concentration of added standards was then prepared, from which the actual concentration in the sample was derived. If necessary, standard additions were performed on the succeeding rinse tanks, as described later in this section.

Before and during the atomic absorption analyses, all laboratory glassware and sample bottles were acid washed in accordance with Standard Methods.

The analyte (sodium or potassium) was determined based on process bath composition, as provided by either industry representatives, manufacturers' material safety data sheets, or previous research conducted by the University of Tennessee's CCPCT.

Because of the extremely high anticipated concentration of analyte in some of the process baths, along with the wide range of anticipated concentrations between the process baths and rinse tanks, atomic absorption analyses were conducted using the least sensitive wavelengths (330.2 nm for sodium, and 404.4 nm for potassium) whenever possible. Dilutions were still necessary on many of the samples. For sodium samples with very low sodium concentrations, it was necessary to use the most sensitive wavelength of 589.0 nm.

The instrument was calibrated at the beginning of each lab session by using generally five calibration standards within the linear range of the instrument, including a zero standard. The standards used for the least sensitive wavelength for sodium (330.2 nm) were usually 0, 20, 50, 100, and 150 mg/L; however these occasionally varied depending on the anticipated concentration of the sample. In all cases, the standards were chosen to best bracket the sample concentration. Standards used for the most sensitive sodium analyses (589.0 nm wavelength) were usually 0, 0.25 0.50. 0.75, 1.0 and 1.25 mg/L. Calibration standards for the least sensitive wavelength for potassium (404.4 nm) were usually 0, 50, 100, 200 and 600. As with the sodium analyses, standards were chosen to best bracket the sample potassium concentration. Standards checks were performed during the measurements to ensure the instrument had not drifted. The checks usually were performed after every four or five measurements, but always after ten measurements were taken.

The samples were prepared for analysis by dilution with deionized water to achieve an anticipated analyte concentration within the linear range of the instrument. The anticipated concentrations were based on previous research conducted by the University of Tennessee's CCPCT. Alkali salts were added to the samples and standards as an ionization suppressant. Potassium chloride was added to sodium samples at 2000 mg/L, and lanthanum chloride at 1000 mg/L was added to the potassium samples. Process and rinse tank samples and standard solutions were acidified to pH < 2 in accordance with Standard Methods, using ultrapure concentrated nitric acid. Electroless copper samples were not acidified due to the possibility of the baths containing cyanide.

As an interference check, a standard additions analysis was performed on one sample for each process bath, and compared with analysis results performed without standard additions. Whenever there was a difference greater than 10 percent between the two measurements, a standard addition analysis was performed on the duplicate bath sample, and the standard addition results were used. If standard additions were necessary for the process bath samples, the succeeding rinse tank samples were also checked, to determine if standard additions should be used.

Quality Assurance and Quality Control (QA/QC)

Prior to the site visit to collect the samples, the 500 ml new HDPE sample bottles were thoroughly cleaned with detergent, triple rinsed with deionized water, and allowed to air dry. Field blanks were used to monitor any contamination from the bottles. The field blanks were pre-labeled and filled with deionized water in the UT laboratory prior to the site visits. During the visit, the bottles were opened for approximately two minutes, then re-sealed.

All laboratory equipment transported to the site was thoroughly cleaned according to Standard Methods prior to leaving the UT laboratory, and was again thoroughly cleaned between sites. All laboratory equipment, including reagents and deionized water was transported from the UT laboratory, including cleaning supplied. The samples remained in the custody of the sampling team until arrival back to the UT laboratory, where they were placed in a limited access, locked cold room until analyses.

Results from Analysis of Field Samples

Mean values of temperature, specific gravity, viscosity, conductivity, surface tension for each of the field samples are summarized in Table 21.

Measurements of conductivity, specific gravity, surface tension, viscosity were all completed in duplicate. The coefficients for all measurements were all excellent (conductivity 0.04, surface tension 0.005, specific gravity 0.001% and viscosity 0.073).

Sodium and potassium concentrations are summarized in Table 22. Replicate samples at plants 1 and 2 were taken in identical manner, and the results were averaged and reported as a single value. At plant 3, two samples were taken at different times in the board cycle time. Samples labeled “A” were taken just prior to the boards entering the rinse tank and should normally correspond to the lowest concentration present in the rinse tank. Samples “B” and “R” were taken just after the boards were removed from the rinse tank and should be near the maximum concentration in the rinse cycle. The individual samples from plant 3 were not averaged, but reported individually. Details of the analytical procedure used for each sample are summarized in the Appendix.

Table 21. Temperature, Specific Gravity, Viscosity, Conductivity, Surface Tension for Field Samples.

Sample Name	Temp., ºC	Specific Gravity	Viscosity, cP	Conductivity, mS/cm, 25 ºC	Surface Tension, dynes/cm
Plant 1 ME Process	30	1.110	1.140	304,000	76.2
Plant 1 ME Rinse 1	20	1.005	1.112	1,935	75.9
Plant 1 ME Rinse 2	20	1.004	1.142	213	75.6
Plant 1 EC Process	45.5	1.170	1.218	224,000	73.2
Plant 1 EC Rinse 1	21	1.003	.977	1,043	76.0
Plant 1 EC Rinse 2	20	1.005	1.097	224	76.3
Plant 1 AT Process	19	1.004	1.172	341	72.2
Plant 1 AT Rinse 1	20	1.002	1.097	229	74.4
Plant AT Rinse 2	20	1.002	1.022	223	76.2
Plant 1 FB	NA	NA	NA	1.8	76.2
Plant 2 ME Process	37	1.175	1.246	477,000	78.0
Plant 2 ME Rinse 1	15	1.004	1.172	2,170	77.0
Plant 2 EC Process	38	1.110	1.421	119,600	51.2
Plant 2 EC Rinse 1	20	1.002	.932	676	73.2
Plant 2 AT Process	19	1.005	1.202	353	75.0
Plant 2 AT Rinse	16.5	1.005	1.037	256	76.3
Plant 2 FB	NA	NA	NA	1.9	76.1
Plant 3 ME Process	29	1.145	1.340	168,400	77.6
Plant EC Process	54	1.115	1.139	261,000	56.2
Plant 3 EC Rinse 1	27	1.002	0.992	736	74.0
Plant 3 EC Rinse 2	30	1.003	NA	155	75.4
Plant 3 AT Process	25	1.005	1.127	543	72.2
Plant 3 AT Rinse	30.5	0.994	0.798	156	73.6
Plant 3 FB	NA	NA	NA	1.8	75.0

Table 22. Metals Concentrations Measured in Field Samples.

Sample Name	Sodium, mg/L	Potassium, mg/L	Method
Plant 1 ME Process		20,380	Standard Additions
Plant 1 ME Rinse 1		77.4	Standard Curve
Plant 1 ME Rinse 2		<7.5	Standard Curve
Plant 1 EC Process	67,750		Standard Additions
Plant 1 EC Rinse 1	242		Standard Curve
Plant 1 EC Rinse 2	24.5		Standard Curve

Sample Name	Sodium, mg/L	Potassium, mg/L	Method
Plant 1 AT Process	2.8	94	Standard Additions
Plant 1 AT Rinse 1		<7.5	Standard Curve
Plant 1 AT Rinse 2		<7.5	Standard Curve
Plant 1 Makeup water	20.15	<7.5	Standard Curve
Plant 1 FB		<7.5	Standard Curve
Plant 2 ME Process		62,300	Standard Additions
Plant 2 ME Rinse 1		98.8	Standard Curve
Plant 2 EC Process	63,450		Standard Additions
Plant 2 EC Rinse 1	128.6		Standard Curve
Plant 2 AT Process	30.8	<7.5	Standard Additions
Plant 2 AT Rinse	34.5	<7.5	Standard Curve
Plant 2 Makeup water	31.36	<7.5	Standard Curve
Plant 2 FB	<0.01		Standard Curve
Plant 3 ME Process	41,550		Standard Additions
Plant 3 ME Rinse 1-A	173.6		Standard Additions
Plant 3 ME Rinse 1-B	242		Standard Additions
Plant 3 ME Rinse 1-R	289		Standard Additions
Plant 3 EC Process	72,950		Standard Additions
Plant 3 EC Rinse 1-A	109.3		Standard Curve
Plant 3 EC Rinse 1-B	173.5		Standard Additions
Plant 3 EC Rinse 1-R	191.7		Standard Curve
Sample Name	Sodium, mg/L	Potassium, mg/L	Method
Plant 3 EC Rinse 2-A	24.3		Standard Curve
Plant 3 EC Rinse 2-B	24.4		Standard Curve
Plant 3 AT Process	111		Standard Additions
Plant 3 AT Rinse 1-A	19.1		Standard Curve
Plant 3 AT Rinse 1-B	19.1		Standard Curve
Plant 3 AT Rinse 1-R	23.2		Standard Curve
Plant 2 Makeup water	23.1	<7.5	Standard Curve
Plant 3 FB	<0.1		Standard Curve

The pooled instrumental relative standard deviation for potassium was determined to be 0.77%, based on eighteen potassium samples with a mean sample concentration of 113.6 mg/L, and a pooled instrumental standard deviation of 0.87 mg/L. The pooled instrumental relative standard deviation for sodium was determined to be 1.6% based on seventy-three analyses with a mean concentration of 60.6 mg/L. The pooled instrumental standard deviation was 0.97 mg/L. Data on which these calculations are based are included in the Appendix.

The relative standard deviation for duplicate potassium samples ranged from 0.17 to 6.95% for tests run with no standard additions, with a pooled standard deviation of 3.46 mg/L. There were no duplicate or replicate analyses for potassium using the method of standard additions. The relative standard deviation for duplicate sodium measurements without standard additions ranged from 0.11 percent to 18.94 percent, with a pooled standard deviation of 8.05 mg/L. The relative standard deviation for duplicate sodium analyses performed with standard additions ranged from 0.52 to 6.13%, with a pooled standard deviation of 2.76 mg/L. Data for duplicate samples from which these results were determined are listed in the Appendix.

DYNAMIC MASS BALANCE MODEL
FOR INTERPRETATION OF FIELD DATA

The field data collected at the PWB manufacturers was used to validate the drag-out component of the wastewater generation model. The output from the model is the *average* mass rate of contaminant in the rinse water from a particular process bath; the model can also calculate average concentrations in the rinse tank effluent by dividing by the rinse flow rate.

However, the average concentration predicted by the model does not correspond directly to the contaminant concentrations measured in the field samples. The MHC process is dynamic in that the concentrations of contaminants in the rinse effluent change as a function of time. The operation cycle of a given rinse tank consists of a short period of time in which a board is immersed in the tank, followed by a longer period of time during which no boards are in the tanks. Contaminants are continually flushed from the rinse tank during the entire operation time of the bath. As a result of this operational practice, the rinse-tank concentration history will be a periodic saw-tooth wave function. In the field, *instantaneous grab* samples were collected from the rinse tanks, usually immediately after removal of the board. Clearly, the concentrations in the instantaneous grab samples may not be directly comparable to the average concentration calculated by the model; therefore, a means of verifying the model is needed. A dynamic material balance model was used to compare the concentration of contaminant in the grab samples with the average concentration of contaminant predicted by the models.

The following material balance equation describes the concentration of contaminant in a completely-mixed rinse tank:

$$QC_o - QC = V\frac{dC}{dt} \qquad \text{Eqn 21}$$

where:

Q = flow rate through the tank, L^3/t
V = tank volume, L^3
C = concentration of contaminant in the tank, M/L^3
C_o = concentration of contaminant in the feed water to the tank, M/L^3
t = time, t

The concentration of contaminant in the tank as a function of time can be determined by separating the variables in equation 21 and integrating using appropriate boundary conditions. Assume that when the line is first started (before the first board is dipped in the tank) that the contaminant concentration in the tank is equal to the feed water concentration. Also assume that at t=0 a rack of boards, containing mass of contaminant M, instantly releases all of its contaminant to solution. Under these conditions, the concentration in the tank at t=0 is:

$$C = C_0 + \frac{M}{V} \qquad \text{Eqn 22}$$

The solution to equation 21 describing the concentration history after removal of the first board is then given by:

$$\int_0^t \frac{Q}{V} dt = \int_{M/V + C_o}^{C} \frac{dC}{C_o - C} \qquad \text{Eqn 23}$$

$$C = C_o + \frac{M}{V} \exp\left(-\frac{Qt}{V} \right) \qquad \text{Eqn 24}$$

As time progresses additional boards will enter the rinse tank. Assume that additional boards enter the tank at a constant period of l. It is convenient to redefine t as:

$$t = n\, l + q \qquad \text{Eqn 25}$$

where

n = number of cycles completed since t = 0

q = time elapsed in the current cycle, t

The effluent history during the rinsing cycle for the second board processed after start-up would be given by:

$$\int_0^q \frac{Q}{V} dq = \int_{(M/V)[1+\exp(-Ql/V)]+C_o}^{C} \frac{dC}{C_o - C} \qquad \text{Eqn 26}$$

$$C = C_o + \frac{M}{V} \exp\left(-\frac{Qq}{V} \right) + \frac{M}{V} \exp\left(-\frac{Q(l+q)}{V} \right) \qquad \text{Eqn 27}$$

This result can be extended to represent the effluent history for the rinsing period after the n^{th} board is rinsed:

$$C = C_o + \frac{M}{V} \exp\left(-\frac{Qq}{V} \right) \sum_{k=0}^{n} \exp\left(-\frac{kQl}{V} \right) \qquad \text{Eqn 28}$$

Steady-state is defined to occur when n = ∞. Substituting

$$\sum_{k=0}^{\infty} \exp\left(-\frac{kQl}{V}\right) = \frac{1}{1-\exp\left(\frac{-Ql}{V}\right)} \qquad \text{Eqn 29}$$

yields an expression concentration history for a single rinse tank, operating at steady-state:

$$C = C_o + \frac{M}{V} \exp\left(-\frac{Qq}{V}\right) \frac{1}{1-\exp\left(\frac{-Ql}{V}\right)} \text{ for } q<l. \qquad \text{Eqn 30}$$

Example:

A rinsing tank receives a rack containing 60 ft^2 of boards every 30 minutes. The drag-out rate is 10 mL/ft^2 and the contaminant concentration in the process tank is 3000 mg/L. The rinse rate is 2 gpm and the tank is 220 gallons in volume. The feed water contains 40 mg/L of the contaminant. Calculate the effluent concentration history during the 30 minute cycle period under steady-state conditions:

$$\frac{M}{V} = 60ft^2 \left(\frac{10mL}{ft^2}) \right) \left(\frac{3000g}{L} \right) \left(\frac{L}{1000mL} \right) \left(\frac{1}{220gal]} \right) \left(\frac{gal}{3.78L} \right) = 21.6mg/L \qquad Eqn\,31$$

$$C = 40 + 2.16\exp\left(-\frac{2q}{220}\right) \frac{1}{1-\exp\left(\frac{-2 \bullet 30}{220}\right)} \qquad \text{Eqn 32}$$

Equation 32 is plotted over the course of one process cycle in Figure 6.

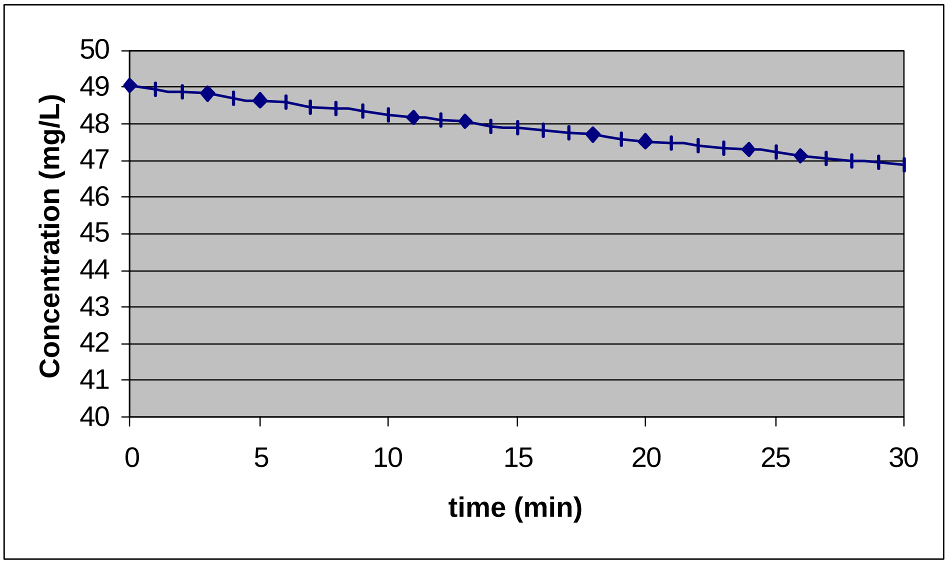

Figure 6. Example Concentration History of Rinse Tank Effluent During One Plating Cycle.

MODEL VALIDATION

The purpose of the field samples was to validate the drag-out prediction model and the overall mass balance approach to predicting wastewater quality from PWB facilities. The dynamic material balance model for the rinsing process was developed in the previous section to facilitate this comparison. First, equation 30 was solved for the mass of contaminant in the drag-out:

$$M = (C - C_0)V \exp\left(\frac{Qq}{V}\right)\left[1 - \exp\left(\frac{-Q\,l}{V}\right)\right] \qquad \text{Eqn 33}$$

The volume of the drag-out could then be calculated by dividing the mass of contaminant in the drag-out by the bath concentration:

$$V_{drag-out} = \frac{M}{C_{bath}} \qquad \text{Eqn 34}$$

The drag-out volumes calculated from the field data and the dynamic mass balance (equations 33 and 34) are compared to those predicted using the drag-out regression model (equation 15) in Table 23. Replicate samples at the plants 1 and 2 were taken in identical manner, and the results were averaged and reported as a single value. At plant 3, the duplicate samples were taken at different times in the board cycle time. Samples labeled “A” were taken just prior to the boards entering the rinse tank and should normally correspond to the lowest concentration present in the rinse tank. Samples “B” and “R” were taken just after the boards were removed from the rinse tank and should be near the maximum concentration in the rinse cycle. Samples 3MER1-A and -B were taken soon after the MHC line had been shut down for a short period of time and may have been erroneously low. The individual samples from plant 3 were not averaged; separate calculations were made for each one. Sodium and potassium concentrations in the anti-tarnish rinse tanks were too low to accurately calculate either the mass of contaminant in the drag-our or the drag-out volume.

The drag-out volumes calculated from the field data are consistently less than those predicted by the drag-out model. They are also significantly less than those measured both in the laboratory experiments performed as a part of this work and the data collected by Pagel (1992). For example, the drag-out volumes from Microetch baths calculated from our field data ranged from 22.8 to 53.6 mL/m^2, compared to a range of 76 to 122 mL/m^2 in this study and a range of 57 to 145 mL/m^2 in Pagel’s work. Similarly, the drag-out volumes from the Electroless baths calculated from our field data ranged from 9.73 to 32.9 mL/m^2, compared to a range of 20.4 to 81.8 mL/m^2 in Pagel’s work. A possible explanation is that the drag-out volumes calculated from the field data were based on the assumption in the dynamic mass balance model that all the contaminant was released instantaneously from the PWB and that the rinse tank was perfectly mixed. The rinsing tanks used in PWB plants may not approximate this ideal behavior. Rinse water typically enters the bottom of the rinse tank and flows over a weir at the water surface. As the board enters the tank, it is likely that a significant fraction of the pollutant flows over the weir prior to being mixed throughout the tank. Fluid shear may contribute to the loss of contaminant near the water surface of the tank as the board enters the tank. The grab samples were generally collected immediately following removal of the board from the rinse tank. We hypothesize that the short-circuiting process described above may have caused a large fraction of the contaminant to be removed from the rinse tank prior to the time that we collected the sample. Our laboratory drag-out study, and the work of Pagel (in which the rinse water flow rate was set to zero during the sampling) were not subject to this influence.

Table 23. Comparison of Drag-Out Volumes Calculated from Field Samples to Those Predicted by Regression Model.

Sample Description	Drag-Out Volume Calculated from Field Data, mL/m^2	Drag-Out Volume Calculated from Regression Model, mL/m^2
Plant 1, Microetch	53.6	127
Plant 1, Electroless Copper	32.9	59.1
Plan 2, Microetch	22.8	102
Plant 2, Electroless Copper	23.2	39.9
Plant 3, Microetch A	28.2	98.2
Plant 3, Microetch B	41.0	98.2
Plant 3, Microetch R	37.9	98.2
Plant 3, Electroless A	9.73	34.7
Plant 3, Electroless B	6.83	34.7
Plant 3, Electroless R	10.9	34.7

A regression equation was fitted to the data in Table 23, resulting in the following relationship(r^2 = 0.71):

$$V_{field} = 0.36V_{predicted} + 0.68 \qquad \text{Eqn 35}$$

where:

V_{field} = drag-out volume calculated from the field data

$V_{predicted}$ = is the drag-out volume predicted by the regression model

The slope of the regression equation suggests that about 2/3 of the total mass of contaminant flows over the weir prior to being mixed. The relatively good correlation coefficient indicates that the field and predicted drag-out volumes were comparative on a relative basis. This suggests that the drag-out regression model and overall mass balance approach may be valid for making relative comparisons between process alternatives.

CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE WORK

Conclusions

- Contaminant mass in PWB process wastewaters can be expressed as a mass balance in which the mass of contaminant in the wastewater is equal to the mass of contaminant released via drag-out from the process baths (which ultimately ends up in the rinse tanks), periodic dumping of process tanks into the wastewater, and stripping deposits from racks. Drag-out is generally considered to be the major contaminant source. Data quantifying composition of the process baths, the volume of wastewater produced, and the frequency of bath dumps are usually collected during the course of the DFE process. For example, this information was collected for the MHC process during a previous study by the University of Tennessee CCPCT (Kincaid et al. 1997).
- Very little data exists quantifying the rate of drag-out from PWB processes, i.e., the mass or volume of drag-out per unit surface area of PWB, e.g., mL/m^2. A study reported by Pagel at Micom, Inc. is the only readily available study on PWB facilities. Limited drag-out research has been conducted on flat pieces, most notably by Süβ. However, the numerous small holes present in PWBs renders application of drag-out volumes measured from non-PWB pieces problematic. Practitioners tend to use rules-of-thumb or historically accepted values for drag-out. This one-size-fits-all approach ignores process specific information such as bath type, viscosity, surface tension, board withdrawal rate, or drain time. Drag-out rates reported in the literature for vertically-oriented flat pieces. range from 10 to 160 mL/m^2.
- Commonly-cited equation found in the literature offer predictions of the drag-out rate as a function of kinematic viscosity and board withdrawal rate. Süβ showed that this equation does not predict drag-out very well for the rectangular flat pieces that he studied. There was no relationship between kinematic viscosity and drag-out, and two previously proposed predictive equations performed poorly.
- Several variables have been shown to affect the drag-out rate. Studies at Micom, Inc. reported by Pagel (1992) showed the importance of longer drainage time and slower withdrawal rate in reducing drag-out. Süβ (1990, 1992) also found that these variables are important as well as the angle of the board during drainage. No research was found that addressed the effect of surface tension. Based on the present study, surface tension may be an important variable.
- Considerable literature exists on rinsing theory which appears highly developed and well studied for ideal mixing situations. While rinsing theory is not as well developed for non-ideal mixing, previous researchers have concluded the assumption of ideal mixing is valid for estimating long-term-average wastewater concentrations because nearly all of the drag-out ultimately reaches the wastewater effluent.
- Laboratory studies conducted as part of this research expanded the data base of drag-out rates for two PWB process baths and several operating conditions. The experimental procedures showed good reproducibility, and the data were consistent with previous research.

- A regression model for predicting drag-out volume was developed using the available data bases of Süβ (1990, 1992), Pagel (1992), and the present study. The dependent variables were a choice of two types of process baths (plus a default for any other type of bath), board withdrawal rate, drain time, board size, and presence of drilled holes. The model had an R^2 of 0.852.
- The regression model for predicting drag-out rate was incorporated in a computer model for predicting contaminant mass loading and mean pollutant concentrations from PWB manufacturing process lines. The model was written as a Visual Basic macro within an EXCEL spreadsheet. Input variables included facility production rate, board size, number and types of process baths, bath composition, frequency of bath dumps, and wastewater production rate.
- Samples were collected from three PWB facilities in order to validate the drag-out model. Samples were collected from various process and rinse tanks and analyzed for temperature, specific gravity, viscosity, surface tension, conductivity, and potassium or sodium concentration. Since it was not convenient to collect composite samples from the rinse tanks, grab samples were collected at various times after a board was inserted into a rinse tank. An equation was developed to relate the time-dependent concentration of potassium or sodium in the rinse tank to the drag-out volume. Unfortunately, it appears that poor mixing in the rinse tanks led to unrepresentative sampling. Although the apparent drag-out rates were about 1/3 of the predicted rates, a comparison of drag-out rates between process tanks showed a correlation ($r^2 = 0.71$) with the previously developed regression model, and in that sense lend support to it.

Recommendations

- The authors believe that this work has resulted in a more universally applicable method for estimating the mass and concentration of contaminants in a PWB process wastewater than currently exists, especially for relative evaluations. However, much can still be done to improve the model since the existing data are so limited. Previous work has not studied the effect of surface tension, but the laboratory studies in this work showed that surface tension may be an important variable. Indeed, one of the drag-out reduction best practices is to use a wetting agent which would reduce surface tension. The effect of viscosity was previously thought to be important, but neither Süβ nor this work found it to be significant. There has also been only one previously reported study of an actual PWB facility. The authors believe that a better quantitative understanding of the variables affecting drag-out could lead to the development of a better prediction equation. The first phase of such research should focus determining the effect of bath fluid properties and operating variables under controlled laboratory conditions. Expansion and testing of the model could be accomplished by samples collected at PWB facilities during a second phase of the study.
- Beyond determining the wastewater quality emanating from PWB manufacturing processes, there is a need to assess the fate of the chemicals in the PWB wastewater both in the onsite treatment processes at PWB manufacturing facilities and at Publicly-Owned Treatment Works (POTW). Information of the effect of chemical speciation on the fate of

pollutants is especially needed. For example, metals are one of the primary pollutants of concern in PWB wastewater, and it is likely that many of the metals are chemically complexed in PWB wastewater. On-site treatment processes are likely to preferentially remove the least stable metal complexes, while the most stable complexes are discharged to the POTW. Standard removal efficiencies for metals in activated sludge processes are probably not applicable to these highly complexed metals and the potential for release of the metals to the aquatic environment may be underestimated.

- A third issue needful of better understanding is the volatilization of chemicals from tanks and baths such as in PWB plating processes and other manufacturing processes. The volatilization models used in the previous assessment of emissions for the MHC process and the present assessment of surface finishing assume gas-side control of the mass transfer, i.e., volatilization, of chemicals from the process baths. In the MHC, and presumably in the surface finishing process, there were several chemicals whose mass transfer appeared to be liquid-side controlled. The mass transfer model used does not apply for this situation and could lead to an overestimate of the emission and consequent risk for these chemicals. It would be productive to research the literature to find more appropriate liquid-side control mass transfer models and applicable constants for various types of manufacturing process tanks. For example, there is a body of literature available on surface renewal theory models which would be more appropriate for liquid-side mass transfer control. This literature search could be completed within a year and a decision made at that time as to whether any lab based research is warranted.

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LIST OF SYMBOLS

A = area of the sheet
c_i = mass content of the component is kg of component per kg of solution
C_o = concentration of contaminant solution being drug into rinse tank
C_r = concentration of contaminant in the effluent of the r^{th} rinse tank
C_t = concentration of contaminant in rinse tank after t min
D = volume of drag-over or drag-out on rack and work rinsing operation
D_i = coefficient calculated as shown below for each component for use in the method given by Zaytsev and Aseyev
d_{0i}, d_{1i}, d_{2i} = empirical coefficients chosen for each electrolyte component from a table for use in the method given by Zaytsev and Aseyev
f = film thickness, cm
f_{dr} = thickness of the film that drains off the sheet
F_{dr} = function describing a relationship between the independent variables and thickness of the film that drains from the sheet
g = gravity (981 cm/s^2)
h = height of metal sheet
K = unknown constant determined by experiments
m = unknown exponent determined by experiments
n = number of rinsing operations in t min
Q = rate of fresh water flow
r = number of rinse tanks in series
t = time interval between rinsing operations
T = temperature of solution, ^{o}C
t_{dr} = drainage time, s
t_w = withdrawal time, s
V = velocity of withdrawal
v_A = withdrawal rate of metal sheet, cm/s
V_t = volume of rinse tank
ΔV = volume of liquid that drains from the rectangular sheet
ν = kinematic viscosity, cm^2/s
ρ = density of electrolyte, gm/cm^3
μ = dynamic viscosity of electrolyte, g/(cm·s)
μ_o = viscosity of water, Pa·s
σ_{dr} = surface tension of the liquid

Appendix F

Supplemental Performance Demonstration Information

F.1 Modeling the Test Results

General linear models (GLMs) were used to analyze the test data for each of the 23 electrical circuits in Table 4.1 at each test time. The GLM analysis determines which experimental factors or, when possible, combinations of factors (interactions) explain a statistically significant portion of the observed variation in the test results.

A GLM used to analyze the test results with respect to sites, flux type, and their interactions (where possible) is expressed as the following 22-term equation:

$$\begin{aligned}
Y = {} & \beta_0 + \beta_1 D_1 + \beta_2 D_2 + \beta_3 D_3 + \beta_4 D_4 + \beta_5 D_5 + \beta_6 D_6 + \beta_7 D_7 + \beta_8 D_8 + \beta_9 D_9 + \beta_{10} D_{10} + \beta_{11} D_{11} && \text{(F.1)} \\
& + \beta_{12} D_{12} + \beta_{13} D_{13} + \beta_{14} D_{14} + \beta_{15} D_{15} + \beta_{16} D_{16} && \text{(Main effects)} \\
& + \beta_{17} D_3 D_{16} + \beta_{18} D_4 D_{16} + \beta_{19} D_6 D_{16} + \beta_{20} D_{10} D_{16} && \text{(Two-factor interactions)} \\
& + \beta_{21} D_{12} D_{16} + \beta_{22} D_{15} D_{16}
\end{aligned}$$

The coefficients in the GLM (β_0, β_1, β_2, …) are estimated using ordinary least squares regression techniques. The dummy variables, D_1 to D_{16}, are set equal to 1 to identify type of surface finish/manufacturing site and type of flux that are associated with individual test results. Otherwise, the dummy variables are set to 0. The following dummy variables can be used to represent the experimental variables for each test environment for each electrical response variable.

D_1 = 0 if surface finish is not HASL – Site 2
= 1 if surface finish is HASL – Site 2
D_2 = 0 if surface finish is not HASL – Site 3
= 1 if surface finish is HASL – Site 3
D_3 = 0 if surface finish is not OSP – Site 4
= 1 if surface finish is OSP – Site 4
D_4 = 0 if surface finish is not OSP – Site 5
= 1 if surface finish is OSP – Site 5
D_5 = 0 if surface finish is not OSP – Site 6
= 1 if surface finish is OSP – Site 6
D_6 = 0 if surface finish is not immersion Sn – Site 7
= 1 if surface finish is immersion Sn – Site 7
D_7 = 0 if surface finish is not immersion Sn – Site 8
= 1 if surface finish is immersion Sn – Site 8
D_8 = 0 if surface finish is not immersion Sn – Site 9
= 1 if surface finish is immersion Sn – Site 9
D_9 = 0 if surface finish is not immersion Sn – Site 10
= 1 if surface finish is immersion Sn – Site 10
D_{10} = 0 if surface finish is not immersion Ag – Site 11
= 1 if surface finish is immersion Ag – Site 11
D_{11} = 0 if surface finish is not immersion Ag – Site 12
= 1 if surface finish is immersion Ag – Site 12
D_{12} = 0 if surface finish is not Ni / Au – Site 13
= 1 if surface finish is Ni / Au – Site 13
D_{13} = 0 if surface finish is not Ni / Au – Site 14
= 1 if surface finish is Ni / Au – Site 14
D_{14} = 0 if surface finish is not Ni / Au – Site 15
= 1 if surface finish is Ni / Au – Site 15
D_{15} = 0 if surface finish is not Ni / Pd / Au – Site 16
= 1 if surface finish is Ni / Pd / Au – Site 16
D_{16} = 0 if flux is not water soluble
= 1 if flux is water soluble

The "base case" is obtained by setting all $D_i = 0$. Note that the surface finish/manufacturing site is HASL / Site 1 if $D_1 = D_2 = D_3 = D_4 = D_5 = D_6 = D_7 = D_8 = D_9 = D_{10} = D_{11} = D_{12} = D_{13} = D_{14} = D_{15} = 0$. Likewise, if $D_{16} = 0$, the flux is low-residue. Thus, the base case is HASL / Site 1 with LR flux.

Note the GLM in Equation F.1 contains six interactions terms that represent the last six sites in Table 4.2 (5, 6, 7, 11, 13, and 16) for which both LR and WS fluxes were used.

The GLM approach provides a tool for identifying the statistically significant experimental variables and their interactions. That is, all terms in the model that are *significantly different from the base case* are identified through tests of statistical hypotheses of the form:

$$H_0: \beta_i = 0 \text{ versus } H_1: \beta_i \neq 0 \text{ for all } i$$

If the null hypothesis is rejected, then the coefficient of the corresponding term in the GLM is significantly different from 0, which means that the particular experimental conditions represented by that term (surface finish or flux type) differ significantly from the base case. If the null hypothesis is not rejected, then the coefficient of the corresponding term in the GLM is not significantly different from 0 and, therefore, the experimental conditions represented by that term *do not* differ significantly from the base case. Such terms are sequentially eliminated from the GLM (see Iman, 1994, for complete details).

The GLM approach is quite flexible and easily adaptable to a variety of requirements. For example, if the focus is on surface finishes and not sites; the GLM in Equation F.1 would be replaced by one of the following form:

$$Y = \beta_0 + \beta_1 D_1 + \beta_2 D_2 + \beta_3 D_3 + \beta_4 D_4 + \beta_5 D_5 + \beta_6 D_6 \qquad \text{F.2}$$

This model contains only main effects where the dummy variables are defined as follows.

D_1 = 0 if surface finish is not OSP
= 1 if surface finish is OSP
D_2 = 0 if surface finish is not immersion Sn
= 1 if surface finish is immersion Sn
D_3 = 0 if surface finish is not immersion Ag
= 1 if surface finish is immersion Ag
D_4 = 0 if surface finish is not Ni / Au
= 1 if surface finish is Ni / Au
D_5 = 0 if surface finish is not Ni / Pd / Au
= 1 if surface finish is Ni / Pd / Au
D_6 = 0 if flux is not water soluble
= 1 if flux is water soluble

As before, the "base case" is obtained by setting all $D_i = 0$, which is HASL with LR flux. Note that the base case associated with the GLM in Equation F.1 was also HASL with LR flux, but also required Site 1. That requirement is not part of the latter model since sites are not included in the model in Equation F.2.

As a final illustration of the flexibility of the GLM approach consider a subset of the data base that only includes the results for Sites 1, 4, 5, 7, 11, 13, and 16 in Table 4.2. These sites were selected because their surface finish was processed with both LR and WS fluxes, which allows an interaction term to be added to the model in Equation F.2 for each surface finish and flux combination. However, by excluding the other sites, the number of data points is reduced from 164 to 92.

Example of GLM Analysis

The data base for the electrical responses incorporates the dummy variables used to define the experimental parameters for each measurement. The data base contains 164 rows (one for each PWA). Sample data base entries for the GLM in Equation F.2 for leakage measurement on the 10-mil pads (response number 18 in Table 4.1) in $\log_{10}$ ohms could appear as follows:

Row	OSP	Imm Sn	Imm Ag	Ni/Au	Ni/Pd/Au	Flux	Leakage
1	0	0	0	0	0	0	12.8
2	1	0	0	0	0	1	11.9
3	0	1	0	0	0	0	12.1
4	0	0	0	0	1	1	11.8
•	•	•	•	•	•	•	•
•	•	•	•	•	•	•	•
•	•	•	•	•	•	•	•

The interpretation of these data base entries is as follows. The first row has zeros for OSP, immersion Sn, immersion Ag, Ni/Au, and Ni/Pd/Au. This implies that the surface finish is HASL. The surface finishes for rows 2, 3, and 4 are OSP, immersion Sn, and Ni/Pd/Au, respectively. Water soluble flux is used on rows 2 and 4. The leakage measurements are given in the last column. The above table would be expanded to include other experimental parameters or products (interactions) of the experimental parameters depending on the requirements of the GLM such as given in Equation F.1. The above table would also include columns containing the other 22 electrical measurements.

Computer software is used with the entries in the data base to find the least squares estimates of coefficients in the GLM. For example, such an analysis for the GLM in Equation F.2 could produce an estimated equation such as the following for leakage for the 10-mil pads.

$$Y = 12.5 - 0.200\ \text{OSP} + 0.192\ \text{Immersion Sn} - 0.164\ \text{Immersion Ag} + 0.006\ \text{Ni/Au} - 0.292\ \text{Ni/Pd/Au} - 1.04\ \text{Flux}$$

Note that the least squares process has simply solved a set of equations to determine an estimated coefficient for each term appearing in the GLM in Equation F.2. However, it does not necessarily follow that each of the terms in this estimated model makes a statistically significant contribution toward explaining the variation in the leakage measurements. Rather, this determination is accomplished by subjecting the coefficients in the *full* model to the following hypothesis test in a sequential (stepwise) manner to determine if they are significantly different from 0:

$$H_0\text{: } \boldsymbol{\beta}_i = 0 \text{ versus } H_1\text{: } \boldsymbol{\beta}_i \neq 0$$

If the coefficient is not significantly different from 0, it is eliminated from the model. Thus, the only terms remaining in the model at the conclusion of this sequence of tests are those that are declared to be significantly different from 0. This stepwise process eliminates some of the terms from the model and the least squares calculations are repeated without those terms, which produces a *reduced* model such as:

$$Y = 12.35 - 0.34\ \text{OSP} - 0.38\ \text{Immersion Ag} - 0.24\ \text{Ni/Pd/Au} - 1.06\ \text{Flux}$$

The intercept in this model, 12.35, is the estimated resistance for the base case—HASL processed with LR flux. Mean predictions for other combinations of the experimental parameters can be made by substituting the appropriate dummy variables into the model. For example, the mean prediction for a OSP (D_1=1, D_2=0, D_3=0, D_4=0, D_5=0) PWA processed with WS flux (D_6=1) is found as:

$$Y = 12.35 - 0.34\ (1) - 1.06\ (1) = 10.95$$

F.2 Overview of Test Results

Table F.1 Anomaly Summary by Surface Finish after Exposure to 85/85

MSN	Site	Flux		Circuit	Test Technician Comments
HASL					
083-2	1	WS	7	HF PTH 50MHz	Open PTH
			8	HF PTH f(-3dB)	Open PTH
			9	HF PTH f(-40dB)	Open PTH
OSP					
056-4	5	LR	7	HF PTH 50MHz	Open PTH
			8	HF PTH f(-3dB)	Open PTH
			9	HF PTH f(-40dB)	Open PTH
Immersion Sn					
030-4	9	WS	4	HVLC SMT	
032-4	8	LR	7	HF PTH 50MHz	Open PTH
			8	HF PTH f(-3dB)	Open PTH
086-2	7	WS	12	HF SMT f(-40dB)	Waveform did not go to -40dB
102-4	10	WS	17	HF TLC RNR	
Immersion Ag					
082-2	11	LR	21	Gull Wing	Burnt etch in multiple places
094-4	12	WS	7	HF PTH 50MHz	Open PTH
			8	HF PTH f(-3dB)	Open PTH
			9	HF PTH f(-40dB)	Open PTH
Ni/Au					
013-1	13	LR	6	HSD SMT	Device failed, U3
015-4	14	LR	9	HF PTH f(-40dB)	Wrong value capacitor

Table F.2 Anomaly Summary After Exposure to Thermal Shock

MSN	Site	Flux		Circuit	Test Technician Comments
HASL					
079-4	1	WS	12	HF SMT f(-40dB)	
083-2	1	WS	7	HF PTH 50MHz	Open PTH
			8	HF PTH f(-3dB)	Open PTH
			9	HF PTH f(-40dB)	Open PTH
			10	HF SMT 50MHz	Open PTH
			11	HF SMT f(-3dB)	Open PTH
			12	HF SMT f(-40dB)	Open PTH
096-4	3	WS	10	HF SMT 50MHz	Open PTH
			11	HF SMT f(-3dB)	Open PTH
			12	HF SMT f(-40dB)	Open PTH
098-3	3	WS	10	HF SMT 50MHz	Open PTH
			11	HF SMT f(-3dB)	Open PTH
			12	HF SMT f(-40dB)	Open PTH
098-4	3	WS	11	HF SMT f(-3dB)	Waveform shifted
099-1	3	WS	12	HF SMT f(-40dB)	Distorted Waveform (does not quite go to -40dB, reads at-3dB)
111-3	3	WS	23	Stranded Wire 2	Minor
OSP					
006-4	5	LR	12	HF SMT f(-40dB)	Distorted waveform (goes to 40db but flattens and crosses beyond 900mhz
009-2	6	LR	10	HF SMT 50MHz	Open PTH on coil
			11	HF SMT f(-3dB)	Open PTH on coil
			12	HF SMT f(-40dB)	Open PTH on coil

014-3	5	LR	10	HF SMT 50MHz	Open PTH
			11	HF SMT f(-3dB)	Open PTH
			12	HF SMT f(-40dB)	Open PTH
056-2	5	LR	7	HF PTH 50MHz	Open PTH
			8	HF PTH f(-3dB)	Open PTH
056-4	5	LR	7	HF PTH 50MHz	2 open PTHs
			8	HF PTH f(-3dB)	2 open PTHs
			9	HF PTH f(-40dB)	2 open PTHs
			10	HF SMT 50MHz	2 open PTHs
			11	HF SMT f(-3dB)	2 open PTHs
			12	HF SMT f(-40dB)	2 open PTHs
058-1	5	WS	10	HF SMT 50MHz	Open PTH
			12	HF SMT f(-40dB)	Open PTH
060-1	5	WS	12	HF SMT f(-40dB)	
060-2	5	WS	10	HF SMT 50MHz	Open PTH
			12	HF SMT f(-40dB)	Open PTH
Immersion Sn					
028-2	9	LR	10	HF SMT 50MHz	Open PTH
			12	HF SMT f(-40dB)	Open PTH
030-4	9	LR	4	HVLC SMT	Burnt etch (visual)
032-4	8	LR	7	HF PTH 50MHz	Open PTH
			8	HF PTH f(-3dB)	Open PTH
033-2	8	LR	17	HF TLC RNR	
037-2	9	LR	5	HSD PTH	Likely component failure
			10	HF SMT 50MHz	Open PTH
			11	HF SMT f(-3dB)	Open PTH
			12	HF SMT f(-40dB)	Open PTH
084-1	7	LR	10	HF SMT 50MHz	Open PTH
			11	HF SMT f(-3dB)	Open PTH
			12	HF SMT f(-40dB)	Open PTH
086-2	7	WS	5	HSD PTH	Likely component failure
		WS	12	HF SMT f(-40dB)	Distorted Waveform
087-3	7	WS	7	HF PTH 50MHz	High resistance on coil (acts like open PTH)
			8	HF PTH f(-3dB)	High resistance on coil (acts like open PTH)
			9	HF PTH f(-40dB)	High resistance on coil (acts like open PTH)
			12	HF SMT f(-40dB)	High resistance on coil (acts like open PTH)
088-3	7	LR	10	HF SMT 50MHz	Open PTH
			11	HF SMT f(-3dB)	Open PTH
			12	HF SMT f(-40dB)	Open PTH
089-1	7	WS	7	HF PTH 50MHz	Open PTH
			8	HF PTH f(-3dB)	Open PTH
			9	HF PTH f(-40dB)	Open PTH
			12	HF SMT f(-40dB)	Open PTH
089-2	7	WS	10	HF SMT 50MHz	High resistance on coil (acts like open PTH)
			11	HF SMT f(-3dB)	High resistance on coil (acts like open PTH)
			12	HF SMT f(-40dB)	High resistance on coil (acts like open PTH)
089-4	7	WS	10	HF SMT 50MHz	Open PTH
			11	HF SMT f(-3dB)	Open PTH
			12	HF SMT f(-40dB)	Open PTH
090-2	7	WS	7	HF PTH 50MHz	Open PTH on coil
			8	HF PTH f(-3dB)	Open PTH on coil
			9	HF PTH f(-40dB)	Open PTH on coil
102-4	10	WS	17	HF TLC RNR	
Immersion Ag					
071-1	11	LR	10	HF SMT 50MHz	Open PTH on coil
			11	HF SMT f(-3dB)	Open PTH on coil
			12	HF SMT f(-40dB)	Open PTH on coil
072-1	11	LR	7	HF PTH 50MHz	Open PTH

			8	HF PTH f(-3dB)	Open PTH
			9	HF PTH f(-40dB)	Open PTH
073-3	11	LR	7	HF PTH 50MHz	Open PTH
			8	HF PTH f(-3dB)	Open PTH
			9	HF PTH f(-40dB)	Open PTH
			15	HR TLC 1GHz	
082-2	11	WS	12	HF SMT f(-40dB)	Burnt etch
085-1	12	WS	7	HF PTH 50MHz	Open PTH
			8	HF PTH f(-3dB)	Open PTH
			9	HF PTH f(-40dB)	Open PTH
			10	HF SMT 50MHz	Open PTH
			11	HF SMT f(-3dB)	Open PTH
			12	HF SMT f(-40dB)	Open PTH
085-2	12	WS	7	HF PTH 50MHz	Open PTH (2 places)
			8	HF PTH f(-3dB)	Open PTH (2 places)
			9	HF PTH f(-40dB)	Open PTH (2 places)
			10	HF SMT 50MHz	Open PTH (2 places)
			11	HF SMT f(-3dB)	Open PTH (2 places)
			12	HF SMT f(-40dB)	Open PTH (2 places)
091-4	12	WS	12	HF SMT f(-40dB)	
094-1	12	WS	7	HF PTH 50MHz	Burnt Etch, High Resistance PTH, and Open PTH
			8	HF PTH f(-3dB)	Burnt Etch, High Resistance PTH, and Open PTH
			9	HF PTH f(-40dB)	Burnt Etch, High Resistance PTH, and Open PTH
			10	HF SMT 50MHz	Burnt Etch, High Resistance PTH, and Open PTH
			11	HF SMT f(-3dB)	Burnt Etch, High Resistance PTH, and Open PTH
			12	HF SMT f(-40dB)	Burnt Etch, High Resistance PTH, and Open PTH
094-4	12	WS	7	HF PTH 50MHz	Open PTH
			8	HF PTH f(-3dB)	Open PTH
			9	HF PTH f(-40dB)	Open PTH
Ni/Au					
013-1	13	LR	6	HSD SMT	Device failed, U3
015-2	14	LR	7	HF PTH 50MHz	Open PTH on coil
			8	HF PTH f(-3dB)	Open PTH on coil
			9	HF PTH f(-40dB)	Open PTH on coil
055-1	13	WS	7	HF PTH 50MHz	Open PTH
			8	HF PTH f(-3dB)	Open PTH
			9	HF PTH f(-40dB)	Open PTH
Ni/Pd/Au					
036-1	16	WS	6	HSD SMT	Likely component failure

Table F.3 Anomaly Summary After Mechanical Shock
(shaded entries signify carry over TS anomalies)

HASL					
MSN	**Site**	**Flux**		**Circuit**	**Test Technician Comments**
039-2	2	LR	12	HF SMT f(-40dB)	Waveform distorted
046-1	2	LR	10	HF SMT 50MHz	Open PTH
			11	HF SMT f(-3dB)	
			12	HF SMT f(-40dB)	
046-2	2	LR	10	HF SMT 50MHz	Open PTH
			11	HF SMT f(-3dB)	
			12	HF SMT f(-40dB)	
046-4	2	LR	12	HF SMT f(-40dB)	Distorted waveform
076-1	1	LR	10	HF SMT 50MHz	High resistance
			11	HF SMT f(-3dB)	
			12	HF SMT f(-40dB)	
076-2	1	LR	1	HCLV PTH	
079-4	1	WS	12	HF SMT f(-40dB)	Waveform does not go to -40dB

080-4	1	WS	12	HF SMT f(-40dB)	
083-2	1	WS	7	HF PTH 50MHz	Open PTH
			8	HF PTH f(-3dB)	
			9	HF PTH f(-40dB)	
			11	HF SMT f(-3dB)	
			12	HF SMT f(-40dB)	
096-4	3	WS	7	HF PTH f(-3dB)	Open PTH, distorted waveform
			10	HF SMT 50MHz	
			11	HF SMT f(-3dB)	
			12	HF SMT f(-40dB)	
			13	HF TLC 50MHz	
098-2	3	WS	12	HF SMT f(-40dB)	
098-3	3	WS	10	HF SMT 50MHz	Open PTH
			11	HF SMT f(-3dB)	
			12	HF SMT f(-40dB)	
098-4	3	WS	10	HF SMT 50MHz	Open PTH
			11	HF SMT f(-3dB)	Waveform shifted
			12	HF SMT f(-40dB)	
099-1	3	WS	12	HF SMT f(-40dB)	Distorted waveform
099-4	3	WS	12	HF SMT f(-40dB)	Distorted waveform
100-3	3	WS	12	HF SMT f(-40dB)	Distorted waveform
OSP					
006-4	6	LR	12	HF SMT f(-40dB)	Distorted waveform
007-3	6	LR	12	HF SMT f(-40dB)	
009-2	6	LR	10	HF SMT 50MHz	Open PTH
			11	HF SMT f(-3dB)	
			12	HF SMT f(-40dB)	
010-1	4	LR	1	HCLV PTH	Distorted waveform
			12	HF SMT f(-40dB)	
010-2	4	LR	12	HF SMT f(-40dB)	
010-4	4	LR	14	HF TLC 500MHz	
014-1	5	LR	10	HF SMT 50MHz	Open etch
			11	HF SMT f(-3dB)	
			12	HF SMT f(-40dB)	
014-3	5	LR	1	HCLV PTH	Open PTH
056-1	5	LR	12	HF SMT f(-40dB)	Waveform does not go to -40 at the correct frequency
056-2	5	LR	1	HCLV PTH	Open PTH
			7	HF PTH 50MHz	
			8	HF PTH f(-3dB)	
			9	HF SMT 50MHz	
			10	HF SMT f(-3dB)	
			12	HF SMT f(-40dB)	
056-3	5	LR	12	HF SMT f(-40dB)	Waveform shifted
056-4	5	LR	7	HF PTH 50MHz	Open PTH - 2 places
			8	HF PTH f(-3dB)	
			9	HF PTH f(-40dB)	
			10	HF SMT 50MHz	
			11	HF SMT f(-3dB)	
			12	HF SMT f(-40dB)	
057-1	5	WS	12	HF SMT f(-40dB)	Waveform does not go to -40dB
058-1	5	WS	10	HF SMT 50MHz	Open PTH
			11	HF SMT f(-3dB)	
			12	HF SMT f(-40dB)	
060-1	5	WS	12	HF SMT f(-40dB)	Distorted waveform
060-2	5	WS	7	HF SMT 50MHz	Open PTH
			9	HF SMT f(-40dB)	
060-4	5	WS	12	HF SMT f(-40dB)	Distorted waveform
061-4	4	WS	12	HF SMT f(-40dB)	

062-1	4	WS	12	HF SMT f(-40dB)	Distorted waveform
062-4	4	WS	12	HF SMT f(-40dB)	Waveform shifted
065-1	4	WS	12	HF SMT f(-40dB)	High resistance
065-4	4	WS	12	HF SMT f(-40dB)	
Immersion Sn					
026-4	9	LR	5	HSD PTH	Bad HSD PTH device
028-2	9	LR	10	HF SMT 50MHz	Open etch
			11	HF SMT f(-3dB)	
			12	HF SMT f(-40dB)	
029-1	9	LR	1	HCLV PTH	
029-2	9	LR	17	HF TLC RNR	
030-4	9	LR	9	HF PTH f(-40dB)	Burnt etch (visual)
032-4	8	LR	7	HF PTH 50MHz	Open PTH
			9	HF PTH f(-40dB)	
033-2	8	LR	17	HF TLC RNR	
037-2	9	LR	5	HSD PTH	Open etch
			10	HF SMT 50MHz	
			11	HF SMT f(-3dB)	
			12	HF SMT f(-40dB)	
040-3	8	LR	9	HF PTH f(-40dB)	Distorted waveform
084-1	7	LR	10	HF SMT 50MHz	Open PTH
			11	HF SMT f(-3dB)	
			12	HF SMT f(-40dB)	
084-2	7	LR	9	HF PTH f(-40dB)	Open PTH
			10	HF SMT 50MHz	
			11	HF SMT f(-3dB)	
			12	HF SMT f(-40dB)	
084-4	7	LR	10	HF SMT 50MHz	Open PTH
			11	HF SMT f(-3dB)	
			12	HF SMT f(-40dB)	
			15	HF TLC 1GHz	
086-2	7	WS	1	HCLV PTH	Distorted waveform
			12	HF SMT f(-40dB)	
087-1	7	WS	12	HF SMT f(-40dB)	
087-3	7	WS	8	HF PTH f(-3dB)	Open PTH 2 places SMT & PTH
			10	HF SMT 50MHz	
			11	HF SMT f(-3dB)	
			12	HF SMT f(-40dB)	
087-4	7	WS	12	HF SMT f(-40dB)	Distorted waveform
088-3	7	LR	10	HF SMT 50MHz	Open PTH
			11	HF SMT f(-3dB)	
			12	HF SMT f(-40dB)	
089-1	7	WS	7	HF PTH 50MHz	Open PTH
			8	HF PTH f(-3dB)	Waveform does not go to -40dB
			9	HF PTH f(-40dB)	
			12	HF SMT f(-40dB)	
089-2	7	WS	10	HF SMT 50MHz	Open PTH
			11	HF SMT f(-3dB)	
			12	HF SMT f(-40dB)	
089-4	7	WS	7	HF PTH 50MHz	Open PTH - 2 places
			8	HF PTH f(-3dB)	
			10	HF SMT 50MHz	
			11	HF SMT f(-3dB)	
			12	HF SMT f(-40dB)	
090-2	7	WS	7	HF PTH 50MHz	Open PTH 2 places SMT & PTH
			8	HF PTH f(-3dB)	
			10	HF SMT 50MHz	
			11	HF SMT f(-3dB)	

			12	HF SMT f(-40dB)	
102-4	10	WS	17	HF TLC RNR	
104-4	10	WS	12	HF SMT f(-40dB)	
113-1	10	WS	10	HF SMT 50MHz	Open PTH
			11	HF SMT f(-3dB)	
			12	HF SMT f(-40dB)	
Immersion Ag					
072-1	11	LR	7	HF PTH 50MHz	Open PTH
			8	HF PTH f(-3dB)	
			9	HF PTH f(-40dB)	
072-2	11	LR	12	HF SMT f(-40dB)	Waveform shifted
072-4	11	LR	12	HF SMT f(-40dB)	Waveform does not go to -40dB
073-3	11	LR	7	HF PTH 50MHz	Open PTH
			8	HF PTH f(-3dB)	
			9	HF PTH f(-40dB)	
075-2	11	LR	12	HF SMT f(-40dB)	
075-3	11	LR	13	HF TLC 50MHz	Distorted waveform
082-2	11	WS	10	HF SMT 50MHz	Open PTH
			12	HF SMT f(-40dB)	
			13	HF TLC 50MHz	
082-3	11	WS	12	HF SMT f(-40dB)	Open PTH, distorted waveform
085-1	12	WS	7	HF PTH 50MHz	Open PTH - 2 places
			8	HF PTH f(-3dB)	
			9	HF PTH f(-40dB)	
			10	HF SMT 50MHz	
			11	HF SMT f(-3dB)	
085-2	12	WS	1	HCLV PTH	Open PTH
			7	HF PTH 50MHz	
			8	HF PTH f(-3dB)	
			9	HF PTH f(-40dB)	
			10	HF SMT 50MHz	
			11	HF SMT f(-3dB)	
			12	HF SMT f(-40dB)	
091-4	12	WS	1	HCLV PTH	Open etch
			10	HF SMT 50MHz	
			11	HF SMT f(-3dB)	
			12	HF SMT f(-40dB)	
094-1	12	WS	7	HF PTH 50MHz	Open PTH - 2 places
			8	HF PTH f(-3dB)	
			9	HF PTH f(-40dB)	
			10	HF SMT 50MHz	
			11	HF SMT f(-3dB)	
			12	HF SMT f(-40dB)	
			13	HF TLC 50MHz	
094-3	12	WS	9	HF PTH f(-40dB)	Waveform distorted
			12	HF SMT f(-40dB)	
			13	HF TLC 50MHz	
			17	HF TLC RNR	
094-4	12	WS	1	HCLV PTH	Open PTH - 2 places
			7	HF PTH 50MHz	
			8	HF PTH f(-3dB)	
			9	HF PTH f(-40dB)	
			10	HF SMT 50MHz	
			11	HF SMT f(-3dB)	
			12	HF SMT f(-40dB)	
			13	HF TLC 50MHz	
095-4	12	WS	1	HCLV PTH	Open etch

Ni/Au					
013-1	13	LR	6	HSD SMT	HSD device fail
015-2	14	LR	7 9	HF PTH 50MHz HF PTH f(-40dB)	Open etch
051-2	13	WS	8	HF PTH f(-3dB)	
054-4	13	WS	8	HF PTH f(-3dB)	
055-1	13	WS	7 8 9	HF PTH 50MHz HF PTH f(-3dB) HF PTH f(-40dB)	Open etch
055-4	13	WS	12	HF SMT f(-40dB)	Waveform distorted
Ni/Pd/Au					
036-2	16	WS	12	HF SMT f(-40dB)	

F.3 HCLV Circuitry

Pre-test measurements and deltas were analyzed with the GLM in Equation F.1 for the main effects site and flux and their interactions. These data were also subjected to a second GLM analysis based on Equation F.2 for the main effects surface finish and flux. The base case for the GLM in Equation F.1 is defined as HASL at Site 1 and processed with LR flux. The base case for the GLM in Equation F.2 is defined as HASL processed with LR flux.

Tables F.4 and F.5 summarize the results of these GLM analyses for HCLV PTH and HCLV SMT. The upper portion of these tables contain the GLM results for Equation F.1 while the lower portion of these tables contain the GLM results for Equation F.2. The rows labeled “Constant” in these tables contain the least squares estimates of β_0 in Equations F.1 and F.2 for each test time. The numbers in the columns beneath the “Constants” are the estimated coefficients of the terms in Equations F.1 and F.2 that are *significantly different* from the base case. Shaded cells signify that the corresponding term in the GLM is not significantly different from the base case.

The rows labeled Model R^2 in Tables F.4 and F.5 show the percent of variation in the voltage measurements explained by the respective estimated model. This value can range from 0% to 100%. The model R^2s for Equations F.1 and F.2 for the HCLV circuitry are summarized as follows for each test time.

GLM	Circuit	Pre-test	85/85	TS	MS
Site and Flux	HCLV PTH	2.0%	2.3%	3.7%	19.1%
	HCLV SMT	4.2%	7.7%	10.9%	2.1%
Surface Finish and Flux	HCLV PTH	0.7%	1.3%	1.7%	7.7%
	HCLV SMT	1.5%	0.3%	9.8%	0.7%

High R^2 values would indicate a strong cause and effect relationship between the parameters of surface finish, site, flux, and the voltage measurements at pretest. However, these R^2s are all quite small, which indicates that the experimental parameters: surface finish, site, and flux do not significantly affect the HCLV voltage measurements at Pre-test nor do they affect the changes in the voltage after exposure to each of the three test environments. That is, the HCLV measurements are robust with respect to surface finish, site, and flux. The results for the two GLMs used in the analysis are now examined in more detail.

GLM Results for Site and Flux

The uppermost portion of Table F.4 for HCLV PTH shows that only two experimental factors (Site 2 and Site 8) are significantly different from the base case for the GLM in Equation F.1. The estimated GLM at Pre-test for Equation F.1 is obtained from the estimated coefficients in the second column of Table F.4 as:

Y = 7.14 + 0.06 Site2 + 0.07 Site 8

where Y represents the voltage response. The predicted voltage from this estimated model is 7.14V for all site and flux combinations except Sites 2 and 8. The predictions for these two sites are 7.14V + 0.06V = 7.20V and 7.14V + 0.07V = 7.21V, respectively. Note that even though these two terms are *statistically significant*, they represent very small changes from the base case voltage and, as such, are not of practical interest. Moreover, the model R^2 is only 2.0%, which has no practical value. Similar comments hold for the GLM analyses at Pre-test for HCLV SMT.

Columns 3 to 5 in Tables F.4 and F.5 give the HCLV PTH and HCLV SMT GLM results for Delta 1, 2, and 3, respectively. Note that these latter three analyses are based on changes in the voltage measurements from Pre-test. The model R^2 values after 85/85 and TS are also quite small, which implies that the experimental parameters did not influence the HCLV measurements after exposure to the 85/85, TS, and MS test environments.

In spite of the lack of significant experimental parameters in the HCLV GLMs, there is one very interesting aspect of the model for HCLV SMT at Post MS. Note that the estimate of the constant term in the last column of Table F.5 is 2.48, whereas, the estimated constants at Post 85/85 and Post TS were 0.04 and 0.05, respectively. This is an increase of approximately 2.43V. The explanation of this increase requires a review of the HCLV circuit, which is given in Section F.10. In particular, Section F.10 explains that the HCLV circuit has seven 10Ω resistors, R_1, R_2, ..., R_7 in parallel. The overall circuit resistance, R_{total}, is the parallel combination of these seven resistors, which is given as:

$$\frac{1}{R_{total}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_2} + \cdots + \frac{1}{R_7} = \frac{7}{10\Omega} \tag{F.3}$$

$$R_{total} = \frac{10\Omega}{7} \tag{F.4}$$

Since a current (I) of 5A was applied to the circuit, Ohm's Law gives the resulting voltage (V) as

$$V = IR = 5A \times \frac{10\Omega}{7} = 7.14V \tag{F.5}$$

During the MS test, it was noted that one to three of the resistors frequently fell off the board. In fact, 158 of the 164 PWAs were missing at least one of these resistors. If a single resistor is missing, Equation F.5 would be revised as follows:

$$V = IR = 5A \times \frac{10\Omega}{6} = 8.33V \tag{F.6}$$

Likewise, two missing resistors increase the voltage to 10V. Next consider the following dotplot of voltage measurements at Post MS.

```
                                              . :
                                              : :    :
                                              : :   ::
                                    : .       : :  .:::
                                    : :  :    : : .::::
                    .               : : ::    : : ::::::
   .                :             ..: : ::    ::: ::::::
 : :                ::: :.: . .. .:::.::::: . :::.::::::.
 +---------+---------+---------+---------+---------+-------Voltage
7.20      7.80      8.40      9.00      9.60     10.20
```

Note how the voltages are lumped around the points at 7.14V, 8.33V, and 10V, which corresponds to the loss of no, one, or two resistors. Thus, the constant term in the GLM represents an average increase in voltage of 2.48V over the nominal expected value of 7.14V, which is between one and two missing resistors.

GLM Results for Surface Finish and Flux

The lower portion of Table F.4 for HCLV PTH shows that only one experimental factor (Ni/Pd/Au) is significantly from the base case at Pre-test for the GLM in Equation F.2. The estimated model is:

$$Y = 7.15 - 0.04 \text{ Ni/Pd/Au}$$

where Y represents the voltage response. The predicted voltage from this estimated model is 7.15V for all surface finish and flux combinations except for Ni/Pd/Au processed with either flux, in which case the prediction is decreased by 0.04V or 7.15V - 0.04V = 7.11V. As was just discussed with the previous GLM, even though the coefficient for Ni/Pd/Au is statistically significant, it actually represents a very small change from the base case and, as such, is not of practical interest. Moreover, the model R^2 is only 0.7%, which has no practical value. Similar comments hold for the GLM analyses at Pre-test for HCLV SMT.

These low R^2 values imply that the experimental parameters do not differ significantly from the base case in terms of their impact on the voltage of the HCLV PTH and HCLV SMT circuits. That is, there is no practical difference from the base case voltage measurements due to surface finish or flux type. This result is to be expected since there were no difference among sites for these circuits in the GLM analysis based on Equation F.1.

Columns 3 to 5 in Tables F.4 and F.5 give the HCLV PTH and HCLV SMT GLM results for Delta 1, 2, and 3, respectively. The model R^2 values at Post 85/85, Post TS, and Post MS are also quite small, which implies that the experimental parameters did not influence the HCLV measurements after exposure to the 85/85 and TS test environments. However, as just explained for the Site and Flux model, the constant term in the last column of Table F.5 is affected by the missing resistors.

Table F.4 Significant Coefficients for the Two GLM Analyses by Test Time for HCLV PTH

GLM from Eq. F.1: Sites and Interactions with Flux

Experimental Factor	Pre-Test	85/85 (Delta 1)	Thermal Shock (Delta 2)	Mech Shock (Delta 3)
Constant	7.14	0.04	0.05	0.14
Flux				
Site 2	0.06		-0.17	
Site 3				
Site 4				
Site 5				
Site 6				
Site 7				
Site 8	0.07			
Site 9				
Site 10				
Site 11		0.13		
Site 12				0.80
Site 13				
Site 14				
Site 15				
Site 16				
Site 4 * Flux				
Site 5 * Flux				
Site 7 * Flux				
Site 11 * Flux		-0.16		
Site 13 * Flux				
Site 16 * Flux				
Model R^2	2.0%	2.3%	3.7%	19.1%
Standard Deviation	0.13	0.18	0.17	0.36

GLM from Eq. F.2: Surface Finishes and Flux

Experimental Factor	Pre-Test	85/85 (Delta 1)	Thermal Shock (Delta 2)	Mech Shock (Delta 3)
Constant	7.15	0.03	0.04	0.13
OSP				
Immersion Sn				
Immersion Ag		0.07	0.07	0.34
Ni/Au				
Ni/Pd/Au	-0.04			
Flux				
Model R^2	0.7%	1.3%	1.7%	7.7%
Standard Deviation	0.10	0.10	0.17	0.38

Table F.5 Significant Coefficients for the Two GLM Analyses by Test Time for HCLV SMT

GLM from Eq. F.1: Sites and Interactions with Flux

Experimental Factor	**Pre-Test**	**85/85 (Delta 1)**	**Thermal Shock (Delta 2)**	**Mech Shock (Delta 3)**
Constant	7.26	0.04	0.05	2.48
Flux				
Site 2				-0.48
Site 3				
Site 4				
Site 5			-0.10	
Site 6				
Site 7				
Site 8	0.06	-0.09		
Site 9				
Site 10	-0.07		0.11	
Site 11				
Site 12				
Site 13				
Site 14				
Site 15				
Site 16				
Site 4 * Flux				
Site 5 * Flux		-0.14		
Site 7 * Flux				
Site 11 * Flux				
Site 13 * Flux			-0.11	
Site 16 * Flux				
Model R^2	4.2%	7.7%	10.9%	2.1%
Standard Deviation	0.09	0.12	0.13	0.70

GLM from Eq. F.2: Surface Finishes and Flux

Experimental **Factor**	**Pre-Test**	**85/85 (Delta 1)**	**Thermal Shock (Delta 2)**	**Mech Shock (Delta 3)**
Constant	7.26	0.03	0.07	2.49
OSP			-0.08	
Immersion Sn				-0.15
Immersion Ag		-0.02		
Ni/Au			-0.10	
Ni/Pd/Au				
Flux	-0.02			
Model R^2	1.5%	0.3%	9.8%	0.7%
Standard Deviation	0.09	0.1	0.13	0.70

F.4 HVLC Circuitry

Results of the GLM analyses for HVLC PTH and HVLC SMT circuits are given in Tables F.6 and F.7, respectively. Columns 3 to 5 in these tables give the GLM results for 85/85, TS, and MS, respectively. The model R^2s for Equations F.1 and F.2 for the HVLC circuitry are summarized as follows for each test time.

GLM	Circuit	Pre-test	85/85	TS	MS
Site and Flux	HVLC PTH	13.3%	5.2%	0.0%	3.2%
	HVLC SMT	20.9%	14.0%	18.7%	NA
Surface Finish and Flux	HVLC PTH	7.6%	2.5%	2.6%	3.2%
	HVLC SMT	14.0%	15.3%	12.9%	NA

These model R^2 values are generally higher that those observed for the HCLV measurements. However, the magnitudes of the coefficients were too small to be of practical significance relative to the JTP acceptance criteria, which indicates that these parameters do not influence the HVLC measurements. To further explain this point, consider the coefficients for site and flux in Table F.6 at Pre-test where the constant term is 5.018μA. The largest coefficient at Pre-test is -0.008μA for the interaction of Site 4 and Flux. Thus, this interaction can decrease the constant term to 5.018μA - 0.008μA = 5.010μA, which is so far from the lower and upper limits of 4μA and 6μA that it is not of practical interest. Note that there are no R^2 values listed for HVLC SMT at Post MS. This is due to resistors coming off the PWA during the MS test, which caused the HVLC SMT circuit to give a constant response for reasons that will now be explained.

Boxplot Displays of Multiple Comparison Results

Figures F.1 to F.8 give boxplots for the HVLC PTH and SMT circuits. It is important to keep the vertical scale in mind relative to the acceptance criteria when viewing these boxplots. That is, the acceptance criteria indicates that the current should be between 4μA and 6μA. These boxplots are centered close to 5μA and the total spread is on the order of 0.02μA for the PTH circuits and approximately 0.5μA for SMT circuits. Hence, even though there are some statistically significantly differences, they are not likely to be of practical concern. Note the boxplots in Figure F.8 for HCLV SMT at Post MS. These values are all either 0μA for very close to it, reflecting the fact that the resistors came off the PWA during the MS test.

Table F.6 Significant Coefficients for the Two GLM Analyses by Test Time for HVLC PTH

GLM from Eq. F.1: Sites and Interactions with Flux

Experimental Factor	Pre-Test	85/85	Thermal Shock	Mech Shock
Constant	**5.018**	**5.004**	**4.999**	**4.998**
Flux				
Site 2				
Site 3				
Site 4	0.007			
Site 5				
Site 6				
Site 7				
Site 8	0.005			
Site 9	0.004			
Site 10				
Site 11				
Site 12	0.004	0.006		
Site 13				
Site 14				-0.005
Site 15				
Site 16				
Site 4 * Flux	-0.008			
Site 5 * Flux				
Site 7 * Flux				
Site 11 * Flux		0.006		
Site 13 * Flux				
Site 16 * Flux				
Model R^2	13.3%	5.2%	0.0%	3.2%
Standard Deviation	0.005	0.006	0.006	0.006

GLM from Eq. F.2: Surface Finishes and Flux

Experimental Factor	Pre-Test	85/85	Thermal Shock	Mech Shock
Constant	5.018	5.004	4.998	4.998
OSP				
Immersion Sn	0.003		0.002	
Immersion Ag	0.003	0.003		
Ni/Au				-0.003
Ni/Pd/Au				
Flux				
Model R^2	7.6%	2.5%	2.6%	3.2%
Standard Deviation	0.005	0.006	0.006	0.006

Table F.7 Significant Coefficients for the Two GLM Analyses by Test Time for HVLC SMT

GLM from Eq. F.1: Sites and Interactions with Flux

Experimental Factor	Pre-Test	85/85	Thermal Shock	Mech Shock
Constant	5.038	5.034	5.039	
Flux				
Site 2				
Site 3				
Site 4				
Site 5				
Site 6				
Site 7				
Site 8	0.172	0.173	0.170	
Site 9				
Site 10	0.111	0.111	0.109	
Site 11				
Site 12	0.122	0.125	0.120	
Site 13				
Site 14				
Site 15	0.125	0.126	0.125	
Site 16				
Site 4 * Flux				
Site 5 * Flux				
Site 7 * Flux				
Site 11 * Flux				
Site 13 * Flux				
Site 16 * Flux				
Model R^2	20.9%	21.5%	18.7%	
Standard Deviation	0.100	0.100	0.112	

GLM from Eq. F.2: Surface Finishes and Flux

Experimental Factor	Pre-Test	85/85	Thermal Shock	Mech Shock
Constant	5.032	5.027	5.033	
OSP				
Immersion Sn	0.095	0.100	0.097	
Immersion Ag	0.087	0.090	0.085	
Ni/Au				
Ni/Pd/Au				
Flux				
Model R^2	14.0%	15.3%	12.9%	
Standard Deviation	0.100	0.100	0.110	

F.5 HSD Circuitry

The complete results of the GLM analyses are given in Tables F.8 and F.9, respectively. Columns 3 to 5 in these tables give the GLM results for 85/85, TS, and MS, respectively. Note that these latter three analyses are based on changes in total propagation delay from Pre-test. The model R^2s for Equations F.1 and F.2 for the HSD circuitry are summarized as follows for each test time.

GLM	Circuit	Pre-test	85/85	TS	MS
Site and Flux	HSD PTH	5.1%	9.8%	4.3%	9.5%
	HSD SMT	6.1%	6.4%	0.0%	2.3%
Surface Finish and Flux	HSD PTH	0.9%	1.6%	1.8%	6.7%
	HSD SMT	1.0%	0.3%	0.8%	0.2%

All these model R^2 values are quite small at each test time, which indicates that the experimental parameters under evaluation do not influence the HSD total propagation delay measurements.

<u>Boxplot Displays of Multiple Comparison Results</u>

Figures F.9 and F.10 give boxplots of Pre-test measurements of total propagation delay for the HSD PTH and HSD SMT circuits, respectively. Note that most total propagation delays in Figure F.9 for HSD PTH are a little over 17 ns with a range of about 1ns. Figure F.10 shows that the total propagation delays for HSD SMT have a range of about 0.4ns and are centered about 9.2ns. The percentage changes in the total propagation delay measurements were small and well within the acceptance criteria so boxplot displays of these measurements are not presented.

Table F.8 Significant Coefficients for the Two GLM Analyses by Test Time for HSD PTH

GLM from Eq. F.1: Sites and Interactions with Flux

Experimental Factor	Pre-Test	85/85 (Delta 1)	Thermal Shock (Delta 2)	Mech Shock (Delta 3)
Constant	17.13	0.55	0.98	0.37
Flux			-0.46	
Site 2				
Site 3				2.60
Site 4	0.14			
Site 5		0.61		
Site 6			-1.00	
Site 7				
Site 8				
Site 9		1.89		
Site 10				
Site 11				-2.30
Site 12				-3.50
Site 13				
Site 14				
Site 15				
Site 16				
Site 4 * Flux				
Site 5 * Flux				
Site 7 * Flux				
Site 11 * Flux				
Site 13 * Flux				
Site 16 * Flux	0.19			
Model R^2	5.1%	9.8%	4.3%	9.5%
Standard Deviation	0.19	1.30	1.33	3.52

GLM from Eq. F.2: Surface Finishes and Flux

Experimental Factor	Pre-Test	85/85 (Delta 1)	Thermal Shock (Delta 2)	Mech Shock (Delta 3)
Constant	17.13	0.88	0.88	0.52
OSP	0.05			
Immersion Sn				
Immersion Ag				-2.89
Ni/Au				
Ni/Pd/Au				
Flux		-0.35	-0.36	
Model R^2	0.9%	1.6%	1.8%	6.7%
Standard Deviation	0.20	1.00	1.30	3.5

Table F.9 Significant Coefficients for the Two GLM Analyses by Test Time for HSD SMT

GLM from Eq. F.1: Sites and Interactions with Flux

Experimental Factor	Pre-Test	85/85 (Delta 1)	Thermal Shock (Delta 2)	Mech Shock (Delta 3)
Constant	9.23	0.94	1.16	-0.002
Flux				
Site 2		-1.59		
Site 3				
Site 4				
Site 5				
Site 6				
Site 7				
Site 8				-1.60
Site 9				
Site 10				
Site 11				
Site 12		-1.27		
Site 13				
Site 14				
Site 15	0.12			
Site 16				
Site 4 * Flux				
Site 5 * Flux	-0.10			
Site 7 * Flux				
Site 11 * Flux				
Site 13 * Flux				
Site 16 * Flux				
Model R^2	6.1%	6.4%	0.0%	2.3%
Standard Deviation	0.13	1.65	1.99	2.25

GLM from Eq. F.2: Surface Finishes and Flux

Experimental Factor	Pre-Test	85/85 (Delta 1)	Thermal Shock (Delta 2)	Mech Shock (Delta 3)
Constant	9.21	0.77	1.23	-0.04
OSP				
Immersion Sn				
Immersion Ag			-0.56	
Ni/Au				-0.25
Ni/Pd/Au		0.35		
Flux	0.03			
Model R^2	1.0%	0.3%	0.8%	0.2%
Standard Deviation	0.10	1.00	1.90	2.2

F.6 HF LPF Circuitry

Pre-test measurements for all HF LPF circuits were subjected to GLM analyses, as were the deltas after 85/85, TS, and MS. The results of the GLM analyses are given in Tables F.10 to F.15. Columns 3 to 5 in these tables give the GLM results for 85/85, TS, and MS, respectively.

Note that these latter three analyses are based on changes from Pre-test measurements. The model R^2s for Equations F.1 and F.2 for the HF LPF circuitry are summarized as follows for each test time.

GLM	Circuit	Pre-test	85/85	TS	MS
Site and Flux	PTH 50MHz	20.6%	29.5%	24.1%	20.5%
	PTH f(-3dB)	7.1%	10.8%	10.2%	23.4%
	PTH f(-40dB)	14.3%	9.6%	7.6%	13.5%
	SMT 50MHz	3.9%	10.3%	21.1%	32.2%
	SMT f(-3dB)	8.8%	10.5%	19.1%	14.3%
	SMT f(-40dB)	5.3%	2.3%	16.1%	29.4%
Surface Finish and Flux	PTH 50MHz	4.3%	2.3%	0.3%	8.1%
	PTH f(-3dB)	7.8%	0.2%	1.6%	10.9%
	PTH f(-40dB)	4.5%	1.8%	1.6%	10.9%
	SMT 50MHz	2.7%	0.6%	0.8%	6.1%
	SMT f(-3dB)	0.7%	1.5%	5.0%	3.0%
	SMT f(-40dB)	5.2%	0.3%	4.9%	14.4%

The model R^2 values are quite small at Pre-test, which indicates that the parameters under evaluation do not influence the HF LPF measurements. The same is true at Post 85/85. The model R^2 values are also quite small at Post TS and Post MS. However, the test measurements contained many extreme outlying observations at both of these later two test times, which greatly increases the sample variance and in turn hinders the interpretation of the GLM results. As indicated in Tables F.1, F.2, and F.3 there were many anomalous HF LPF test measurements (171 at Post MS).

Boxplot Displays of Multiple Comparison Results

Boxplot displays of all test results for HF LPF circuits have been created to aid in the interpretation of the results. Figures 4.9 to 4.15 in Chapter 4 show the boxplots for the analyses with significant differences or values not meeting acceptance criteria. Figures F.11 to F.27 show all remaining boxplots associated with the HF LPF results.

Table F.10 Significant Coefficients for the Two GLM Analyses by Test Time for HF PTH 50 MHz

GLM from Eq. F.1: Sites and Interactions with Flux

Experimental Factor	Pre-Test	85/85 (Delta 1)	Thermal Shock (Delta 2)	Mech Shock (Delta 3)
Constant	-0.721	-0.034	-0.002	-2.666
Flux				
Site 2				
Site 3				
Site 4				
Site 5				
Site 6				
Site 7				
Site 8				
Site 9				
Site 10				
Site 11				
Site 12				-28.1
Site 13	-0.180	0.197	0.192	
Site 14			-0.073	
Site 15				
Site 16				
Site 4 * Flux				
Site 5 * Flux				
Site 7 * Flux				-18.5
Site 11 * Flux				
Site 13 * Flux	0.160	-0.206	-0.180	
Site 16 * Flux				
Model R^2	20.6%	29.5%	24.1%	20.5%
Standard Deviation	0.055	0.048	0.063	14.1

GLM from Eq. F.2: Surface Finishes and Flux

Experimental Factor	Pre-Test	85/85 (Delta 1)	Thermal Shock (Delta 2)	Mech Shock (Delta 3)
Constant	-0.720	-0.034	0.003	-3.28
OSP			-0.010	
Immersion Sn				
Immersion Ag				-13.6
Ni/Au	-0.034	0.023		
Ni/Pd/Au				
Flux				
Model R^2	4.3%	2.3%	0.3%	8.1%
Standard Deviation	0.060	0.050	0.072	15.00

Table F.11 Significant Coefficients for the Two GLM Analyses by Test Time for HF PTH f(-3dB)

GLM from Eq. F.1: Sites and Interactions with Flux

Experimental Factor	**Pre-Test**	**85/85 (Delta 1)**	**Thermal Shock (Delta 2)**	**Mech Shock (Delta 3)**
Constant	283.0	-0.9	0.5	-1.05
Flux				
Site 2				
Site 3				
Site 4				
Site 5				
Site 6			-2.2	
Site 7				
Site 8				
Site 9				
Site 10				
Site 11				
Site 12				-116
Site 13	-1.8			
Site 14				
Site 15	-1.5			
Site 16				
Site 4 * Flux				
Site 5 * Flux		0.7		
Site 7 * Flux		-1.2		-68
Site 11 * Flux				
Site 13 * Flux				-79
Site 16 * Flux				
Model R^2	7.1%	10.8%	10.2%	23.4%
Standard Deviation	2.0	0.9	1.5	58.5

GLM from Eq. F.2: Surface Finishes and Flux

Experimental Factor	**Pre-Test**	**85/85 (Delta 1)**	**Thermal Shock (Delta 2)**	**Mech Shock (Delta 3)**
Constant	283.0	-1.0	0.5	4.19
OSP		0.1	-0.5	
Immersion Sn				
Immersion Ag				-53.0
Ni/Au	-1.6			
Ni/Pd/Au				
Flux				-23.8
Model R^2	7.8%	0.2%	1.6%	10.9%
Standard Deviation	2.0	0.9	1.5	62.0

Table F.12 Significant Coefficients for the Two GLM Analyses by Test Time for HF PTH f(-40dB)

GLM from Eq. F.1: Sites and Interactions with Flux

Experimental Factor	**Pre-Test**	**85/85 (Delta 1)**	**Thermal Shock (Delta 2)**	**Mech Shock (Delta 3)**
Constant	472.9	-0.2	-0.2	-11.7
Flux				
Site 2				
Site 3				
Site 4				
Site 5	-3.8		-1.8	
Site 6		0.9		
Site 7				
Site 8		-1.5		
Site 9	-5.7			
Site 10				
Site 11				
Site 12				-140
Site 13	-5.1			
Site 14				
Site 15	-4.5			
Site 16				
Site 4 * Flux				
Site 5 * Flux			2.6	
Site 7 * Flux				
Site 11 * Flux				
Site 13 * Flux				
Site 16 * Flux				
Model R^2	14.3%	9.6%	7.6%	13.5%
Standard Deviation	5.1	1.2	1.5	77.1

GLM from Eq. F.2: Surface Finishes and Flux

Experimental Factor	**Pre-Test**	**85/85 (Delta 1)**	**Thermal Shock (Delta 2)**	**Mech Shock (Delta 3)**
Constant	472.2	-0.1	-0.3	-8.41
OSP				
Immersion Sn		-0.4		
Immersion Ag				-83.0
Ni/Au	-3.2			
Ni/Pd/Au			0.71	
Flux				
Model R^2	4.5%	1.8%	1.6%	10.9%
Standard Deviation	5.0	1.0	1.5	78.0

Table F.13 Significant Coefficients for the Two GLM Analyses by Test Time for HF SMT 50 MHz

GLM from Eq. F.1: Sites and Interactions with Flux

Experimental Factor	Pre-Test	85/85 (Delta 1)	Thermal Shock (Delta 2)	Mech Shock (Delta 3)
Constant	-0.733	-0.018	0.005	-3.1
Flux				
Site 2				
Site 3			-0.112	-19.2
Site 4				
Site 5				-13.5
Site 6				
Site 7			-0.126	-49.7
Site 8				
Site 9		-0.049		
Site 10				
Site 11				
Site 12	0.031			-31.4
Site 13				
Site 14				
Site 15				
Site 16				
Site 4 * Flux	0.021			
Site 5 * Flux				
Site 7 * Flux				25.0
Site 11 * Flux		-0.047		
Site 13 * Flux				
Site 16 * Flux				
Model R^2	3.9%	10.3%	21.1%	32.2%
Standard Deviation	0.039	0.037	0.069	17.2

GLM from Eq. F.2: Surface Finishes and Flux

Experimental Factor	Pre-Test	85/85 (Delta 1)	Thermal Shock (Delta 2)	Mech Shock (Delta 3)
Constant	-0.733	-0.023	-0.010	-5.62
OSP			0.017	
Immersion Sn				-10.6
Immersion Ag	0.020			-10.7
Ni/Au		0.008		
Ni/Pd/Au				
Flux				
Model R^2	2.7%	0.6%	0.8%	6.1%
Standard Deviation	0.030	0.030	0.077	20.0

Table F.14 Significant Coefficients for the Two GLM Analyses by Test Time for HF SMT f(-3dB)

GLM from Eq. F.1: Sites and Interactions with Flux

Experimental Factor	Pre-Test	85/85 (Delta 1)	Thermal Shock (Delta 2)	Mech Shock (Delta 3)
Constant	319.8	-1.3	0.7	-15.5
Flux				
Site 2		1.0		108
Site 3				
Site 4				
Site 5				
Site 6				
Site 7			-15.3	
Site 8				
Site 9			-4.0	
Site 10				
Site 11		1.5		
Site 12				-143
Site 13	3.7			
Site 14			-3.9	
Site 15				
Site 16				
Site 4 * Flux				
Site 5 * Flux			-3.7	
Site 7 * Flux			11.9	-102
Site 11 * Flux		-2.2		
Site 13 * Flux	-4.4			
Site 16 * Flux				
Model R^2	8.8%	10.5%	19.1%	14.3%
Standard Deviation	1.9	1.1	4.7	112

GLM from Eq. F.2: Surface Finishes and Flux

Experimental Factor	Pre-Test	85/85 (Delta 1)	Thermal Shock (Delta 2)	Mech Shock (Delta 3)
Constant	319.7	-1.3	0.4	-1.98
OSP	0.4			
Immersion Sn			-2.8	
Immersion Ag		0.5		
Ni/Au				
Ni/Pd/Au				
Flux				-41.0
Model R^2	0.7%	1.5%	5.0%	3.0%
Standard Deviation	2.0	1.0	5.0	11.0

Table F.15 Significant Coefficients for the Two GLM Analyses by Test Time for HF SMT f(-40dB)

GLM from Eq. F.1: Sites and Interactions with Flux

Experimental Factor	**Pre-Test**	**85/85 (Delta 1)**	**Thermal Shock (Delta 2)**	**Mech Shock (Delta 3)**
Constant	865.5	1.7	-8.1	-80.3
Flux				
Site 2				
Site 3				-244
Site 4				
Site 5	-10.7			-171
Site 6				
Site 7				-430
Site 8		4.9		
Site 9				
Site 10				
Site 11		2.2		
Site 12	-19.7			-365
Site 13				
Site 14				
Site 15				
Site 16				
Site 4 * Flux				
Site 5 * Flux				
Site 7 * Flux				
Site 11 * Flux			-23.7	
Site 13 * Flux				
Site 16 * Flux				
Model R^2	5.3%	2.3%	16.1%	29.4%
Standard Deviation	21.0	7.6	9.1	221

GLM from Eq. F.2: Surface Finishes and Flux

Experimental Factor	**Pre-Test**	**85/85 (Delta 1)**	**Thermal Shock (Delta 2)**	**Mech Shock (Delta 3)**
Constant	861.2	2.0	-6.8	-146.2
OSP				
Immersion Sn				
Immersion Ag				
Ni/Au	13.4	1.0		192.0
Ni/Pd/Au				171.0
Flux			-4.4	-117.0
Model R^2	5.2%	0.3%	4.9%	14.4%
Standard Deviation	21.0	7.0	9.7	24.0

F.7 HF TLC Circuitry

Pre-test measurements for all HF TLC circuits except RNF were subjected to GLM analyses, as were the deltas after 85/85, TS, and MS. The results of the GLM analyses are given in Tables F.16 to F.20. Columns 3 to 5 in those tables give the HF TLC PTH and HF TLC SMT GLM results for 85/85, TS, and MS, respectively. Note that these latter three analyses are based on changes from Pre-test measurements. The model R^2s for Equations F.1 and F.2 for the HF TLC circuitry are summarized as follows for each test time, except for HF TLC RNF, which gave a constant response.

GLM	Circuit	Pre-test	85/85	TS	MS
Site and Flux	50MHz	62.3%	6.7%	0.0%	14.7%
	500MHz	10.7%	8.1%	0.0%	8.1%
	1GHz	13.2%	10.9%	6.1%	7.9%
	RNF				
	RNR	2.7%	8.2%	2.4%	6.2%
Surface Finish and Flux	50MHz	48.1%	6.6%	5.0%	9.1%
	500MHz	2.5%	0.9%	1.8%	1.4%
	1GHz	0.9%	2,8%	4.1%	0.7%
	RNF				
	RNR	3.6%	0.6%	3.5%	2.0%

The model R^2 values for HF TLC are all quite small at Pre-test except for those at 50MHz, which are of moderate size. The small R^2 values indicate that the experimental parameters do not influence the Pre-test HF TLC measurements. The moderate sized R^2 values for the 50MHz case are examined in further detail below (repeated from Chapter 4).

The predicted response at Pre-test for HF TLC 50MHz for the base case (HASL at Site 1 processed with LR flux) based on the Site & Flux GLM was -47.43dB. The predicted differences from the base case are given in Appendix F in Table F.21. The results show that the sites that produced Ni/Au and Ni/Au/Pd (#13-16) have predicted increases of less than 3dB. While statistically significant, this change is rather small compared to the base case value and is probably not of practical utility. Overall, some of the sites differ from the base case by approximately –1.5dB to 2.9dB. These changes again may not have any practical significance since the important concept is not so much the magnitude of the response, but rather its stability when subject to environmental stress conditions, which is the basis for the acceptance criteria.

The predicted response at Pre-test for HF TLC 50MHz for the base case (HASL processed with LR flux) based on the Surface Finish & Flux GLM was -46.73dB, which is almost identical to that for the Site & Flux GLM. The predicted differences from the base case are given in Appendix F in Table F.22. These predictions are consistent with those in Table F.21 and show that immersion Sn and immersion Ag are approximately 1.0dB lower than the base case and Ni/Au and Ni/Pd/Au are approximately 1 to 2 dB higher than the base case. Again, these differences are most likely not of practical utility.

Boxplot Displays of Multiple Comparison Results

HF TLC 50MHz. A boxplot display of the Post MS test results is given in Figure 4.16. Boxplots for the other three test times are displayed in Figures F.28 to F.30.

HF TLC 500MHz. A boxplot display of the Post MS test results is given in Figure 4.17. Boxplots for the other three test times are displayed in Figures F.31 to F.33.

HF TLC 1GHz. Boxplots displays for are not given for the HF TLC 1GHz test results to conserve space. The total variation at Pre-test for HF TLC 1GHz was only 2dB and there was only one slight anomaly of -5dB at Post MS, which is not of concern.

HF TLC RNR. A boxplot display of the Post MS test results is given in Figure 4.18. Boxplots for the other three test times are displayed in Figures F.34 to F.36.

Table F.16 Significant Coefficients for the Two GLM Analyses by Test Time for HF TLC 50 MHz Forward

GLM from Eq. F.1: Sites and Interactions with Flux

Experimental Factor	Pre-Test	85/85 (Delta 1)	Thermal Shock (Delta 2)	Mech Shock (Delta 3)
Constant	-47.43	0.22	-0.08	0.04
Flux				
Site 2				
Site 3	0.98			4.40
Site 4				
Site 5	1.19			
Site 6	1.48			
Site 7	-1.51			
Site 8				
Site 9				
Site 10	0.90			
Site 11				3.20
Site 12	-1.40			7.60
Site 13	2.90	-1.17		
Site 14	2.69			
Site 15	2.05			
Site 16	2.19			
Site 4 * Flux		0.96		
Site 5 * Flux	-1.37			
Site 7 * Flux				
Site 11 * Flux				
Site 13 * Flux		1.41		
Site 16 * Flux	-1.50			
Model R^2	62.3%	6.7%	0.0%	14.7%
Standard Deviation	1.00	1.0	1.01	4.80

GLM from Eq. F.2: Surface Finishes and Flux

Experimental Factor	Pre-Test	85/85 (Delta 1)	Thermal Shock (Delta 2)	Mech Shock (Delta 3)
Constant	-46.73	0.09	-0.30	0.29
OSP				
Immersion Sn	-0.71			
Immersion Ag	-0.97			4.7
Ni/Au	2.24	-0.45		
Ni/Pd/Au	1.19			
Flux	-0.59	0.48	0.45	
Model R^2	48.1%	6.6%	5.0%	9.1%
Standard Deviation	1.00	1.00	0.99	4.9

Table F.17 Significant Coefficients for the Two GLM Analyses by Test Time for HF TLC 500 MHz Forward

GLM from Eq. F.1: Sites and Interactions with Flux

Experimental Factor	Pre-Test	85/85 (Delta 1)	Thermal Shock (Delta 2)	Mech Shock (Delta 3)
Constant	-17.48	0.06	-0.23	-0.14
Flux				
Site 2				
Site 3	0.64			
Site 4				-1.32
Site 5	0.45			
Site 6	0.53			
Site 7				
Site 8				
Site 9				
Site 10	0.56			
Site 11				
Site 12				-0.85
Site 13		-1.13		
Site 14				
Site 15				
Site 16				
Site 4 * Flux				1.50
Site 5 * Flux				
Site 7 * Flux				
Site 11 * Flux				
Site 13 * Flux		1.35		
Site 16 * Flux				
Model R^2	10.7%	8.1%	0.0%	8.1%
Standard Deviation	0.66	0.62	0.60	0.93

GLM from Eq. F.2: Surface Finishes and Flux

Experimental Factor	Pre-Test	85/85 (Delta 1)	Thermal Shock (Delta 2)	Mech Shock (Delta 3)
Constant	-17.41	0.02	-0.28	-0.09
OSP	0.27			
Immersion Sn			0.20	
Immersion Ag				
Ni/Au				
Ni/Pd/Au		0.23		
Flux				-0.22
Model R^2	2.5%	0.9%	1.8%	1.4%
Standard Deviation	0.60	0.60	0.59	0.96

Table F.18 Significant Coefficients for the Two GLM Analyses by Test Time for HF TLC 1 GHz Forward

GLM from Eq. F.1: Sites and Interactions with Flux

Experimental Factor	Pre-Test	85/85 (Delta 1)	Thermal Shock (Delta 2)	Mech Shock (Delta 3)
Constant	-14.11	0.11	-0.39	-0.22
Flux	-0.16			
Site 2	-0.30			
Site 3	0.37			
Site 4				
Site 5	0.21			
Site 6				
Site 7				-1.26
Site 8				
Site 9				
Site 10	0.46			
Site 11			-0.51	
Site 12				
Site 13		-0.46		
Site 14				
Site 15		-0.35		
Site 16				
Site 4 * Flux				
Site 5 * Flux				
Site 7 * Flux				1.00
Site 11 * Flux				
Site 13 * Flux		0.59		
Site 16 * Flux				
Model R^2	13.2%	10.9%	6.1%	7.9%
Standard Deviation	0.37	0.31	0.52	0.69

GLM from Eq. F.2: Surface Finishes and Flux

Experimental Factor	Pre-Test	85/85 (Delta 1)	Thermal Shock (Delta 2)	Mech Shock (Delta 3)
Constant	-14.16	0.11	-0.38	-0.30
OSP	0.09			0.14
Immersion Sn				
Immersion Ag			-0.33	
Ni/Au		-0.15		
Ni/Pd/Au				
Flux				
Model R^2	0.9%	2.8%	4.1%	0.7%
Standard Deviation	0.30	0.30	0.52	0.71

Table F.19 Significant Coefficients for the Two GLM Analyses by Test Time for HF TLC Rev Null Freq

GLM from Eq. F.1: Sites and Interactions with Flux

Experimental Factor	Pre-Test	85/85 (Delta 1)	Thermal Shock (Delta 2)	Mech Shock (Delta 3)
Constant				
Flux				
Site 2				
Site 3				
Site 4				
Site 5				
Site 6				
Site 7				
Site 8				
Site 9				
Site 10				
Site 11				
Site 12				
Site 13				
Site 14				
Site 15				
Site 16				
Site 4 * Flux				
Site 5 * Flux				
Site 7 * Flux				
Site 11 * Flux				
Site 13 * Flux				
Site 16 * Flux				
Model R^2				
Standard Deviation				

GLM from Eq. F.2: Surface Finishes and Flux

Experimental Factor	Pre-Test	85/85 (Delta 1)	Thermal Shock (Delta 2)	Mech Shock (Delta 3)
Constant				
OSP				
Immersion Sn				
Immersion Ag				
Ni/Au				
Ni/Pd/Au				
Flux				
Model R^2				
Standard Deviation				

Table F.20 Significant Coefficients for the Two GLM Analyses by Test Time for HF TLC Rev Null Resp

GLM from Eq. F.1: Sites and Interactions with Flux

Experimental Factor	**Pre-Test**	**85/85 (Delta 1)**	**Thermal Shock (Delta 2)**	**Mech Shock (Delta 3)**
Constant	-33.90	0.20	-0.05	0.02
Flux				
Site 2				
Site 3				
Site 4				
Site 5	1.13			
Site 6				
Site 7				
Site 8				
Site 9				
Site 10				
Site 11				-3.50
Site 12			-1.60	
Site 13		-3.23		
Site 14				
Site 15				
Site 16				
Site 4 * Flux				
Site 5 * Flux	-1.25			
Site 7 * Flux				
Site 11 * Flux				
Site 13 * Flux		3.60		
Site 16 * Flux				
Model R^2	2.7%	8.2%	2.4%	6.2%
Standard Deviation	1.40	1.70	2.20	3.56

GLM from Eq. F.2: Surface Finishes and Flux

Experimental Factor	**Pre-Test**	**85/85 (Delta 1)**	**Thermal Shock (Delta 2)**	**Mech Shock (Delta 3)**
Constant	-33.70	0.07	0.03	-0.74
OSP				
Immersion Sn	-0.68	0.34		
Immersion Ag			-1.26	
Ni/Au				
Ni/Pd/Au				
Flux				1.03
Model R^2	3.6%	0.6%	3.5%	2.0%
Standard Deviation	1.00	1.00	2.1	3.6

Table F.21 Predicted Changes from the Base Case at Pre-test for HF TLC 50MHz for the GLM in Equation F.1

	LR Flux	WS Flux
Site 2		
Site 3	0.98	0.98
Site 4		
Site 5	1.19	-0.18
Site 6	1.48	1.48
Site 7	-1.51	-1.51
Site 8		
Site 9		
Site 10	0.90	0.90
Site 11		
Site 12	-1.40	-1.40
Site 13	2.90	2.90
Site 14	2.69	2.69
Site 15	2.05	2.05
Site 16	2.19	0.69

Table F.22 Predicted Changes from the Base Case at Pre-test for HF TLC 50MHz for the GLM in Equation F.2

	LR Flux	WS Flux
OSP		-0.59
Immersion Sn	-0.71	-1.30
Immersion Ag	-0.97	-1.56
Ni/Au	2.24	1.65
Ni/Pd/Au	1.19	0.60

F.8 Leakage Measurements

The results of the GLM analyses are given in Tables F.23 to F.26. Columns 3 to 5 in these tables give the GLM results for 85/85, TS, and MS, respectively. The model R^2s for Equations F.1 and F.2 for the GLM analyses of the leakage measurements are summarized as follows.

GLM	Circuit	Pre-test	85/85	TS	MS
Site and Flux	10-Mil Pads	85.6%	22.7%	10.8%	8.6%
	PGA-A	88.4%	3.9%	9.7%	9.0%
	PGA-B	89.4%	5.6%	15.5%	12.5%
	Gull Wing	55.4%	3.3%	2.8%	1.7%
Surface Finish and Flux	10-Mil Pads	74.8%	1.9%	3.4%	1.7%
	PGA-A	81.3%	2.0%	9.7%	6.3%
	PGA-B	88.7%	5.6%	16.0%	6.7%
	Gull Wing	48.2%	1.9%	2.8%	2.6%

It is of interest to note that the model R^2 values at Pre-test for all but the Gull Wing are all quite large. However, these values decrease to close to zero after exposure to the 85/85 environment. These results are now examined in detail for each of the four leakage circuits.

Tables F.27 and F.28 give the predicted changes from their respective base cases for all leakage measurements at Pre-test for the GLMs in Equations F.1 and F.2, respectively.

Table F.23 Significant Coefficients for the Two GLM Analyses by Test Time for 10-Mil Pads

GLM from Eq. F.1: Sites and Interactions with Flux

Experimental Factor	Pre-Test	85/85	Thermal Shock	Mech Shock
Constant	12.20	13.29	14.45	14.76
Flux	0.74			
Site 2	-0.97			
Site 3	1.02			
Site 4	0.93			
Site 5	0.85			
Site 6				
Site 7				
Site 8				
Site 9		-1.24	-0.95	-0.84
Site 10	1.00			
Site 11				
Site 12	0.91			
Site 13	-0.89	0.23		
Site 14	-0.75			
Site 15	0.98		0.55	
Site 16	-0.76			
Site 4 * Flux				
Site 5 * Flux				
Site 7 * Flux	0.85			
Site 11 * Flux	1.06			
Site 13 * Flux	1.95			
Site 16 * Flux	1.74			
Model R^2	85.6%	22.7%	10.8%	8.6%
Standard Deviation	0.42	0.51	0.70	0.59

GLM from Eq. F.2: Surface Finishes and Flux

Experimental Factor	Pre-Test	85/85	Thermal Shock	Mech Shock
Constant	11.75	13.21	14.30	14.69
OSP	0.73			
Immersion Sn	0.33			
Immersion Ag	0.48			
Ni/Au		0.21		
Ni/Pd/Au				0.31
Flux	1.77		0.27	
Model R^2	74.8%	1.9%	3.4%	1.7%
Standard Deviation	0.50	0.50	0.72	0.61

Table F.24 Significant Coefficients for the Two GLM Analyses by Test Time for PGA-A

GLM from Eq. F.1: Sites and Interactions with Flux

Experimental Factor	Pre-Test	85/85	Thermal Shock	Mech Shock
Constant	11.88	12.50	13.66	13.69
Flux	1.58		0.348	0.22
Site 2	-1.19			
Site 3				
Site 4				-0.54
Site 5				
Site 6				
Site 7				
Site 8				
Site 9	-0.81			
Site 10				
Site 11	-0.34			
Site 12				
Site 13	-0.64			
Site 14	-0.94			
Site 15				
Site 16	-1.14			
Site 4 * Flux		-0.50		0.63
Site 5 * Flux				
Site 7 * Flux				
Site 11 * Flux		-0.64		
Site 13 * Flux	0.91			
Site 16 * Flux	1.34			
Model R^2	88.4%	3.9%	9.7%	9.0%
Standard Deviation	0.40	0.71	0.52	0.49

GLM from Eq. F.2: Surface Finishes and Flux

Experimental Factor	Pre-Test	85/85	Thermal Shock	Mech Shock
Constant	11.38	12.41	13.66	13.66
OSP	0.35			
Immersion Sn		0.25		
Immersion Ag				
Ni/Au				
Ni/Pd/Au	-0.35			
Flux	2.05		0.34	0.256
Model R^2	81.3%	2.0%	9.7%	6.3%
Standard Deviation	0.5	0.70	0.51	0.49

Table F.25 Significant Coefficients for the Two GLM Analyses by Test Time for PGA-B

GLM from Eq. F.1: Sites and Interactions with Flux

Experimental Factor	Pre-Test	85/85	Thermal Shock	Mech Shock
Constant	10.71	12.52	13.69	13.83
Flux	2.77		0.40	
Site 2				-0.49
Site 3				
Site 4				
Site 5			-0.44	-0.63
Site 6		-0.41		-0.42
Site 7				
Site 8	0.57			
Site 9				
Site 10				
Site 11				
Site 12				
Site 13				
Site 14				
Site 15				
Site 16	-0.34	-0.61		
Site 4 * Flux				
Site 5 * Flux				0.69
Site 7 * Flux				
Site 11 * Flux				
Site 13 * Flux				
Site 16 * Flux		0.72		
Model R^2	89.4%	8.0%	15.5%	12.5%
Standard Deviation	0.47	0.53	0.56	0.50

GLM from Eq. F.2: Surface Finishes and Flux

Experimental Factor	Pre-Test	85/85	Thermal Shock	Mech Shock
Constant	10.77	12.55	13.72	13.70
OSP		-0.23	-0.33	-0.21
Immersion Sn				
Immersion Ag				
Ni/Au				
Ni/Pd/Au	-0.38	-0.40		
Flux	2.71		0.39	0.20
Model R^2	88.7%	5.6%	16.0%	6.7%
Standard Deviation	0.4	0.50	0.56	0.51

Table F.26 Significant Coefficients for the Two GLM Analyses by Test Time for the Gull Wing

GLM from Eq. F.1: Sites and Interactions with Flux

Experimental Factor	**Pre-Test**	**85/85**	**Thermal Shock**	**Mech Shock**
Constant	11.72	12.59	13.76	13.32
Flux	0.81		-0.37	
Site 2				
Site 3				
Site 4				
Site 5	0.37			
Site 6				
Site 7				
Site 8				-0.64
Site 9				
Site 10	0.47			
Site 11	-0.65			
Site 12	0.54			
Site 13				
Site 14				
Site 15		0.67		
Site 16		0.66		
Site 4 * Flux				
Site 5 * Flux				
Site 7 * Flux	0.47			
Site 11 * Flux	1.61			
Site 13 * Flux				
Site 16 * Flux				
Model R^2	55.4%	3.3%	2.8%	1.7%
Standard Deviation	0.54	1.1	1.10	1.06

GLM from Eq. F.2: Surface Finishes and Flux

Experimental Factor	**Pre-Test**	**85/85**	**Thermal Shock**	**Mech Shock**
Constant	11.55	12.62	13.76	13.22
OSP	0.30			
Immersion Sn	0.27			
Immersion Ag				
Ni/Au				0.46
Ni/Pd/Au		0.63		
Flux	1.09		-0.37	
Model R^2	48.2%	1.9%	2.8%	2.6%
Standard Deviation	0.50	1.00	1.10	1.0

Table F.27 Predicted Changes from the Base Case at Pre-test for the Leakage Measurements for the GLM in Equation F.1

	10-Mil Pads		PGA-A		PGA-B		Gull Wing	
	LR Flux	WS Flux	LR Flux	WS Flux	LR Flux	WS Flux	LR Flux	WS Flux
Site 2	-0.97	-0.23	-1.19	0.39		2.77		0.81
Site 3	1.02	1.76		1.58		2.77		0.81
Site 4	0.93	1.67		1.58		2.77		0.81
Site 5	0.85	1.59		1.58		2.77	0.37	1.18
Site 6		0.74		1.58		2.77		0.81
Site 7		1.59		1.58		2.77		1.28
Site 8		0.74		1.58	0.57	3.34		0.81
Site 9		0.74	-0.81	0.77		2.77		0.81
Site 10		1.74		1.58		2.77	0.47	1.28
Site 11		1.80	-0.34	1.24		2.77	-0.65	1.77
Site 12	0.91	1.65		1.58		2.77	0.54	1.35
Site 13	-0.89	1.80	-0.64	1.85		2.77		0.81
Site 14	-0.75	-0.01	-0.94	0.64		2.77		0.81
Site 15	0.98	1.72		1.58		2.77		0.81
Site 16	-0.76	1.72	-1.14	1.78	-0.34	2.43		0.81

Table F.28 Predicted Changes from the Base Case at Pre-test for the Leakage Measurements for the GLM in Equation F.2

	10-Mil Pads		PGA-A		PGA-B		Gull Wing	
	LR Flux	WS Flux	LR Flux	WS Flux	LR Flux	WS Flux	LR Flux	WS Flux
OSP	0.73	2.50	0.35	2.40		2.71	0.30	1.39
Imm Sn	0.33	2.10		2.05		2.71	0.27	1.36
Imm Ag	0.48	2.25		2.05		2.71		1.09
Ni/Au		1.77		2.05		2.71		1.09
Ni/Pd/Au		1.77	-0.35	1.70	-0.38	2.33		1.09

10-Mil Pads

Examination of the GLM results in Table F.27 for 10-mil pads shows an effect due to flux of approximately 0.74 orders of magnitude (see column 1 in uppermost portion of Table F.23). There is also evidence of site-to-site variation and some interaction between site and flux that affects resistance either positively or negatively by up to an order of magnitude. Sites applying the OSP surface finish (Sites 6, 7, 8, and 9) as will as Sites 10 and 11 with immersion Sn do not differ from the base case when LR flux is used.

Table F.28 shows a flux effect of approximately 1.77 orders of magnitude when sites are dropped from the GLM and replaced by surface finishes. These results show slight increases in resistance over the base case for OSP, immersion Sn, and immersion Ag.

The differences in the model R^2s for both GLMS essentially disappear after exposure to the 85/85 test environment. This result is not unusual and may be due to a *cleansing effect* from the 85/85 test environment that removes residues resulting from board fabrication, assembly, and handling. This same phenomenon was observed for the other three leakage circuits.

Boxplot Displays of Multiple Comparison Results. Boxplot displays of the Pre-test and Post 85/85 test results are given in Figure 4.19 and 4.20. Boxplots for the other test times are displayed in Figures F.37 and F.38. There are not great changes in the leakage measurements at Post TS and Post MS as shown in the boxplots.

PGA-A

Examination of the GLM results in Table F.27 for PGA-A shows an effect due to flux of approximately 1.58 orders of magnitude. There is also evidence of site-to-site variation and some interaction between site and flux that affects resistance either positively on negatively by up to an order of magnitude. Nine of the sites do not differ from the base case when LR flux is used.

Table F.28 shows a flux effect of approximately 2.05 orders of magnitude when sites are dropped from the GLM and replaced by surface finishes, but no meaningful differences due to surface finishes. As was the case with the 10-mil pads, the differences in the model R^2s for both GLMS essentially disappear after exposure to the 85/85 test environment.

Boxplot Displays of Multiple Comparison Results. A boxplot display of the Pre-test results is given in Figure 4.21. Boxplots for the other three test times are displayed in Figures F.39 to F.41.

PGA-B

Examination of the GLM results in Table F.27 for PGA-B shows a strong effect due to flux of approximately 2.77 orders of magnitude. Thirteen of the sites do not differ from the base case when LR flux is used and the other two only differ slightly. Table F.28 also shows a strong flux effect of approximately 2.71 orders of magnitude when sites are dropped from the GLM and replaced by surface finishes, but no meaningful differences due to surface finishes.

As was the case with the 10-mil pads and PGA-A, the differences in the model R^2s for both GLMS essentially disappear after exposure to the 85/85 test environment.

Boxplot Displays of Multiple Comparison Results. A boxplot display of the Pre-test results is given in Figure 4.22. Boxplots for the other three test times are displayed in Figures F.42 to F.44.

Gull Wing

Examination of the GLM results in Table F.27 for the Gull Wing shows a moderate effect due to flux of approximately 0.81 orders of magnitude. There is evidence of modest site-to-site variation and some interaction between site and flux. Eleven of the sites do not differ from the base case when LR flux is used and the other two only differ slightly. Table F.28 shows a flux effect of approximately 1.09 orders of magnitude when sites are dropped from the GLM and replaced by surface finishes, but no meaningful differences due to surface finishes.

As was the case with the 10-mil pads, PGA-A, and PGA-B the differences in the model R^2s for both GLMS essentially disappear after exposure to the 85/85 test environment.

Boxplot Displays of Multiple Comparison Results. A boxplot display of the Pre-test results is given in Figure 4.23. Boxplots for the other three test times are displayed in Figures F.45 to F.47.

F.9 Stranded Wires

Pre-test measurements for the stranded wire circuits were subjected to GLM analyses, as were the deltas after 85/85, thermal shock, and mechanical shock. The results of the GLM analyses are given in Tables F.29 and F.30. Columns 3 to 5 in these tables give the results for 85/85, TS, and MS, respectively. Note that these latter three analyses are based on changes from Pre-test measurements. The model R^2s for Equations F.1 and F.2 for the stranded wire circuitry are summarized as follows for each test time.

GLM	**Circuit**	**Pre-test**	**85/85**	**TS**	**MS**
Site and Flux	St. Wire 1	3.6%	6.5%	12.5%	11.7%
	St. Wire 2	8.6%	8.2%	8.2%	4.1%
Surface Finish and Flux	St. Wire 1	1.8%	1.6%	4.5%	2.1%
	St. Wire 2	0.8%	0.9%	7.4%	2.2%

The model R^2 values are all near zero at each test time, which indicates that the experimental parameters do not influence the stranded wire voltage measurements.

Boxplot Displays of Multiple Comparison Results. Boxplots displays of the Pre-test voltage measurements (mV) for both stranded wires are displayed in Figures F.48 and F.49.

Table F.29 Significant Coefficients for the Two GLM Analyses by Test Time for Stranded Wire

GLM from Eq. F.1: Sites and Interactions with Flux

Experimental Factor	Pre-Test	85/85 (Delta 1)	Thermal Shock (Delta 2)	Mech Shock (Delta 3)
Constant	12.90	0.000	0.001	0.005
Flux	0.55			
Site 2				
Site 3				
Site 4		-0.001		
Site 5		-0.001		
Site 6				
Site 7				
Site 8				
Site 9				
Site 10				
Site 11				
Site 12			0.024	0.042
Site 13				
Site 14				
Site 15				
Site 16				
Site 4 * Flux				
Site 5 * Flux		0.002		
Site 7 * Flux				
Site 11 * Flux				
Site 13 * Flux	-2.21			
Site 16 * Flux				0.079
Model R^2	3.6%	6.5%	12.5%	11.7%
Standard Deviation	2.57	0.002	0.014	0.041

GLM from Eq. F.2: Surface Finishes and Flux

Experimental Factor	Pre-Test	85/85 (Delta 1)	Thermal Shock (Delta 2)	Mech Shock (Delta 3)
Constant	12.94	0.000	0.001	0.006
OSP		-0.001		
Immersion Sn				
Immersion Ag	1.06		0.010	0.019
Ni/Au				
Ni/Pd/Au				
Flux				
Model R^2	1.8%	1.6%	4.5%	2.1%
Standard Deviation	2.00	0.001	0.014	0.043

Table F.30 Significant Coefficients for the Two GLM Analyses by Test Time for Stranded Wire 2

GLM from Eq. F.1: Sites and Interactions with Flux

Experimental Factor	Pre-Test	85/85 (Delta 1)	Thermal Shock (Delta 2)	Mech Shock (Delta 3)
Constant	23.44	-.000	0.011	0.033
Flux				
Site 2				
Site 3		0.003		
Site 4				
Site 5				
Site 6				
Site 7				
Site 8				
Site 9				
Site 10	-1.56			
Site 11				
Site 12			0.077	
Site 13				
Site 14				
Site 15				
Site 16				
Site 4 * Flux				
Site 5 * Flux	-2.31			
Site 7 * Flux				
Site 11 * Flux		-0.002	0.074	
Site 13 * Flux				
Site 16 * Flux				0.130
Model R^2	8.6%	8.2%	8.2%	4.1%
Standard Deviation	1.90	0.003	0.067	0.098

GLM from Eq. F.2: Surface Finishes and Flux

Experimental Factor	Pre-Test	85/85 (Delta 1)	Thermal Shock (Delta 2)	Mech Shock (Delta 3)
Constant	23.34	0.000	-0.001	0.021
OSP	-0.43			
Immersion Sn				
Immersion Ag		-0.001	0.038	
Ni/Au				
Ni/Pd/Au				
Flux			0.026	0.029
Model R^2	0.8%	0.9%	7.4%	2.2%
Standard Deviation	2.00	0.002	0.067	0.099

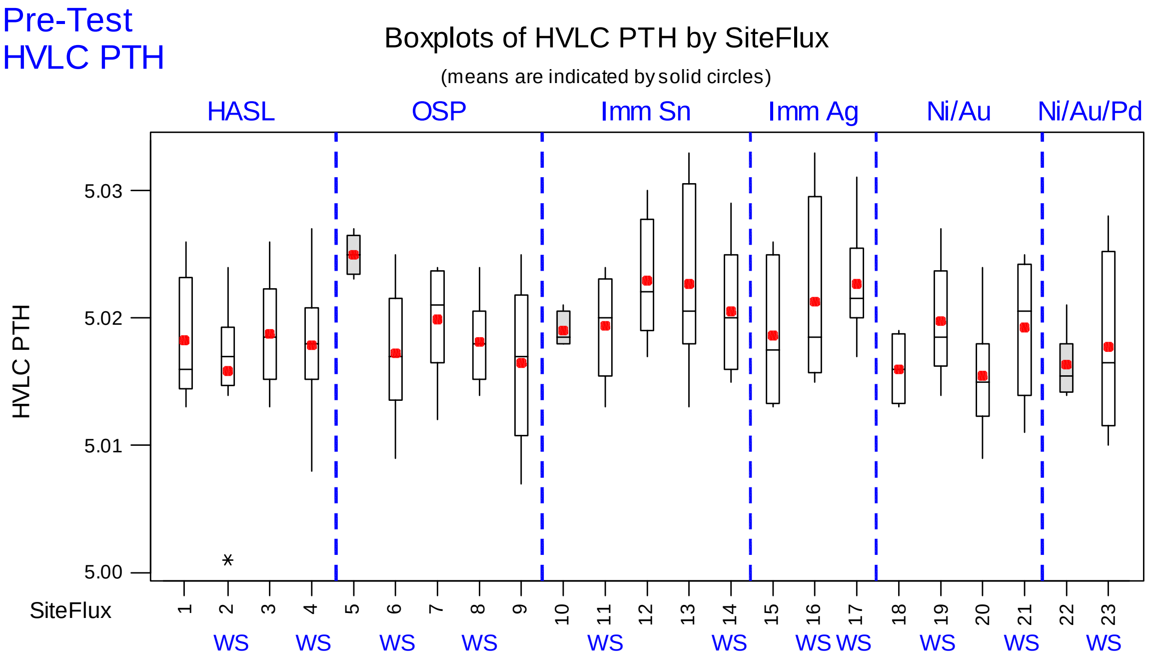

Figure F.1 Boxplot Displays for HVLC PTH Measurements (µA) at Pre-test by Surface Finish
(Acceptance Criterion = 4µA< X <6µA)

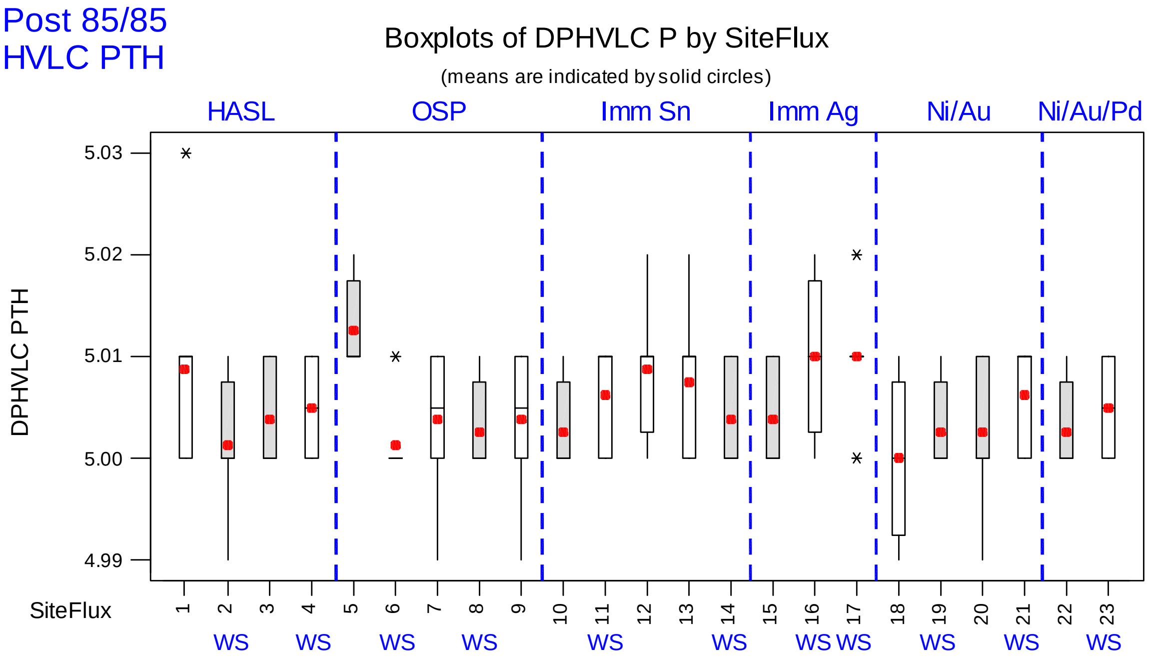

Figure F.2 Boxplot Displays for HVLC PTH Post 85/85 - Pre-test Measurements (µA) by Surface Finish
(Acceptance Criterion = 4µA< X <6µA)

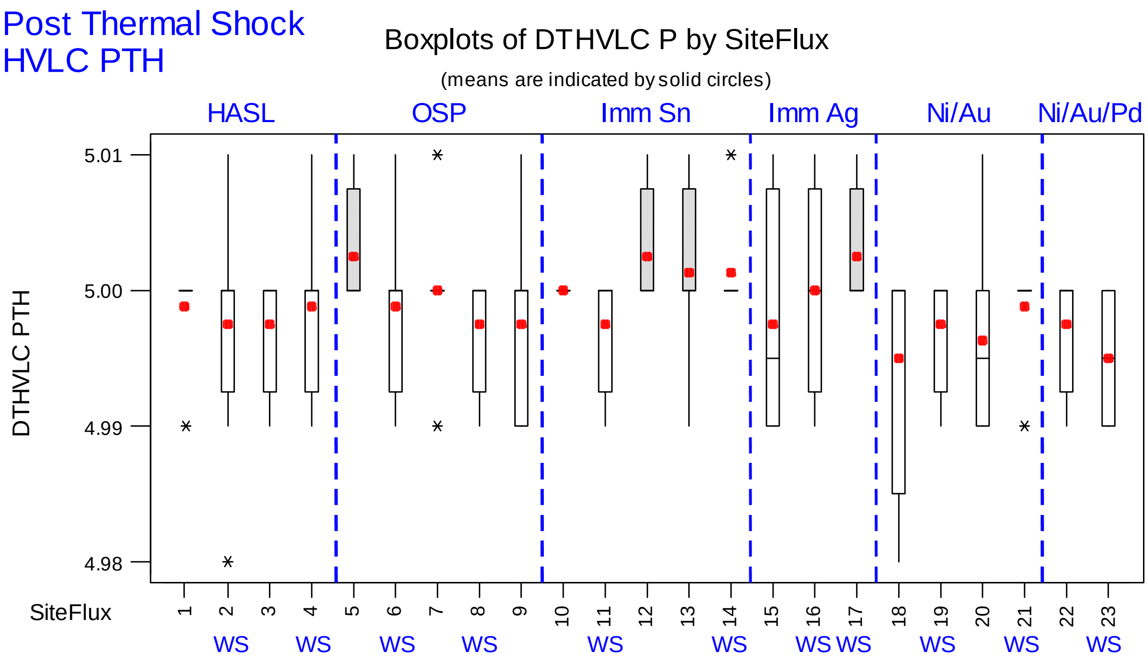

Figure F.3 Boxplot Displays for HVLC PTH Post TS - Pre-test Measurements (µA) by Surface Finish
(Acceptance Criterion = 4µA< X <6µA)

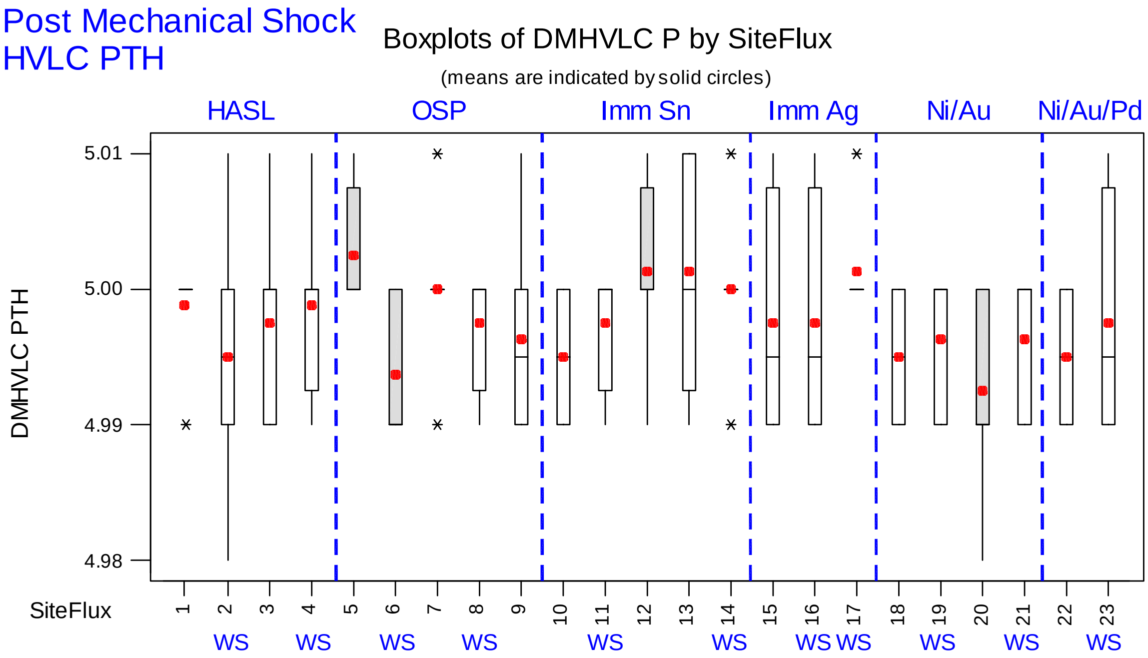

Figure F.4 Boxplot Displays for HVLC PTH Post MS - Pre-test Measurements (µA) by Surface Finish
(Acceptance Criterion = 4µA< X <6µA)

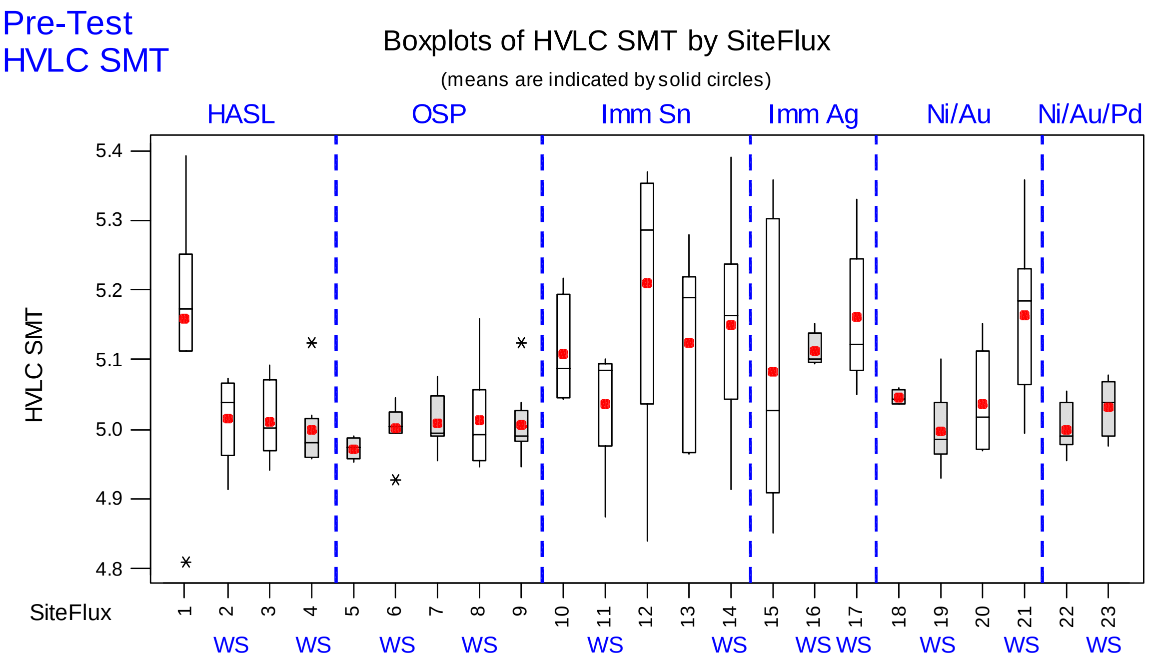

Figure F.5 Boxplot Displays for HVLC SMT Measurements (µA) at Pre-test by Surface Finish
(Acceptance Criterion = 4µA< X <6µA)

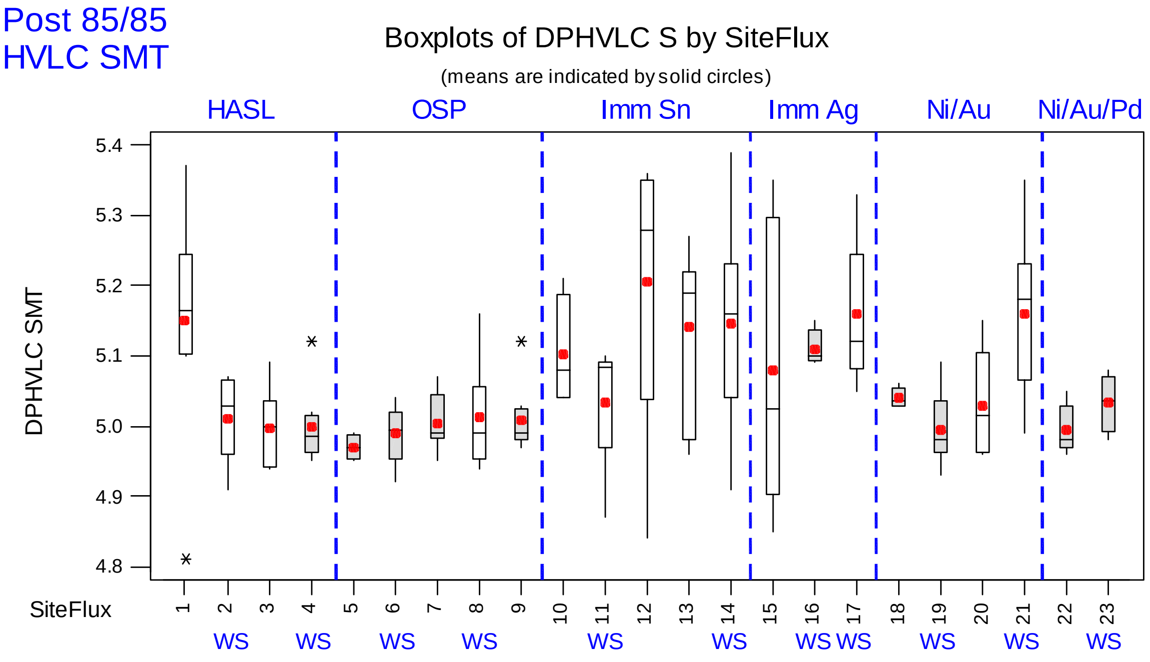

Figure F.6 Boxplot Displays for HVLC PTH Post 85/85 - Pre-test Measurements (µA) by Surface Finish
(Acceptance Criterion = 4µA< X <6µA)

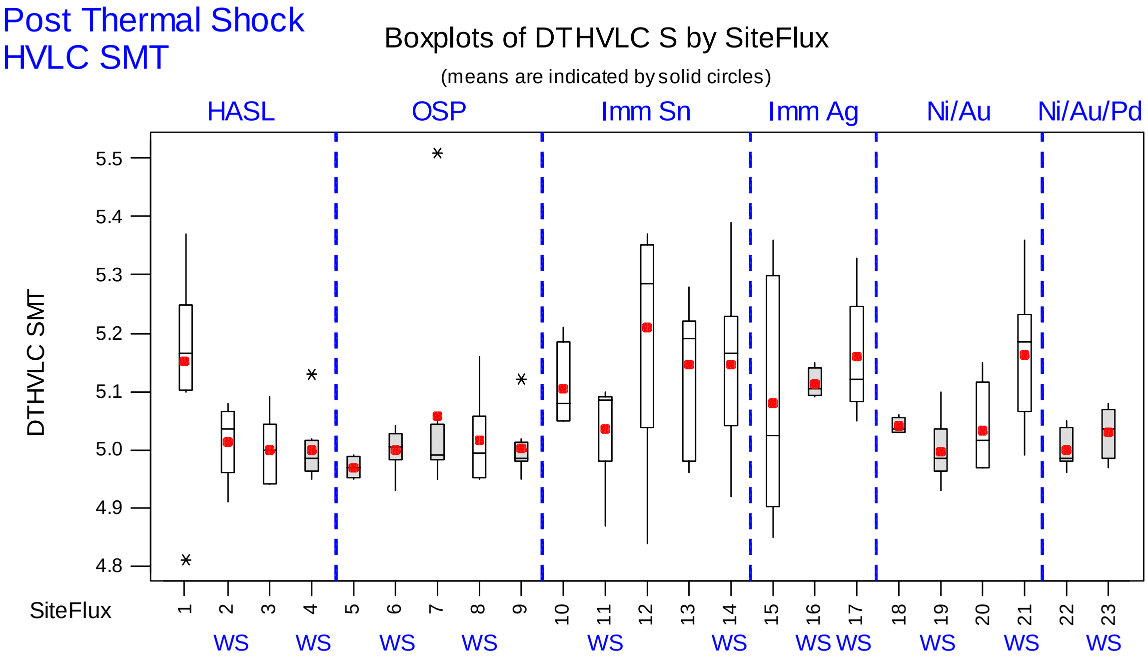

Figure F.7 Boxplot Displays for HVLC PTH Post TS - Pre-test Measurements (µA) by Surface Finish
(Acceptance Criterion = 4µA< X <6µA)

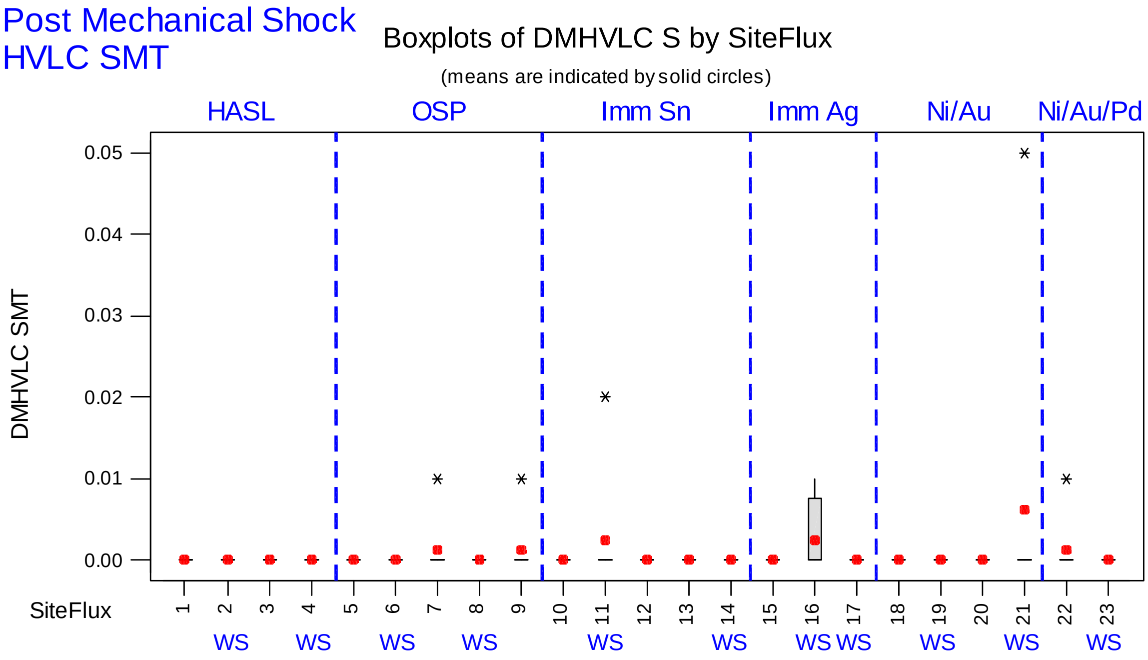

Figure F.8 Boxplot Displays for HVLC PTH Post MS - Pre-test Measurements by Surface Finish
(Acceptance Criterion = 4µA< X <6µA)

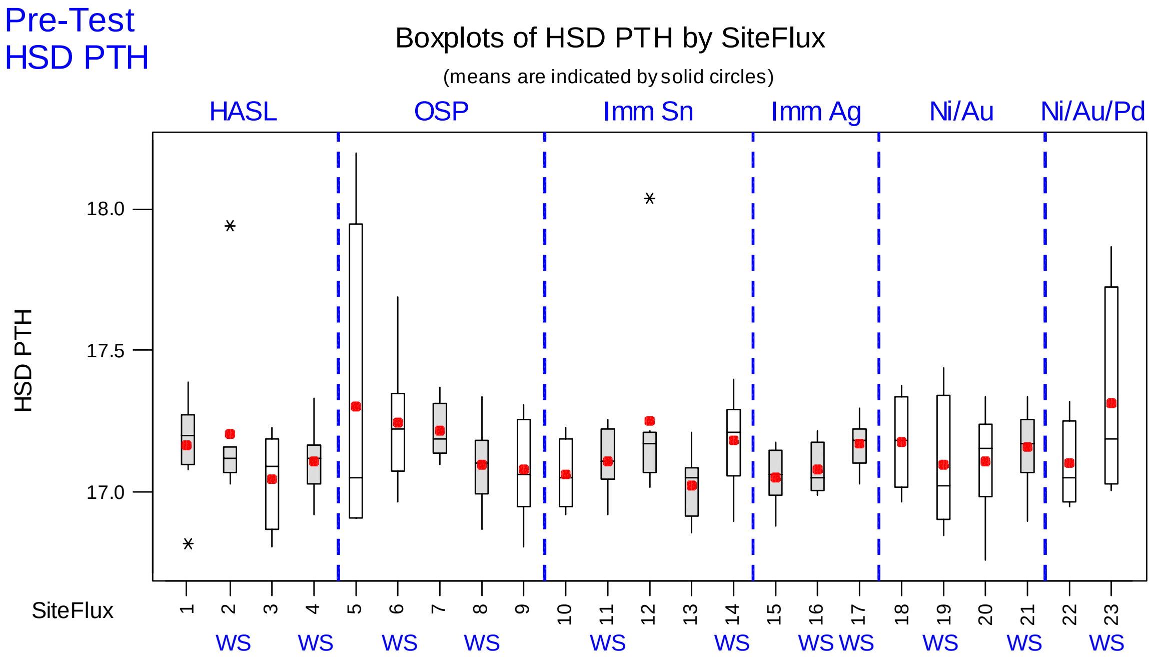

Figure F.9 Boxplot Displays for HSD PTH Measurements (nsec) at Pre-test by Surface Finish

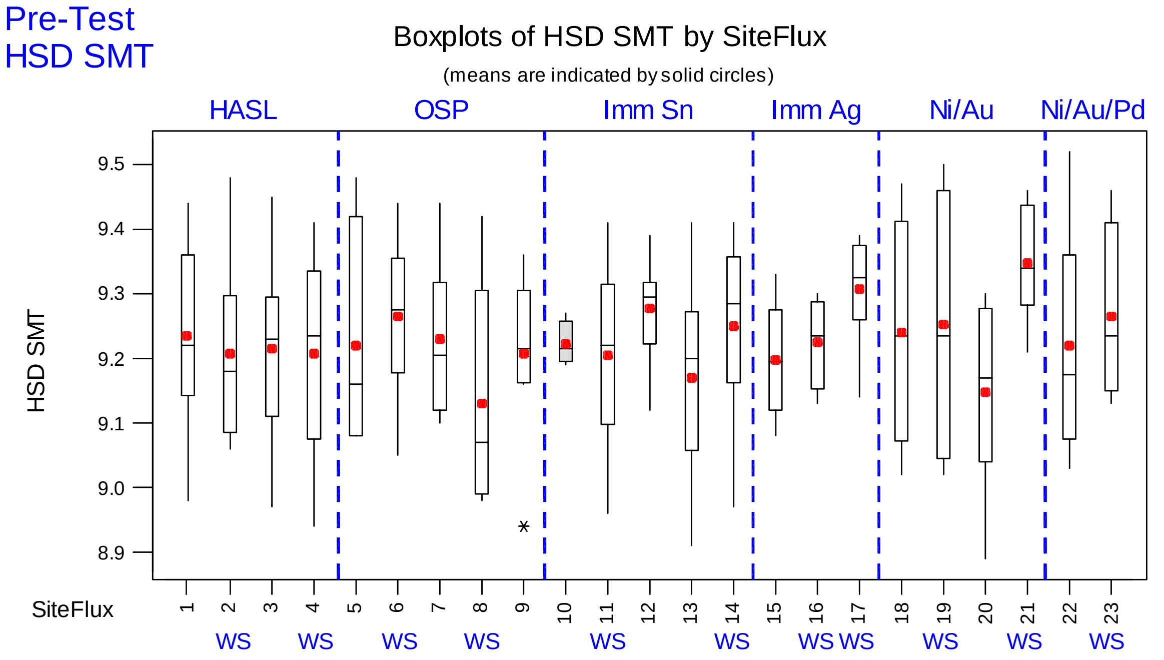

Figure F.10 Boxplot Displays for HSD SMT Measurements (nsec) at Pre-test by Surface Finish

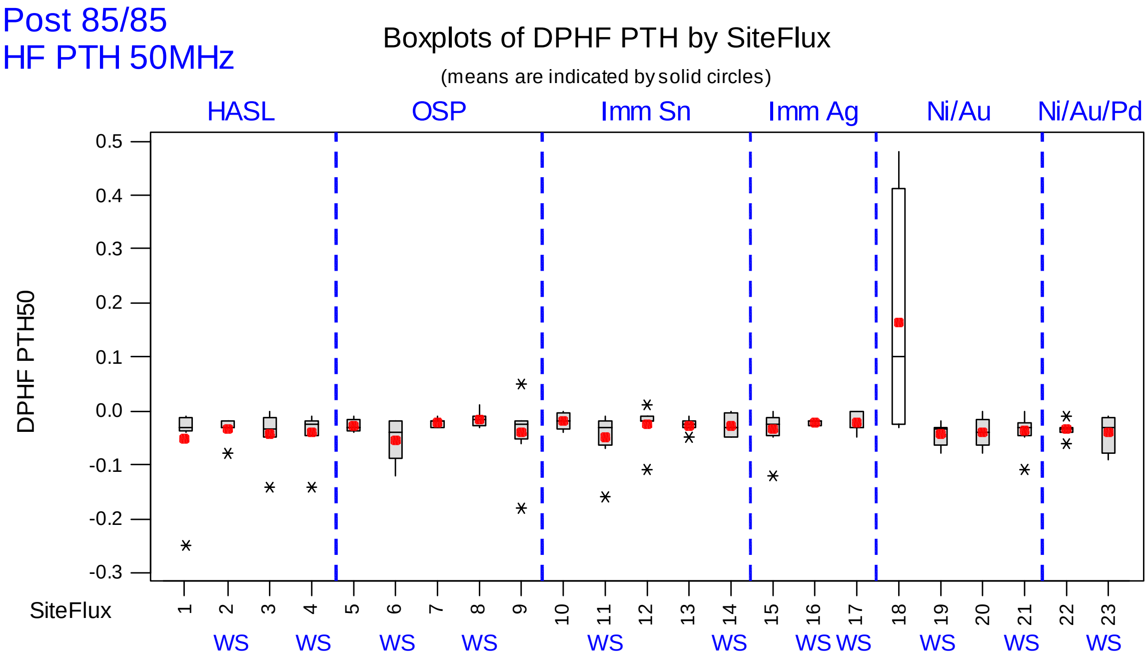

Figure F.11 Boxplot Displays for HF PTH 50MHz Post 85/85 - Pre-test Measurements (dB) by Surf. Finish
(Acceptance Criterion = ±5dB of Pre-test)

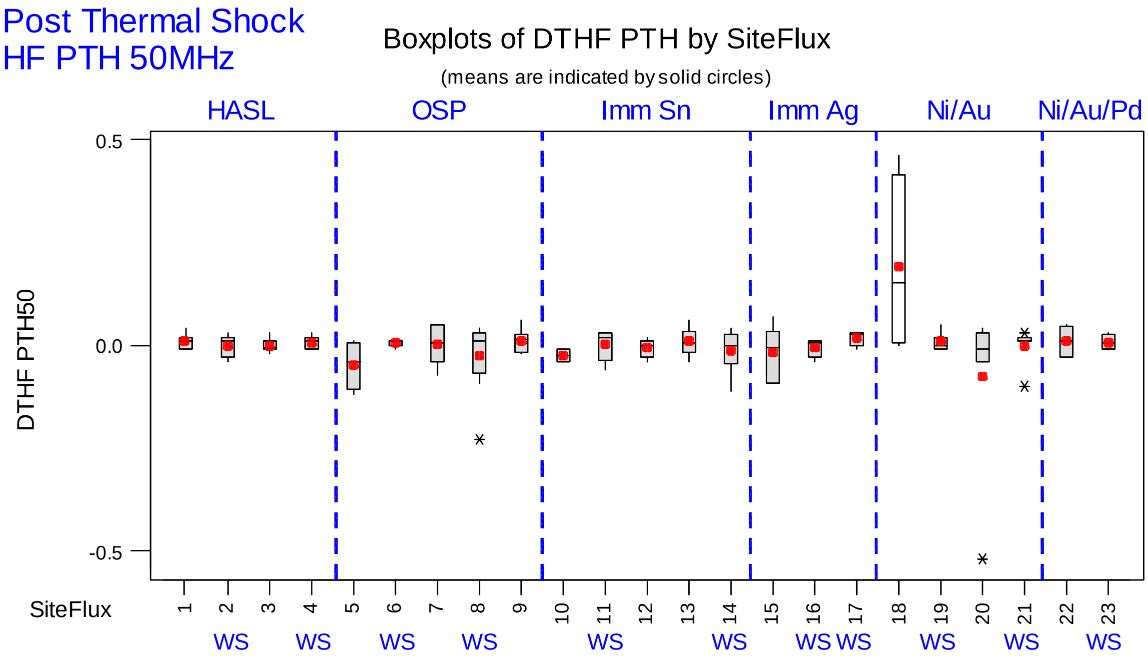

Figure F.12 Boxplot Displays for HF PTH 50MHz Post TS - Pre-test Measurements (dB) by Surface Finish
(Acceptance Criterion = ±5dB of Pre-test)

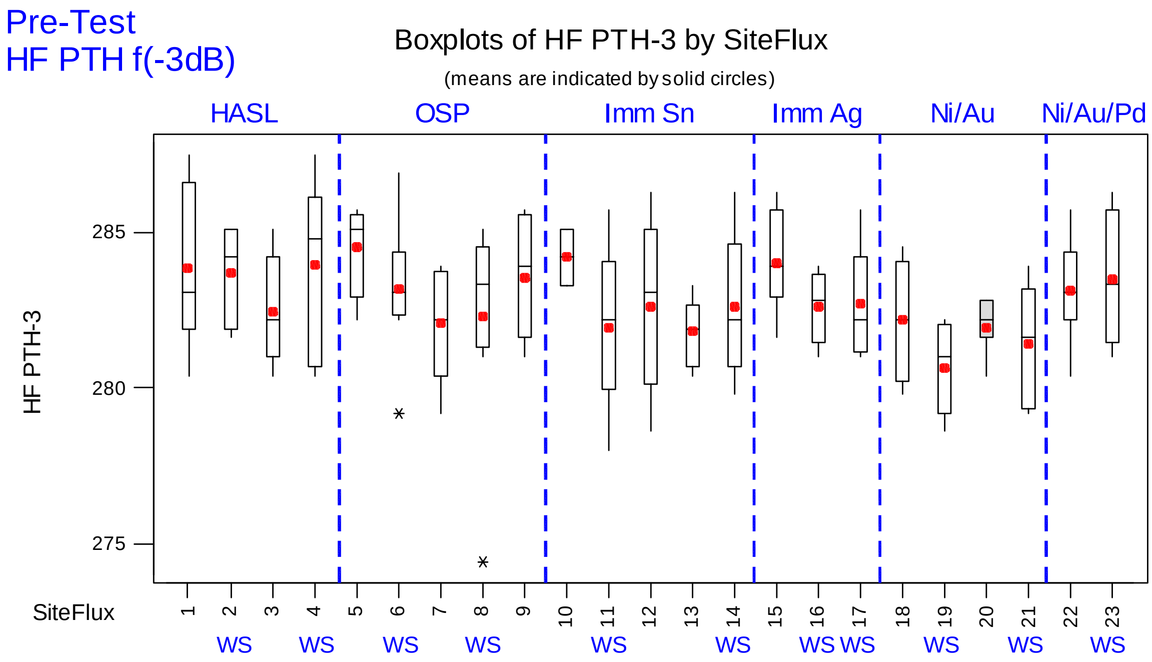

Figure F.13 Boxplot Displays for HF PTH f(-3dB) Measurements (MHz) at Pre-test by Surface Finish
(Acceptance Criterion = ±50Mhz of Pre-test)

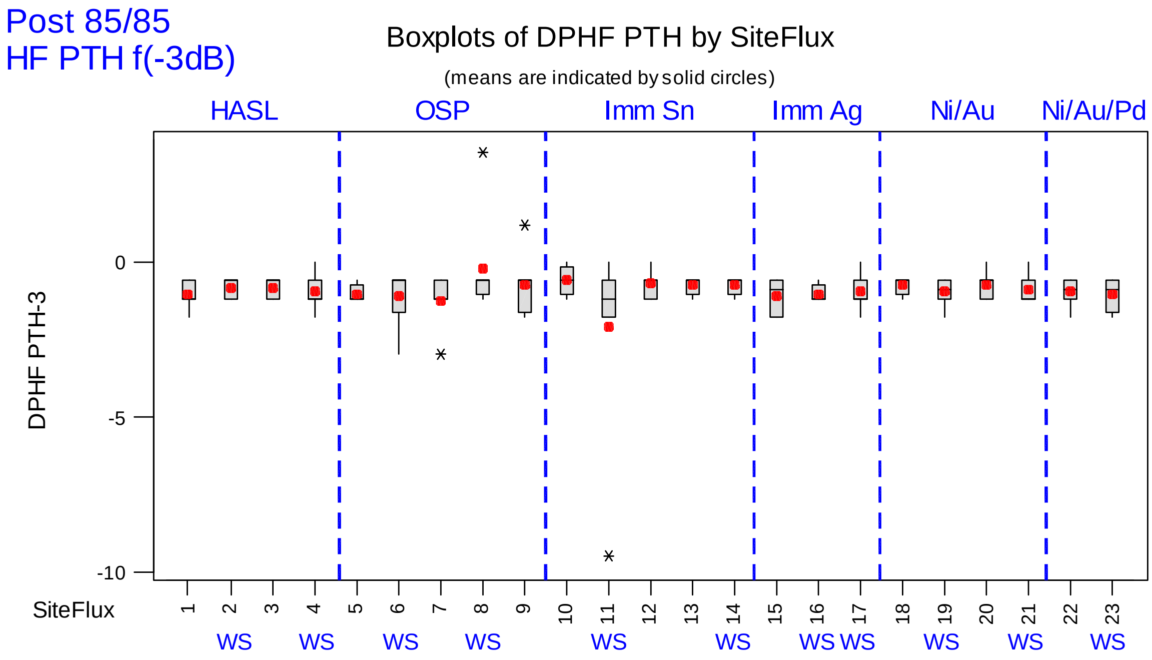

Figure F.14 Boxplot Displays for HF PTH f(-3dB) Post 85/85 - Pre-test Measurements (MHz) by Surf. Finish
(Acceptance Criterion = ±50Mhz of Pre-test)

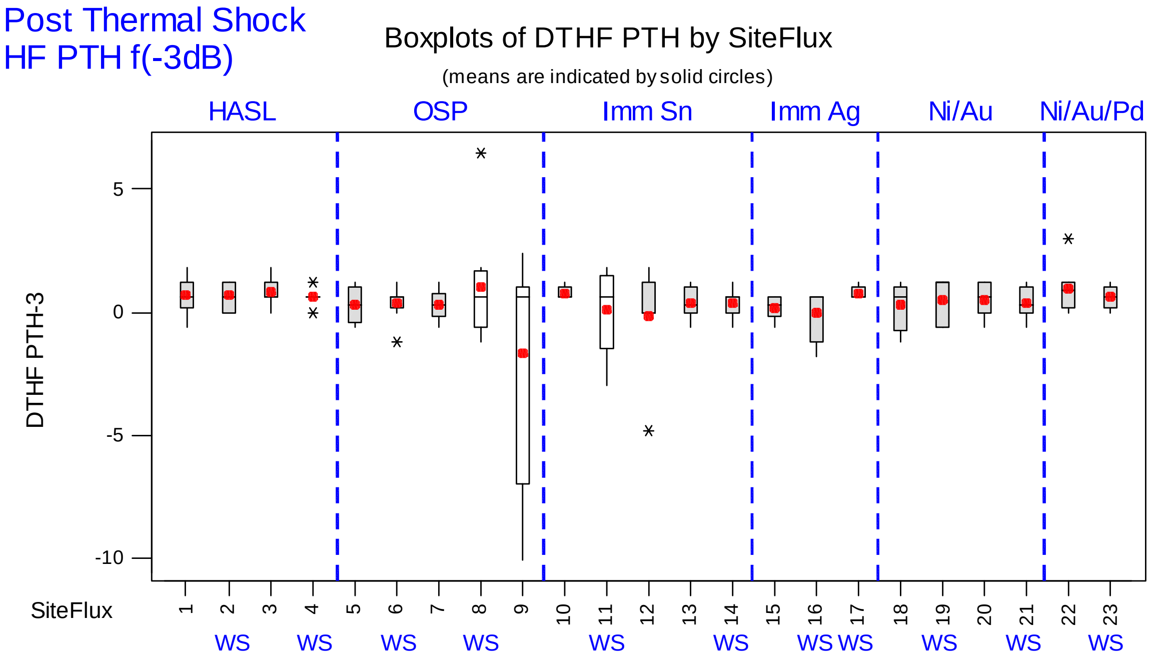

Figure F.15 Boxplot Displays for HF PTH f(-3dB) Post TS - Pre-test Measurements (Mhz) by Surface Finish
(Acceptance Criterion = ±50Mhz of Pre-test)

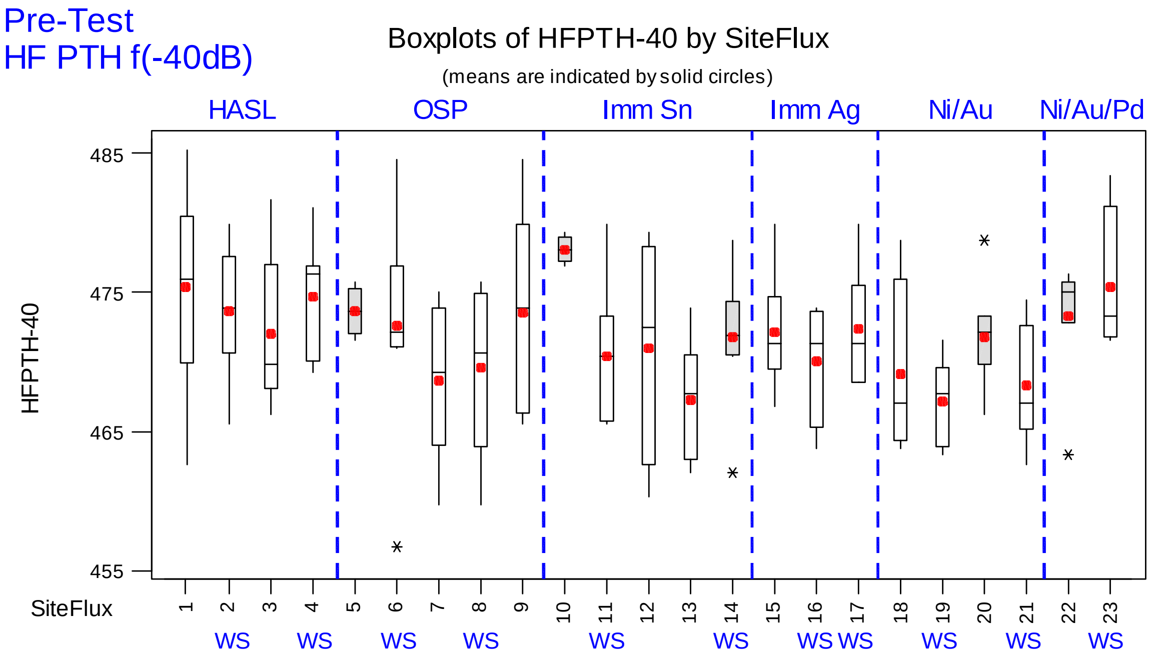

Figure F.16 Boxplot Displays for HF PTH f(-40dB) Measurements (MHz) at Pre-test by Surface Finish
(Acceptance Criterion = ±50Mhz of Pre-test)

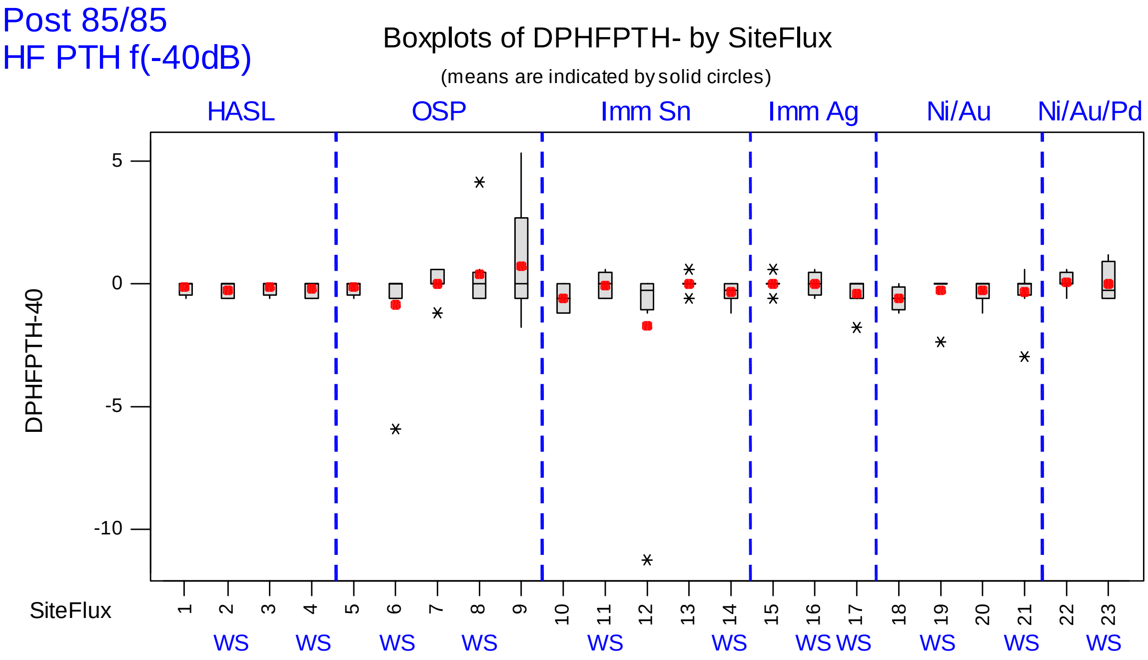

Figure F.17 Boxplot Displays for HF PTH f(-40dB) Post 85/85 - Pre-test Measurements (MHz) by Surf. Fin.
(Acceptance Criterion = ±50Mhz of Pre-test)

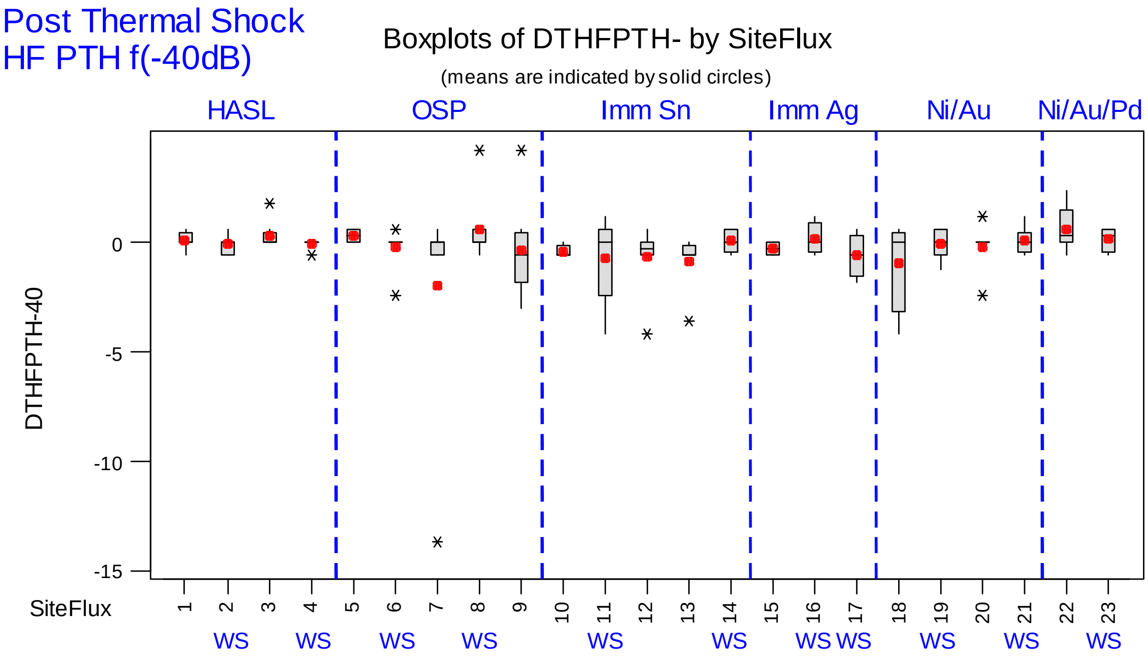

Figure F.18 Boxplot Displays for HF PTH f(-40dB) Post TS - Pre-test Measurements (MHz) by Surf. Finish
(Acceptance Criterion = ±50Mhz of Pre-test)

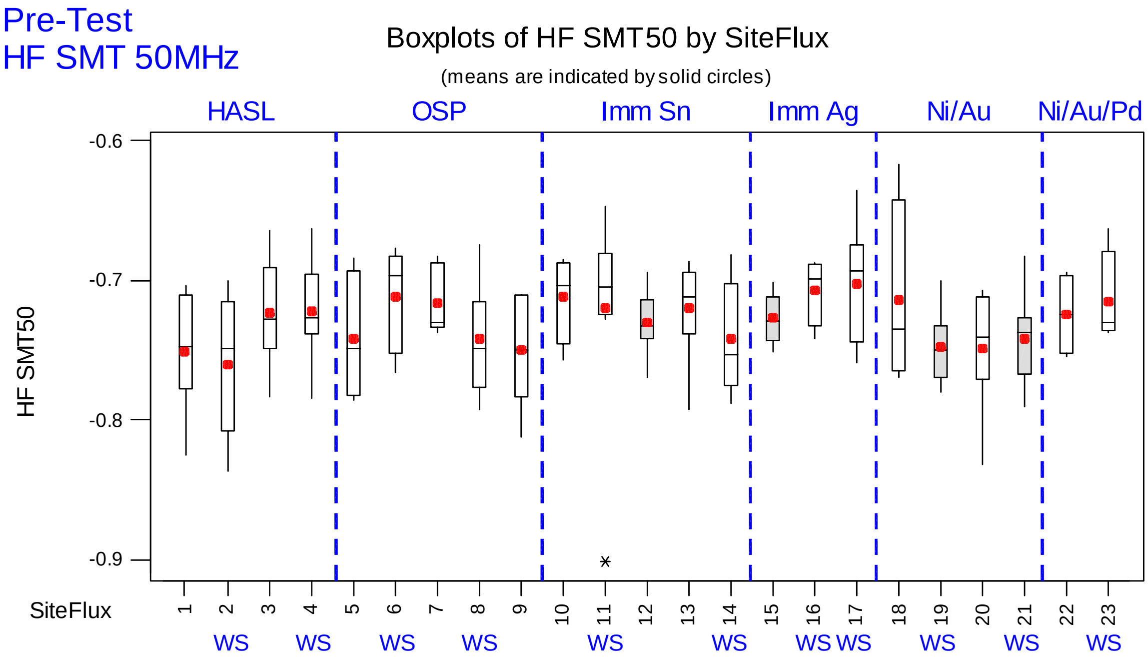

Figure F.19 Boxplot Displays for HF SMT 50MHz Measurements (dB) at Pre-test by Surface Finish

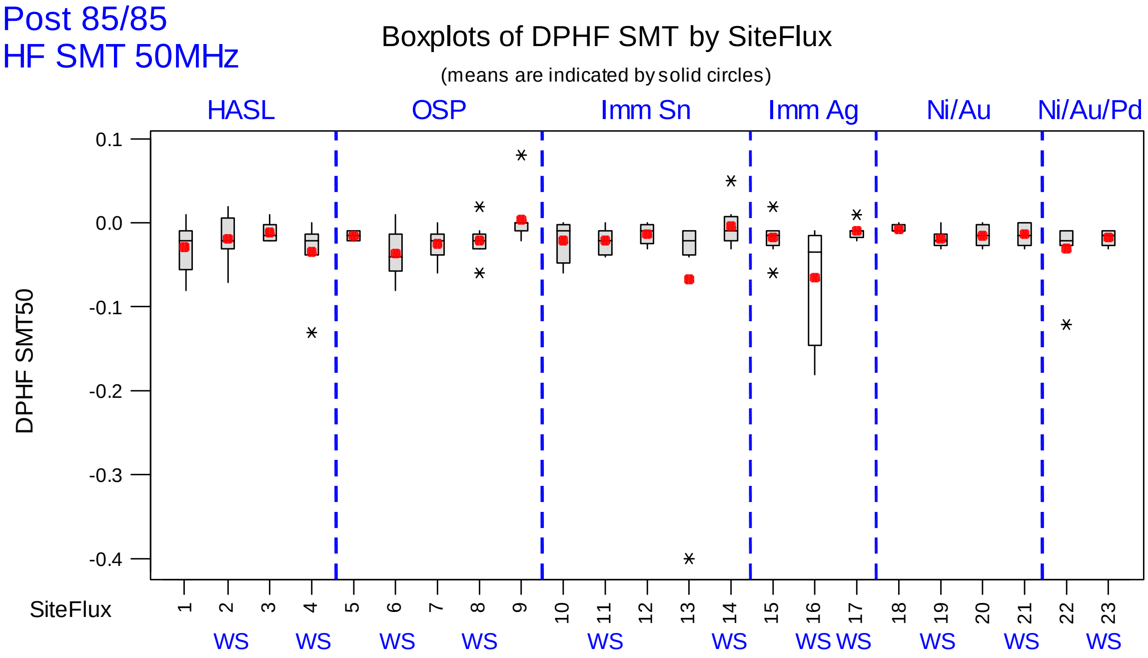

Figure F.20 Boxplot Displays for HF SMT 50MHz Post 85/85 - Pre-test Measurements (dB) by Surf. Finish
(Acceptance Criterion = ±5 dB of Pre-test)

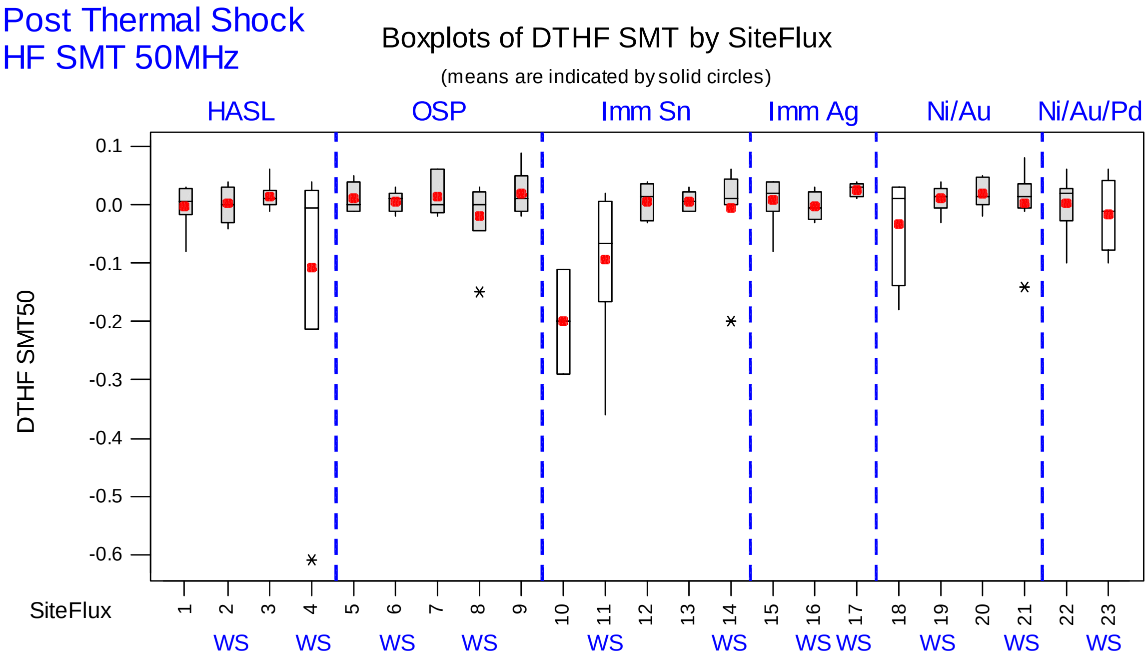

Figure F.21 Boxplot Displays for HF SMT 50MHz Post TS - Pre-test Measurements (dB) by Surface Finish
(Acceptance Criterion = ±5 dB of Pre-test)

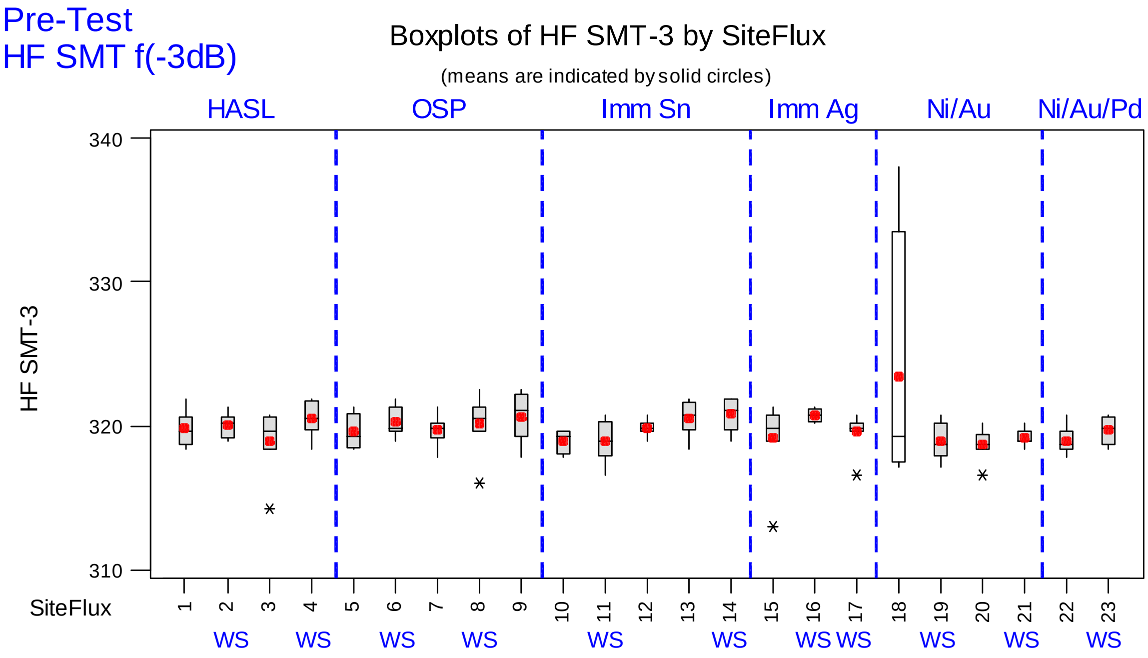

Figure F.22 Boxplot Displays for HF SMT f(-3dB) Measurements (MHz) at Pre-test by Surface Finish
(Acceptance Criterion = ±50Mhz of Pre-test)

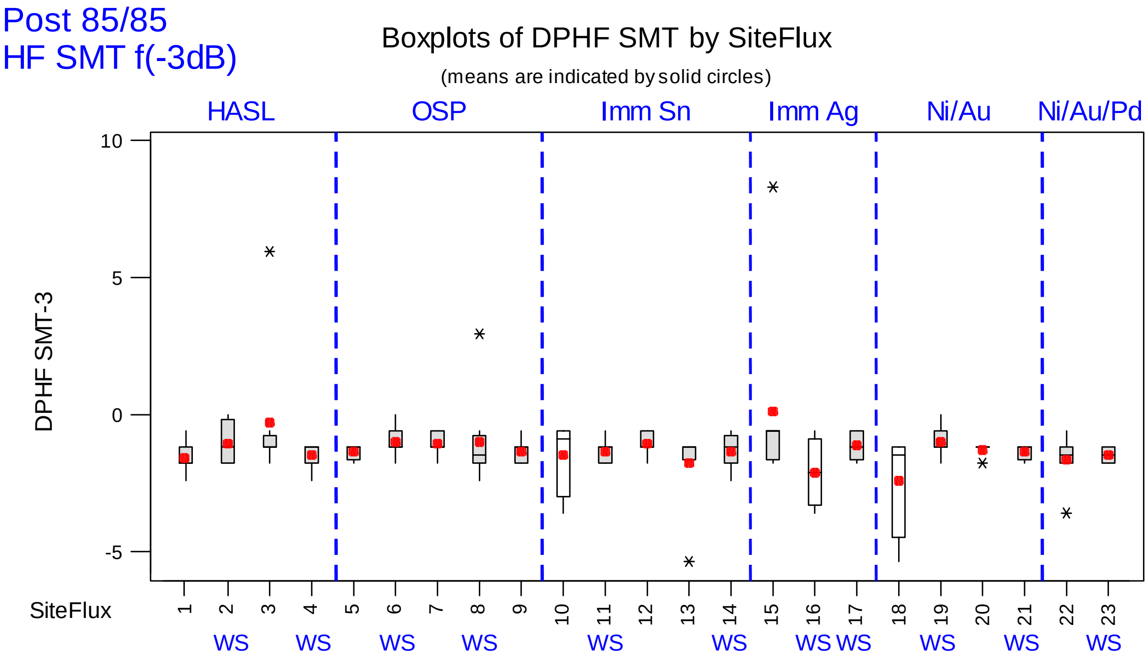

Figure F.23 Boxplot Displays for HF SMT f(-3dB) Post 85/85 - Pre-test Measurements (MHz) by Surf. Finish
(Acceptance Criterion = ±50Mhz of Pre-test)

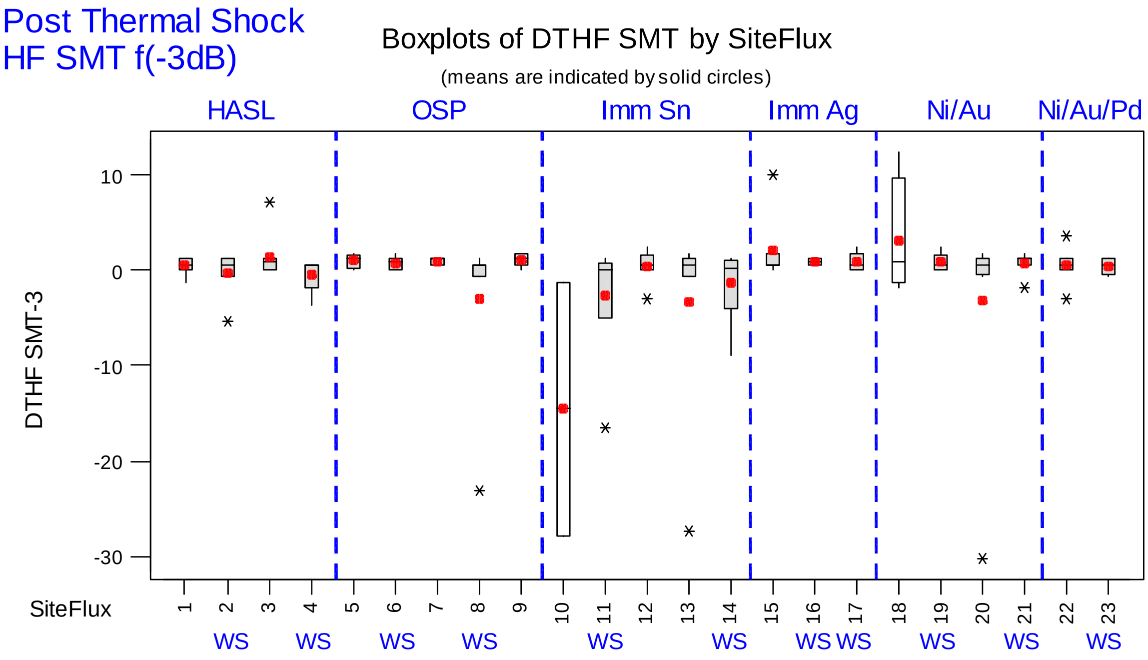

Figure F.24 Boxplot Displays for HF SMT f(-3dB) Post TS - Pre-test Measurements (MHz) by Surface Finish
(Acceptance Criterion = ±50Mhz of Pre-test)

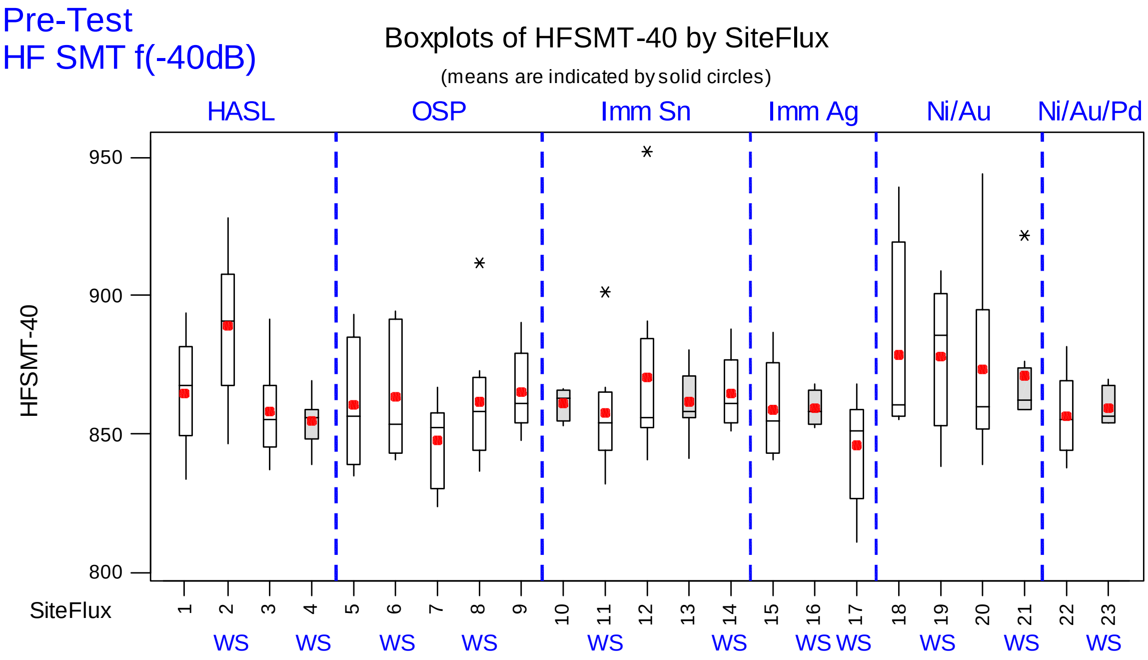

Figure F.25 Boxplot Displays for HF SMT f(-40dB) Measurements (MHz) at Pre-test by Surface Finish
(Acceptance Criterion = ±50Mhz of Pre-test)

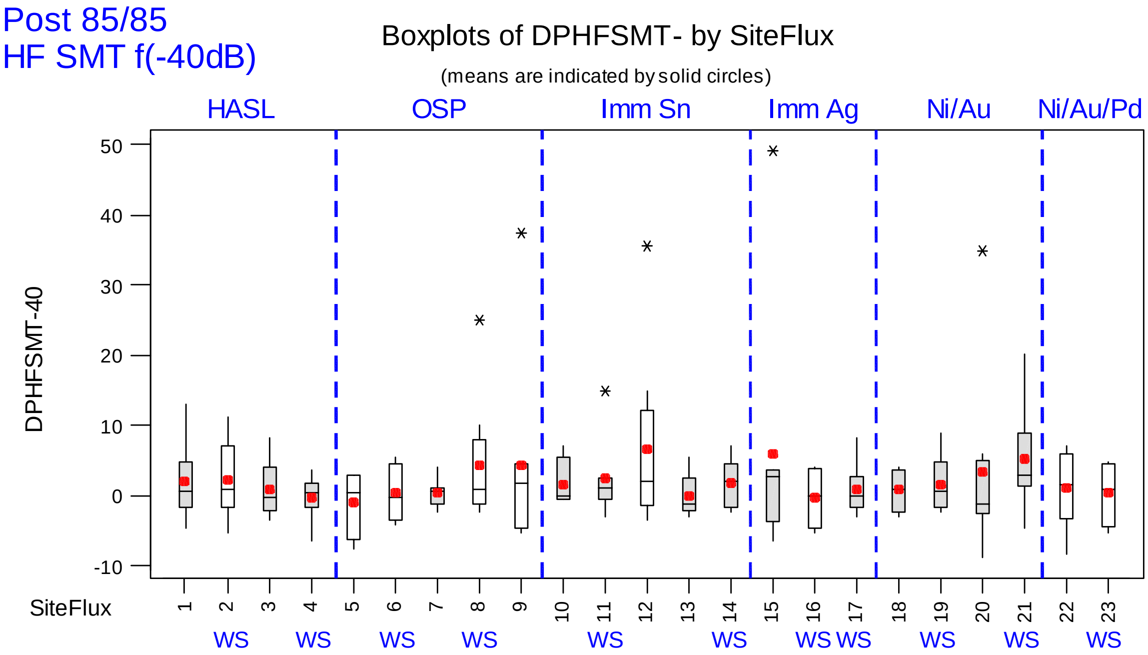

Figure F.26 Boxplot Displays for HF SMT f(-40dB) Post 85/85 - Pre-test Measurements (MHz) by Surf. Fin.
(Acceptance Criterion = ±50Mhz of Pre-test)

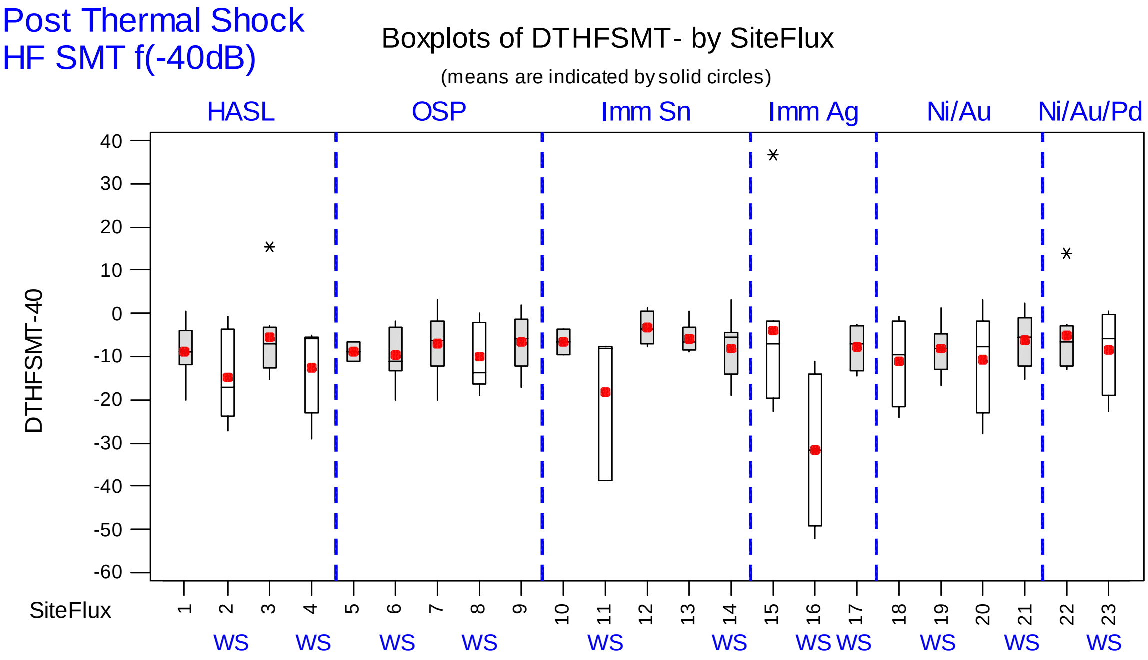

Figure F.27 Boxplot Displays for HF SMT f(-40dB) Post TS - Pre-test Measurements (MHz) by Surf. Finish
(Acceptance Criterion = ±50Mhz of Pre-test)

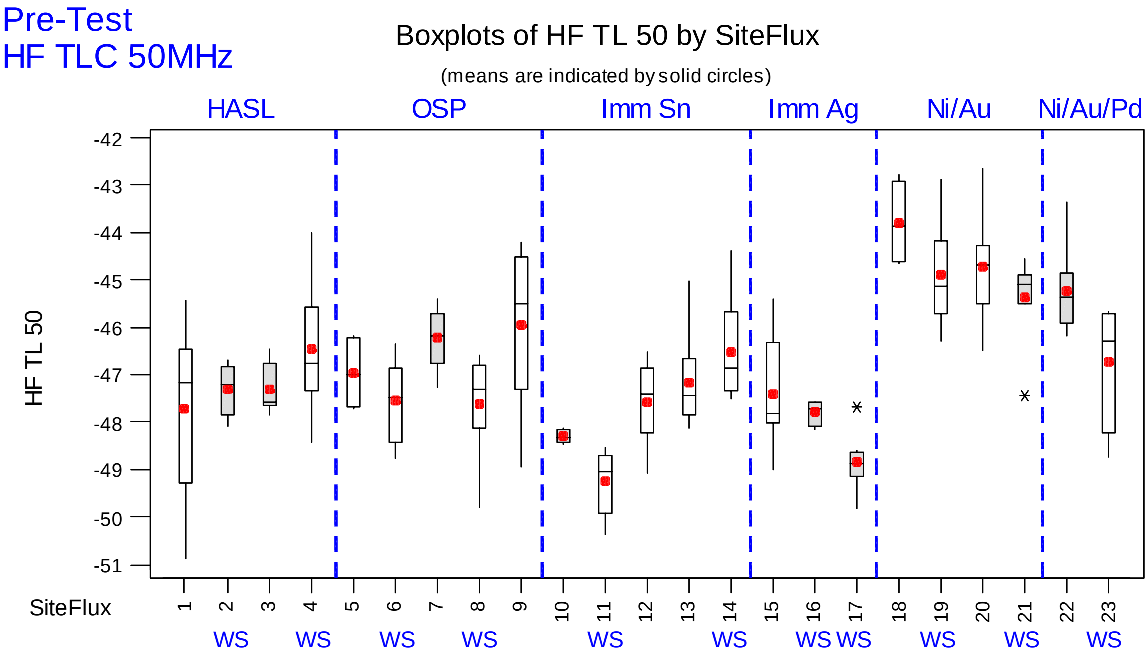

Figure F.28 Boxplot Displays for HF TLC 50MHz Measurements (dB) at Pre-test by Surface Finish

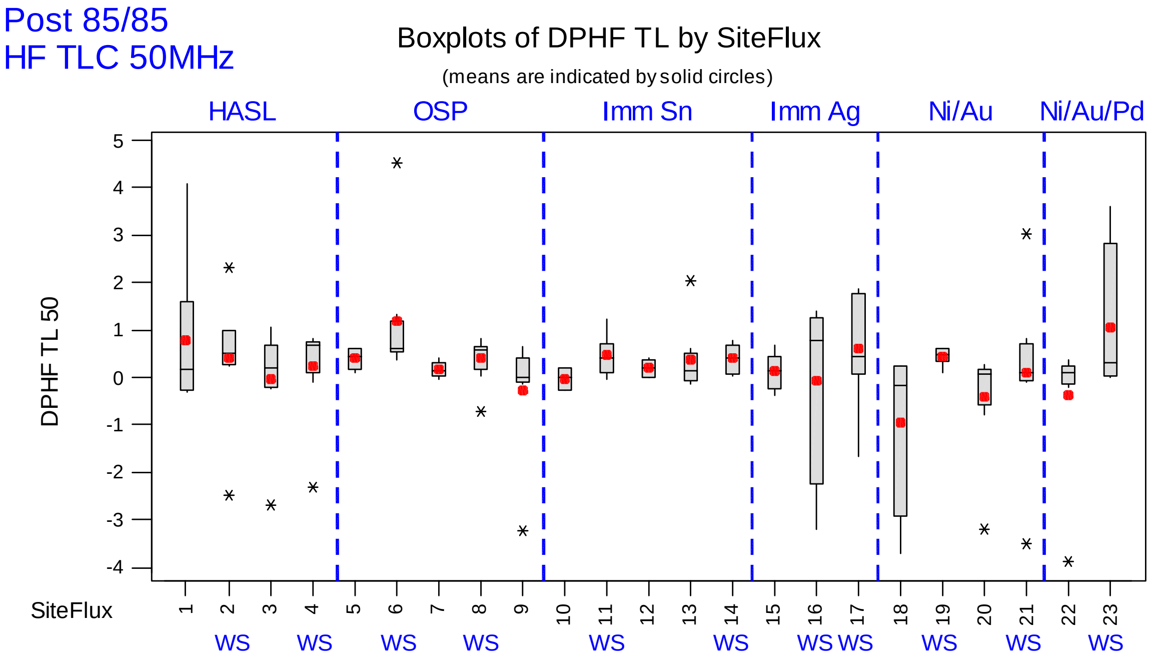

Figure F.29 Boxplot Displays for HF TLC 50MHz Post 85/85 - Pre-test Measurements (dB) by Surf. Finish
(Acceptance Criterion = ±5 dB of Pre-test)

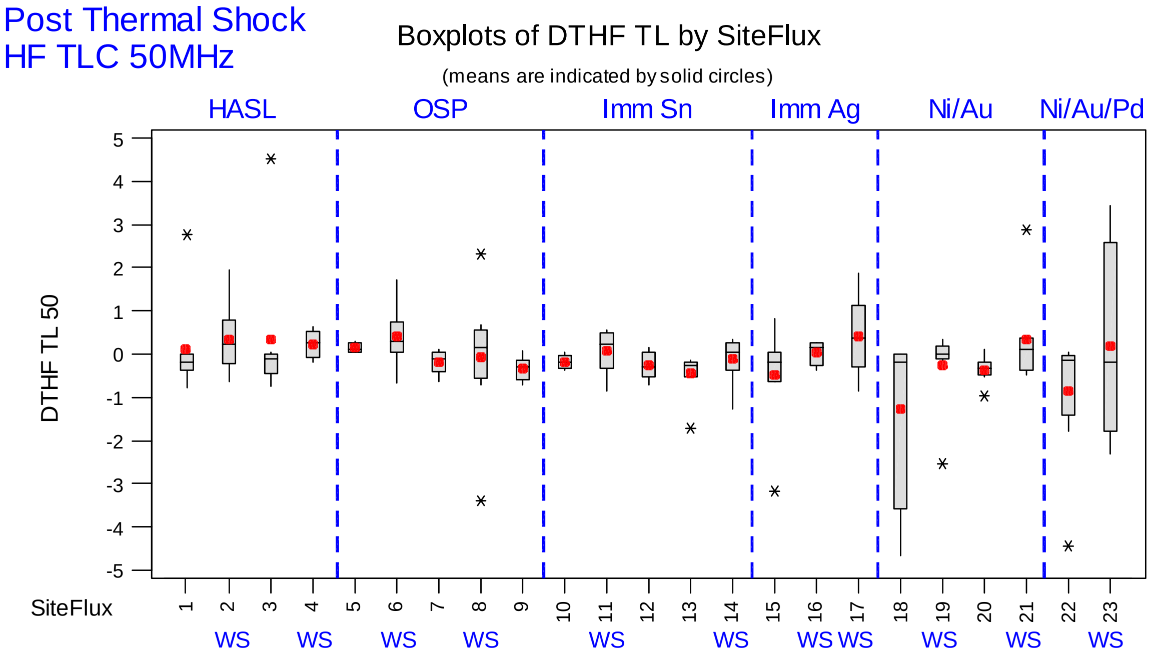

Figure F.30 Boxplot Displays for HF TLC 50MHz Post TS - Pre-test Measurements (dB) by Surface Finish
(Acceptance Criterion = ±5 dB of Pre-test)

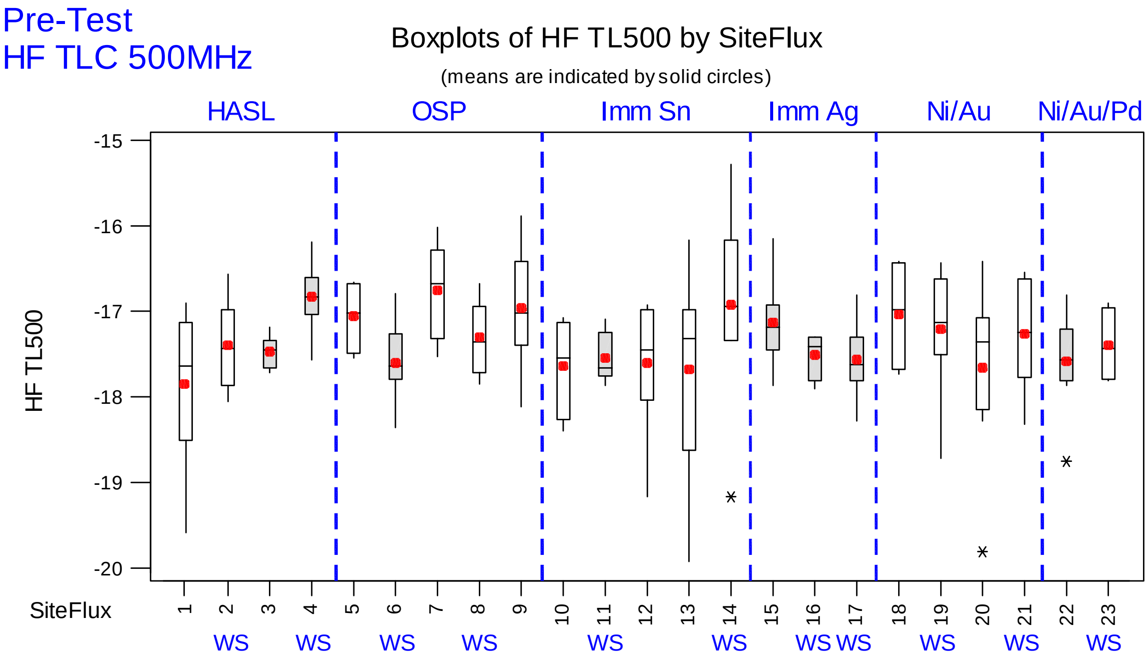

Figure F.31 Boxplot Displays for HF TLC 500MHz Measurements (dB) at Pre-test by Surface Finish

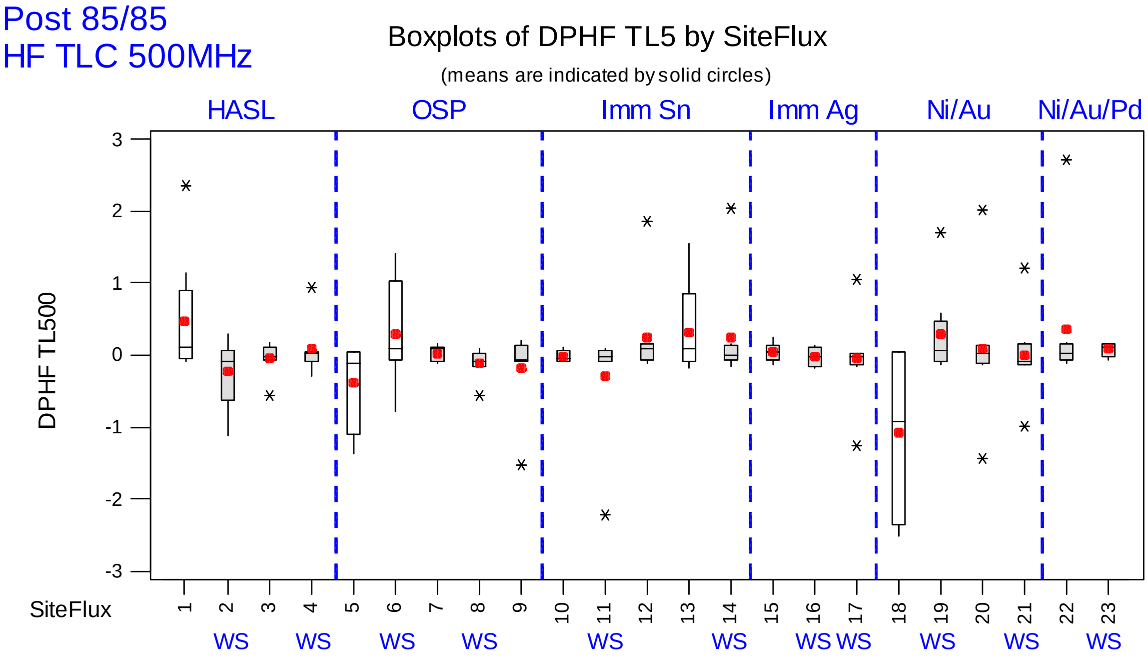

Figure F.32 Boxplot Displays for HF TLC 500MHz Post 85/85 - Pre-test Measurements (dB) by Surf. Finish
(Acceptance Criterion = ±5 dB of Pre-test)

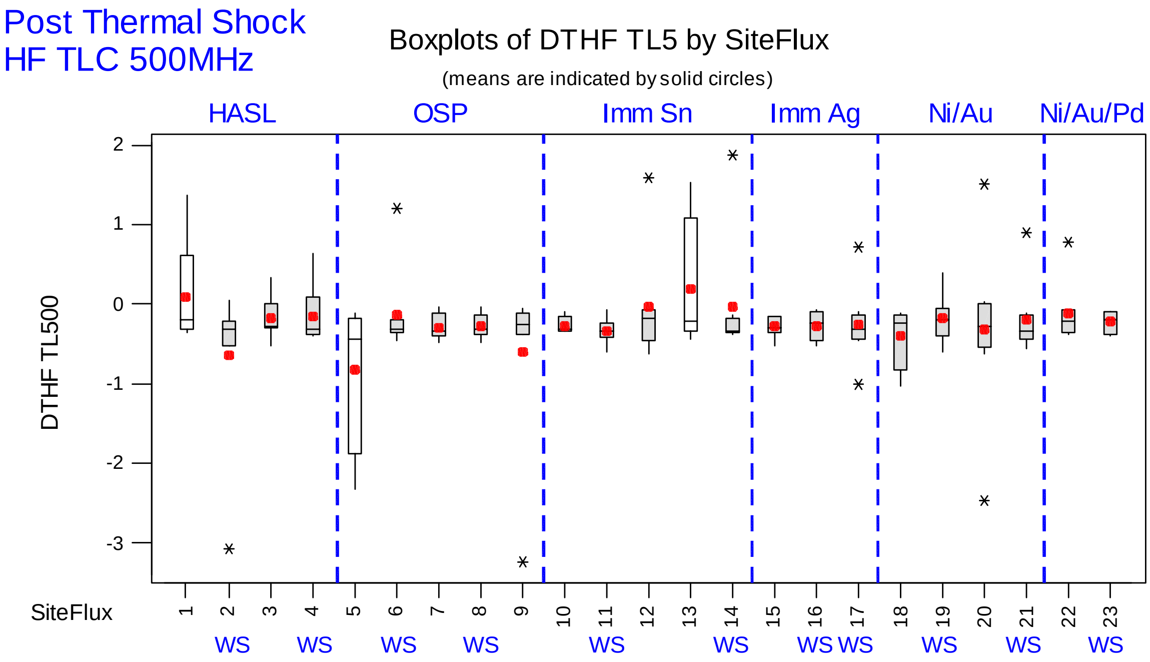

Figure F.33 Boxplot Displays for HF TLC 500MHz Post TS - Pre-test Measurements (dB) by Surface Finish
(Acceptance Criterion = ±5 dB of Pre-test)

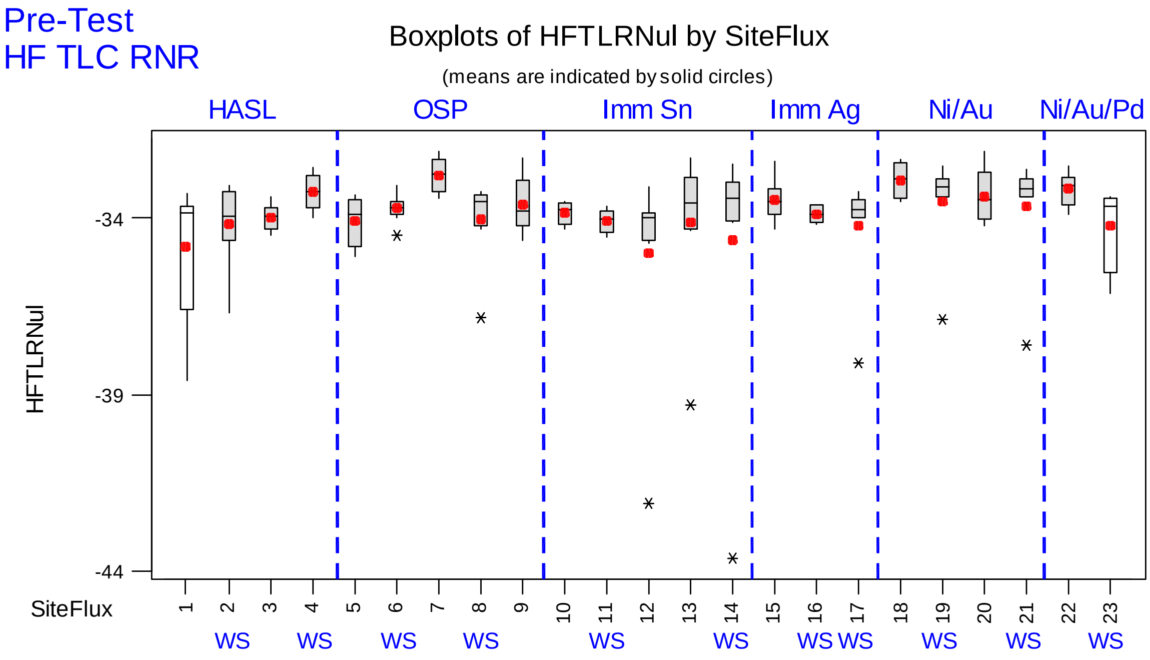

Figure F.34 Boxplot Displays for HF TLC RNR Measurements (dB) at Pre-test by Surface Finish

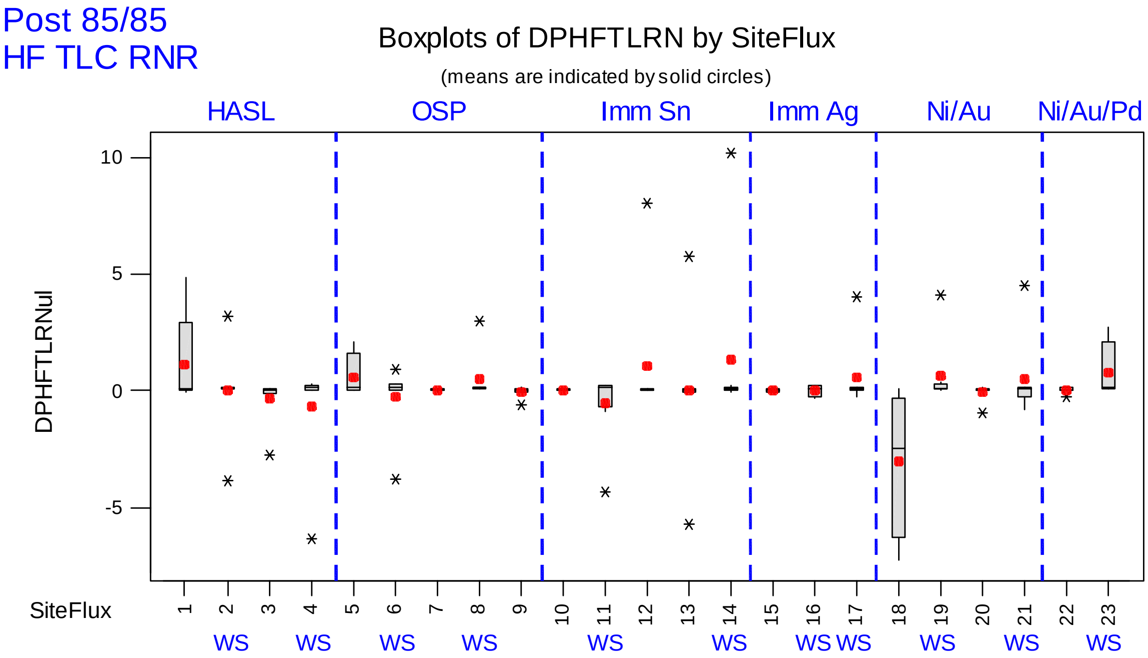

Figure F.35 Boxplot Displays for HF TLC RNR at Post 85/85 - Pre-test Measurements (dB) by Surf. Finish
(Acceptance Criterion = <10 dB increase over Pre-test)

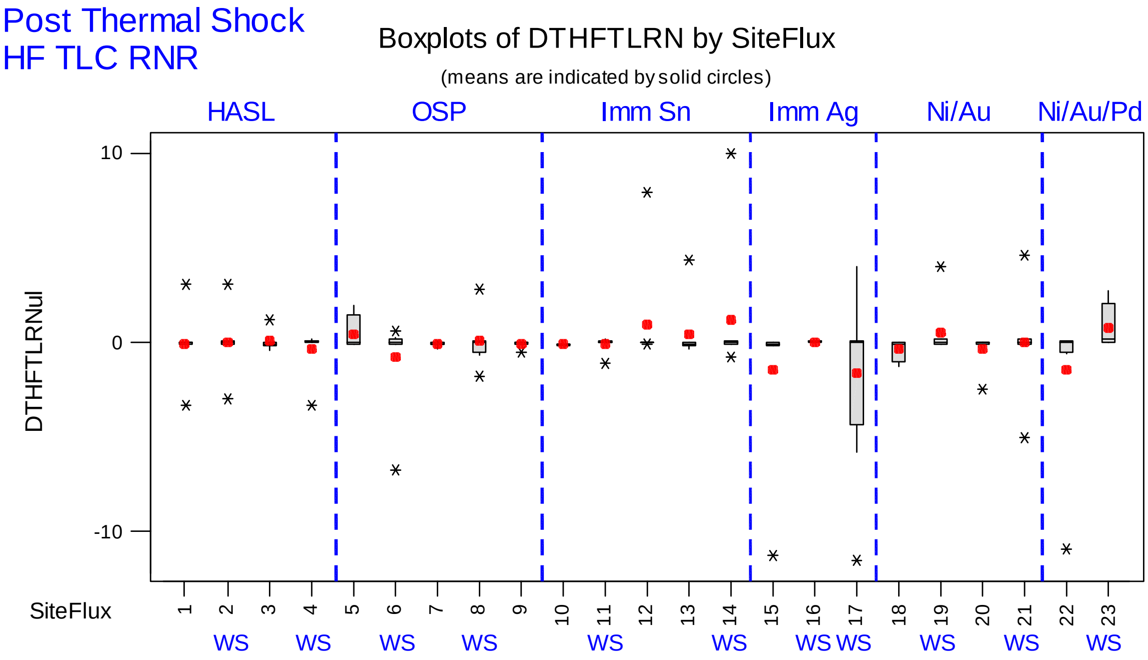

Figure F.36 Boxplot Displays for HF TLC RNR Post TS - Pre-test Measurements (dB) by Surface Finish
(Acceptance Criterion = <10 dB increase over Pre-test)

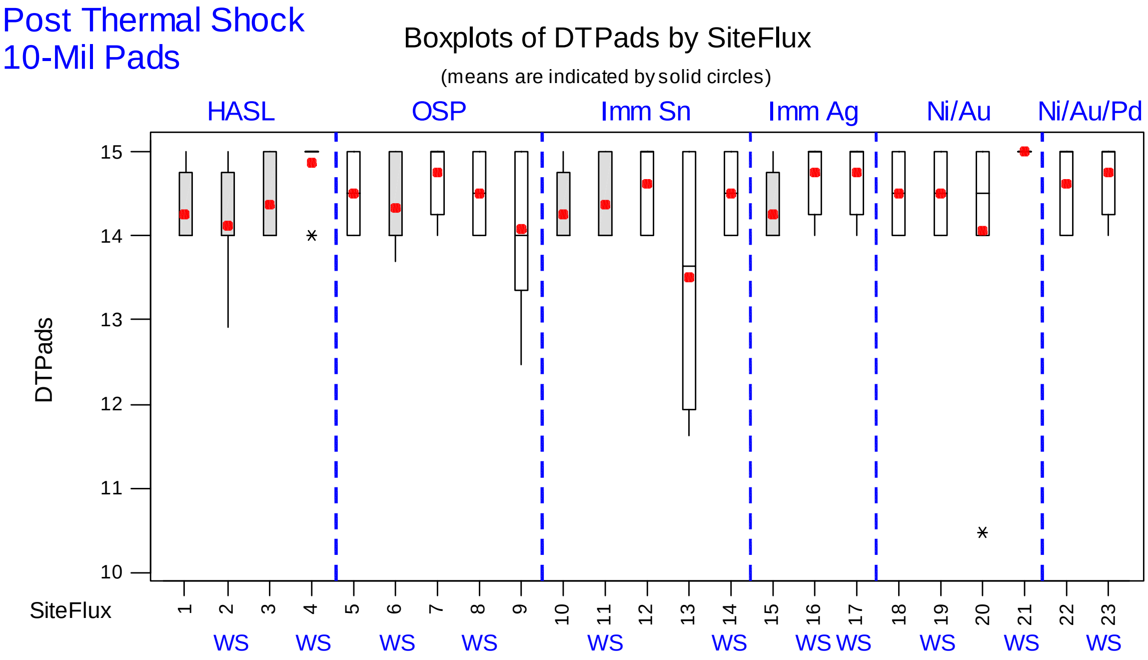

Figure F.37 Boxplot Displays for 10-Mil Pad Post TS - Pre-test Measurements (log$_{10}$ ohms) **by Surf. Finish**
(Acceptance Criterion = Resistance > 7.7 log$_{10}$ ohms)

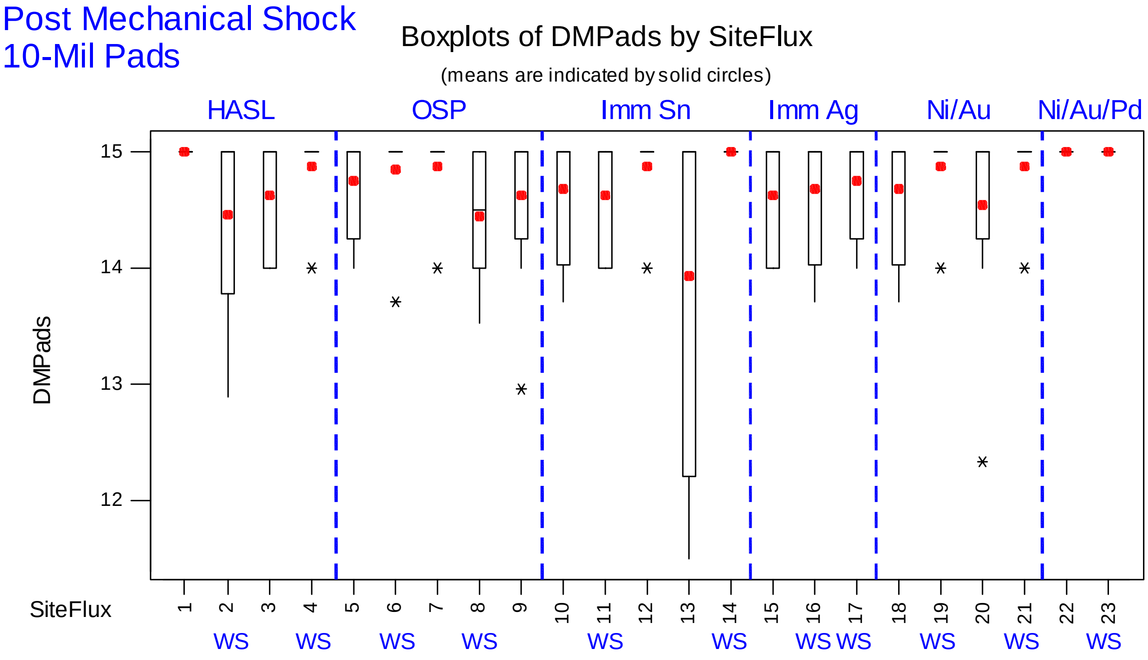

Figure F.38 Boxplot Displays for 10-Mil Pad Post MS - Pre-test Measurements (log$_{10}$ ohms) **by Surf. Finish**
(Acceptance Criterion = Resistance > 7.7 log$_{10}$ ohms)

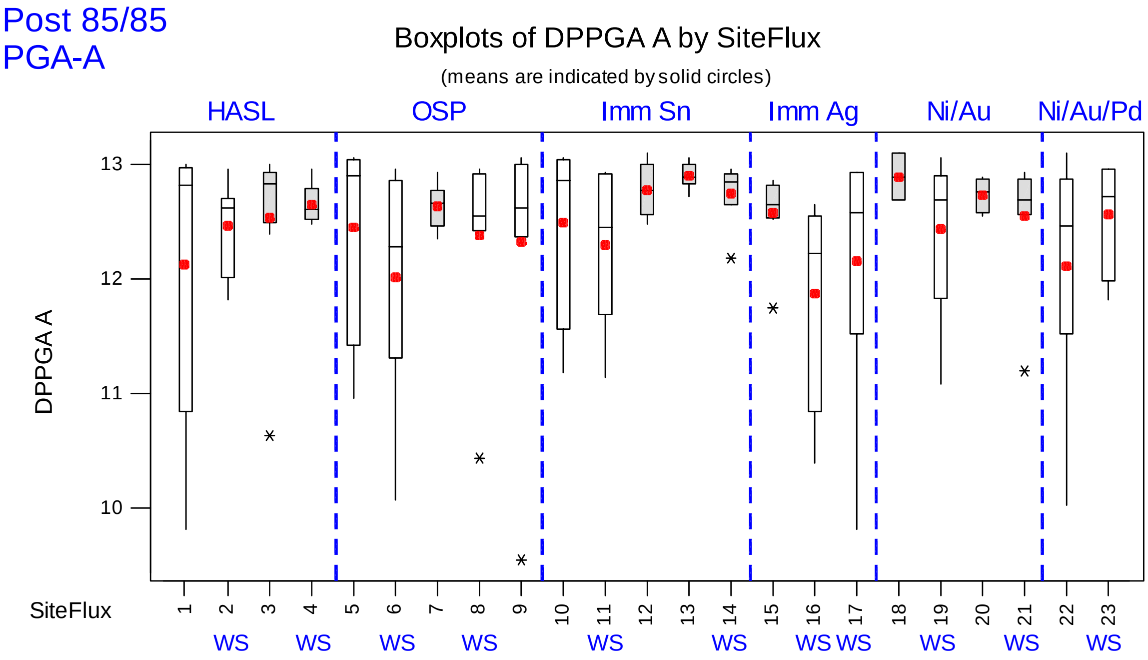

Figure F.39 Boxplot Displays for PGA-A Post 85/85 - Pre-test Measurements (log$_{10}$ ohms) **by Surface Finish**
(Acceptance Criterion = Resistance > 7.7 log$_{10}$ ohms)

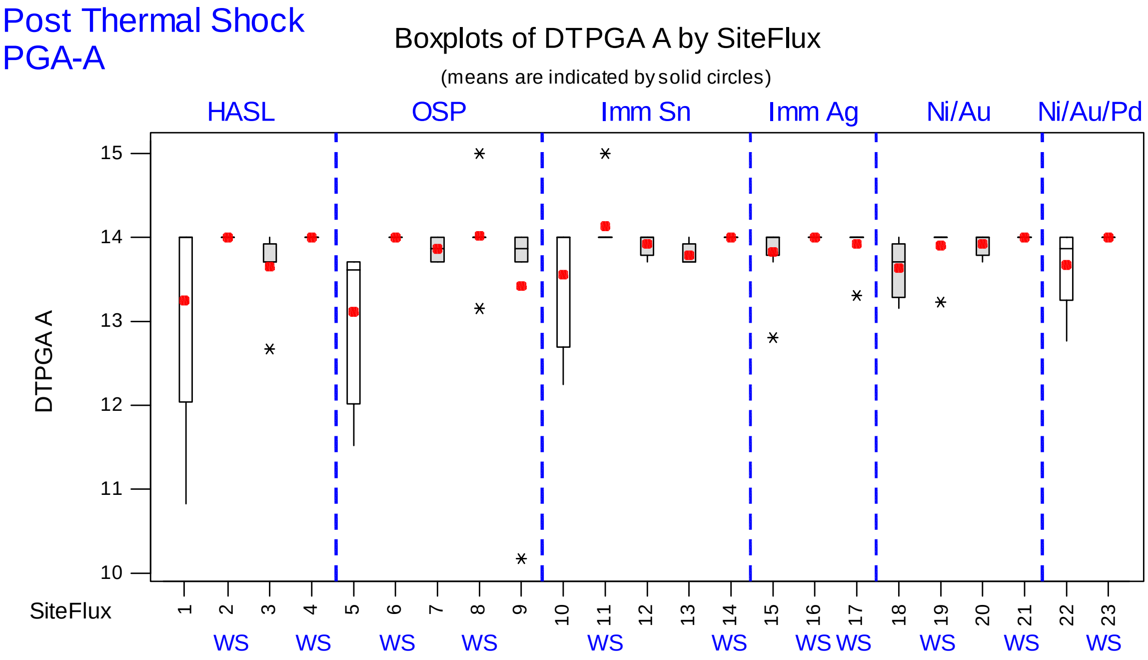

Figure F.40 Boxplot Displays for PGA-A Post TS - Pre-test Measurements (log$_{10}$ ohms) **by Surface Finish**
(Acceptance Criterion = Resistance > 7.7 log$_{10}$ ohms)

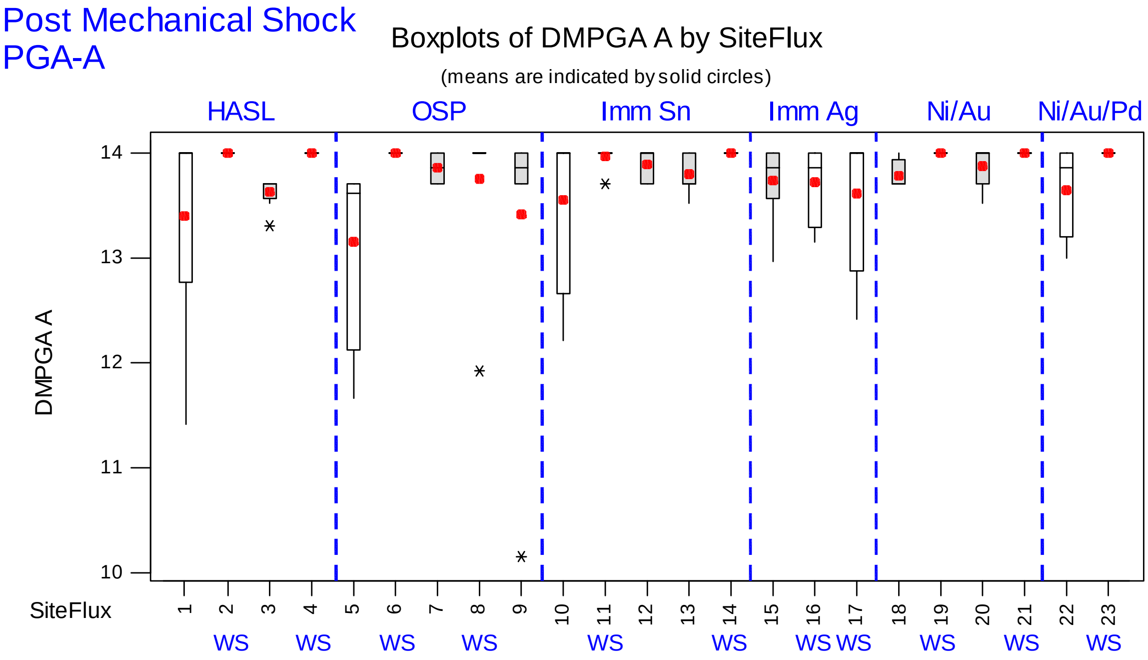

Figure F.41 Boxplot Displays for PGA-A Post MS - Pre-test Measurements (log$_{10}$ ohms) **by Surface Finish**
(Acceptance Criterion = Resistance > 7.7 log$_{10}$ ohms)

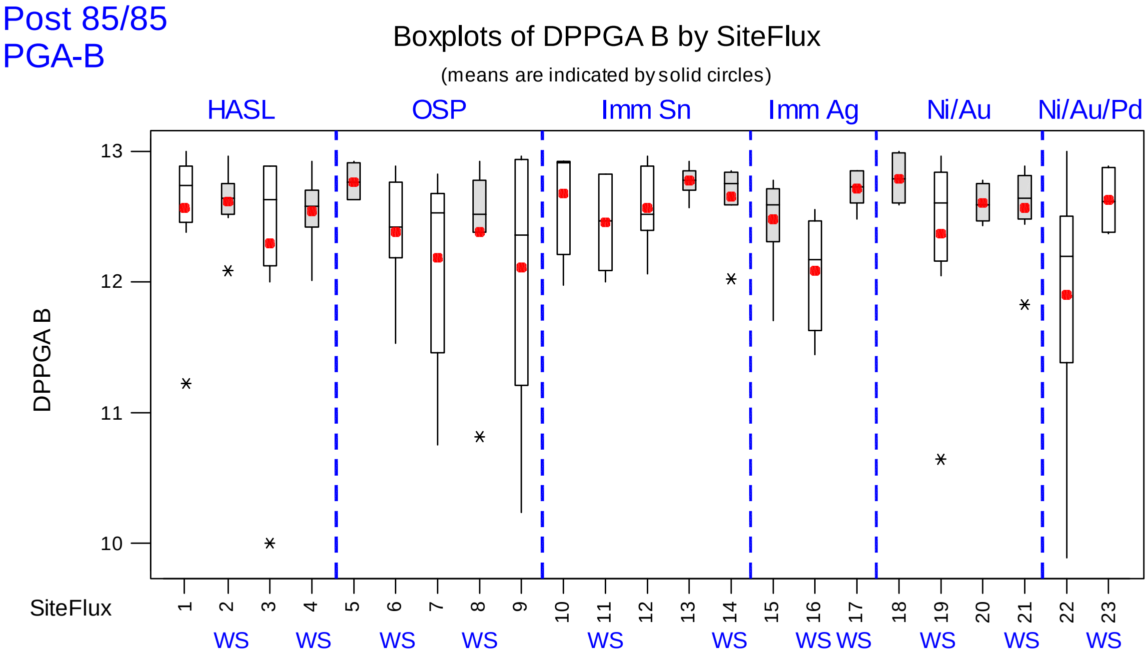

Figure F.42 Boxplot Displays for PGA-A Post 85/85 - Pre-test Measurements (log$_{10}$ ohms) **by Surface Finish**
(Acceptance Criterion = Resistance > 7.7 log$_{10}$ ohms)

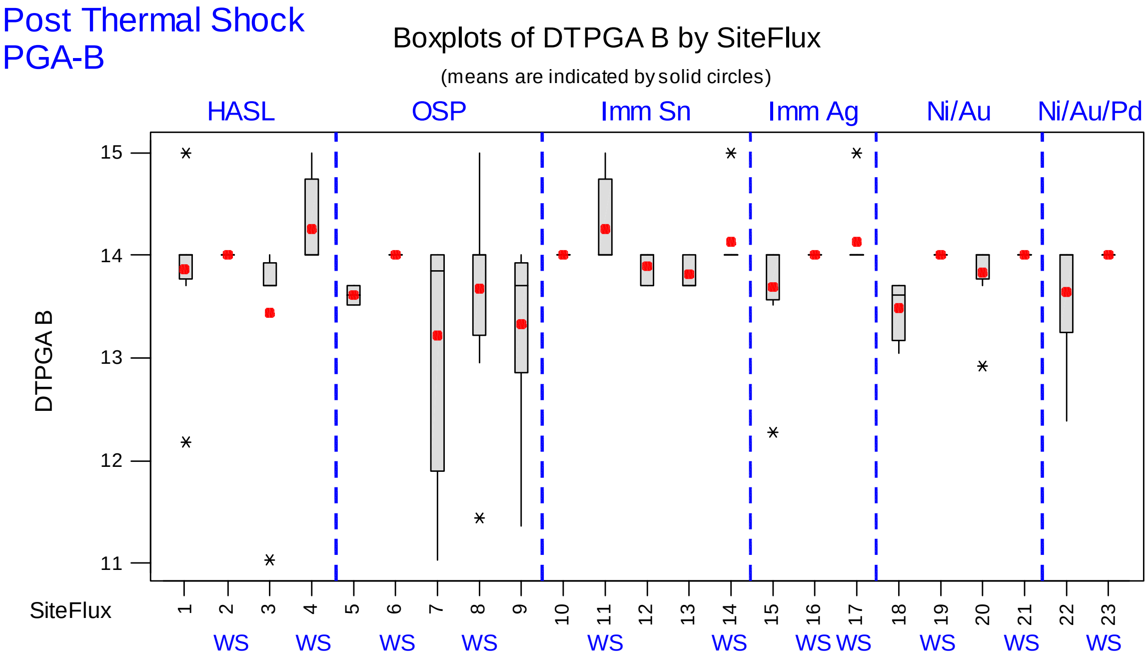

Figure F.43 Boxplot Displays for PGA-A Post TS - Pre-test Measurements (log$_{10}$ ohms) **by Surface Finish**
(Acceptance Criterion = Resistance > 7.7 log$_{10}$ ohms)

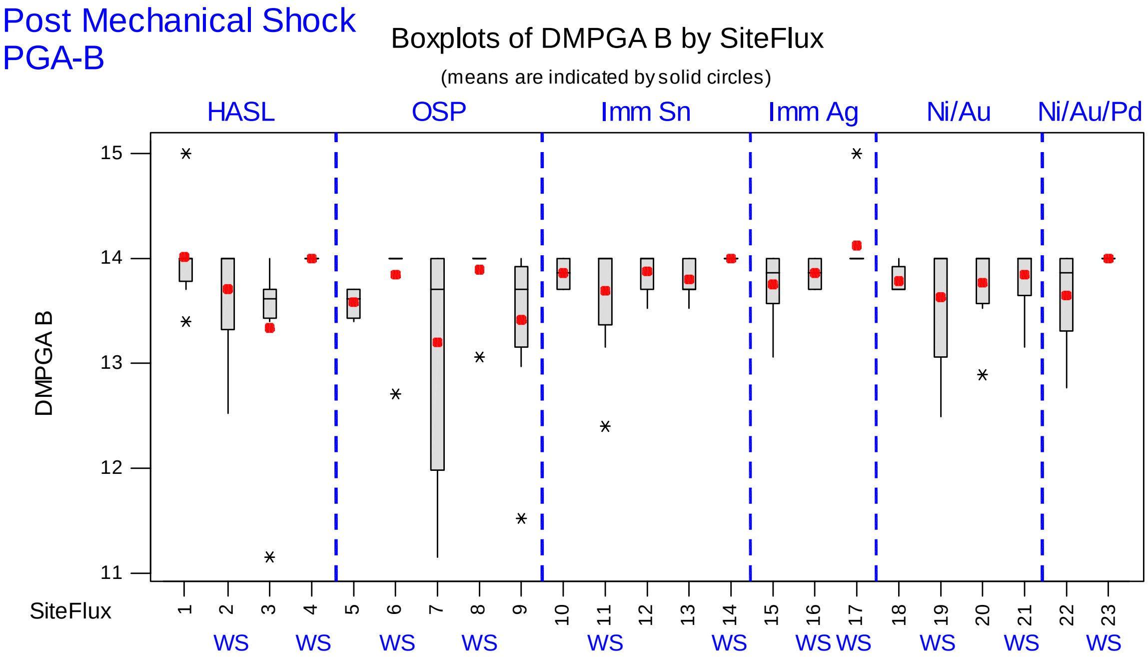

Figure F.44 Boxplot Displays for PGA-A Post MS - Pre-test Measurements (log$_{10}$ ohms) **by Surface Finish**
(Acceptance Criterion = Resistance > 7.7 log$_{10}$ ohms)

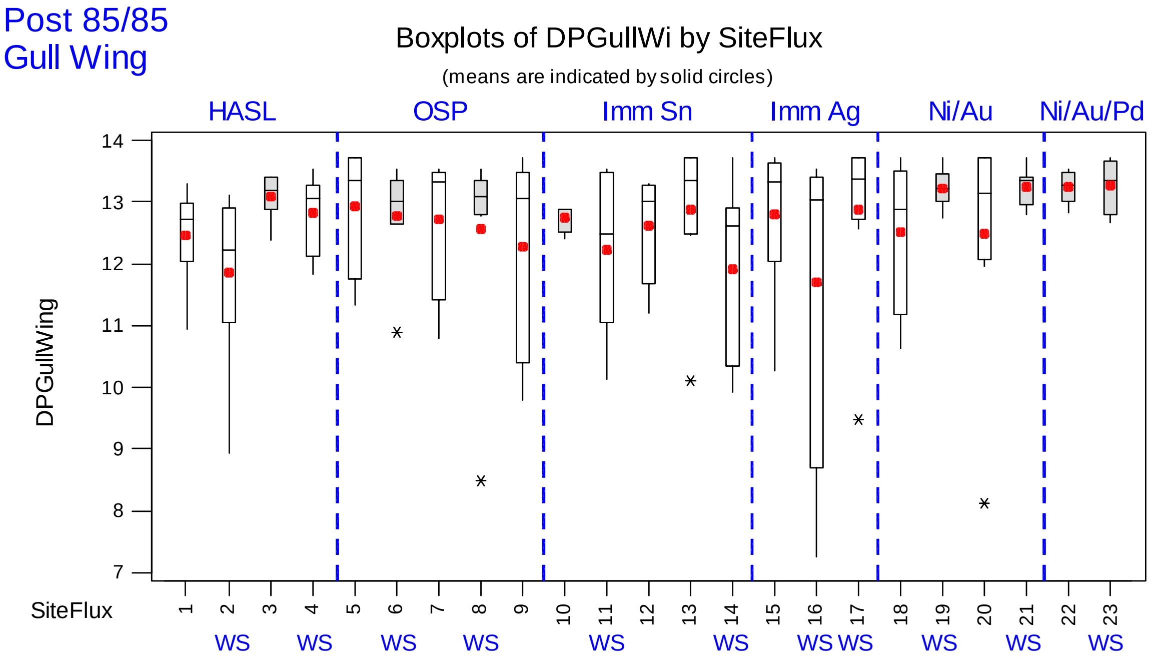

Figure F.45 Boxplot Displays for the Gull Wing Post 85/85 - Pre-test Measuremts. (log$_{10}$ ohms) **by Surf. Fin.**
(Acceptance Criterion = Resistance > 7.7 log$_{10}$ ohms)

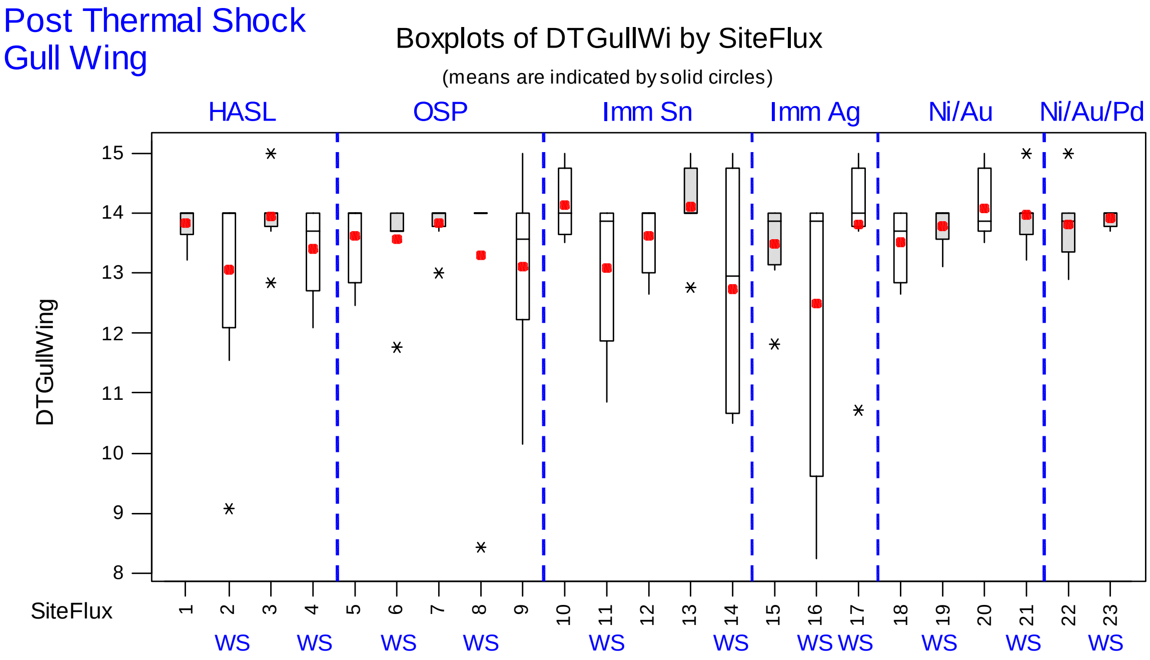

Figure F.46 Boxplot Displays for the Gull Wing Post TS - Pre-test Measurements (log$_{10}$ ohms) **by Surf. Fin.**
(Acceptance Criterion = Resistance > 7.7 log$_{10}$ ohms)

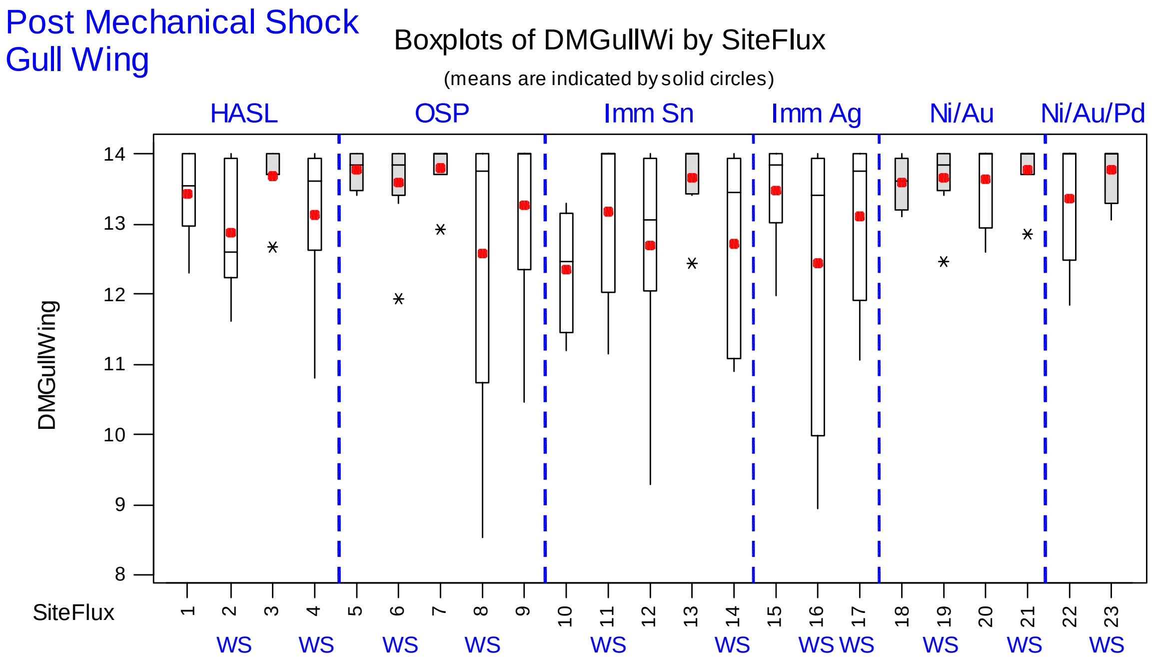

Figure F.47 Boxplot Displays for the Gull Wing Post MS - Pre-test Measurements ($\log_{10}$ ohms) **by Surf. Fin.**
(Acceptance Criterion = Resistance > 7.7 $\log_{10}$ ohms)

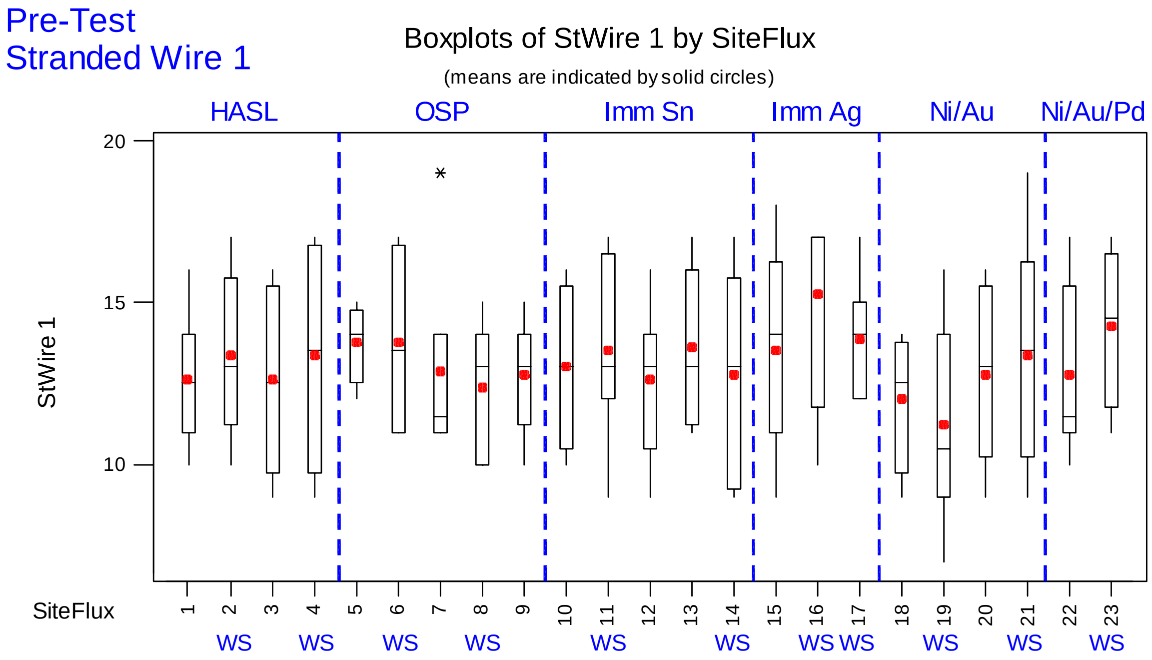

Figure F.48 Boxplot Displays for the Stranded Wire 1 Measurements (volts) at Pre-test by Surface Finish

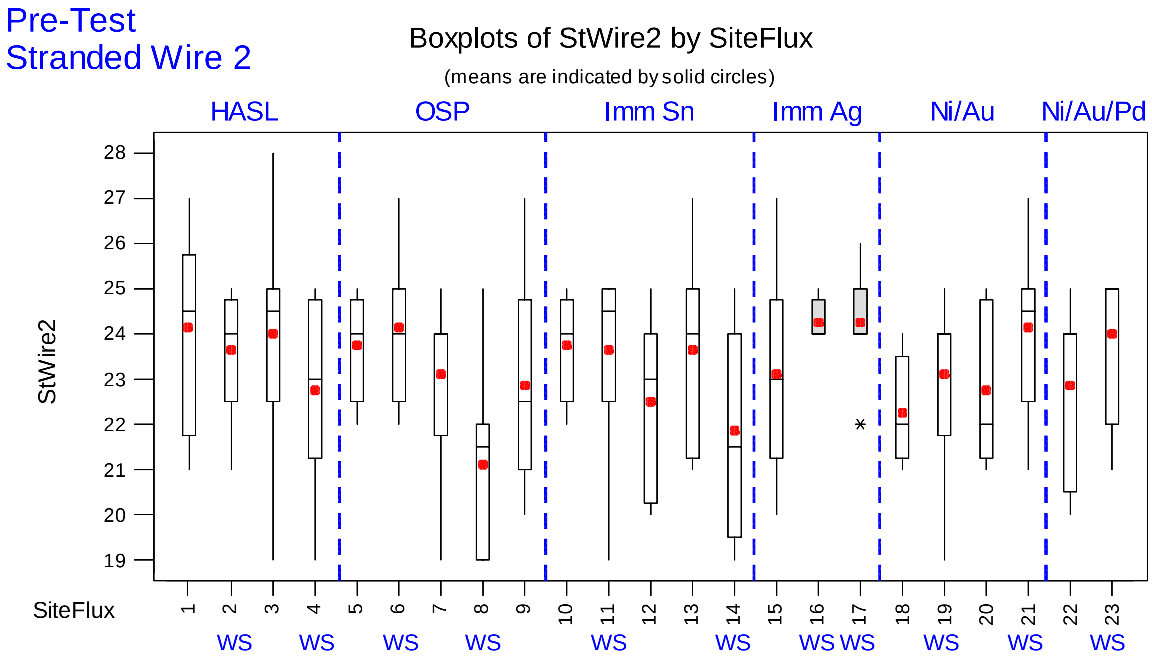

Figure F.49 Boxplot Displays for the Stranded Wire 2 Measurements (volts) at Pre-test by Surface Finish

F.10 Design and CCAMTF Baseline Testing of the Test PWA

F.10.1 Test PWA

As mentioned in Chapter 4, the primary test vehicle used in both the DfE project and in the CCAMTF evaluation of low-residue technology was an electrically functional PWA. This assembly was designed at Sandia National Laboratories in Albuquerque based on input from LRSTF members and from military and industry participants during open review meetings held by the task force. The PWA measures 6.05" x 5.8" x 0.062" and is divided into six sections, each containing one of the following types of electronic circuits:

- High current low voltage (HCLV)
- High voltage low current (HVLC)
- High speed digital (HSD)
- High frequency (HF)
- Other networks (ON)
- Stranded wire (SW)

The layout of the functional assembly is shown in Figure F.50. The components in the HCLV, HVLC, HSD, and HF circuits represent two principal types of soldering technology:

- Plated through hole (PTH)—leaded components are soldered through vias in the circuit board by means of a wave soldering operation
- Surface mount technology (SMT)—leadless components are soldered to pads on the circuit board by passing the circuit board through a reflow oven.

The other networks (ON) are used for current leakage measurements: 10-mil pads, a socket for a PGA, and a gull wing. The two stranded wires (SW) are hand soldered.

The subsections for PTH and SMT components form separate electrical circuits. The PWA includes a large common ground plane, components with heat sinks, and mounted hardware.

Each subsection shown in Figure F.50 contains both functional and nonfunctional components (added to increase component density). A 29-pin PTH edge connector is used for circuit testing. High frequency connectors are used to ensure proper impedance matching and test signal fidelity as required. Board fabrication drawings, schematics, and a complete listing of all components are available by contacting the authors of this report. A discussion of each of the sections of the test PWA is now given. This discussion is supplemented with baseline test results for each of the 23 electrical responses listed in Table 4.1.

F.10.2 High Current Low Voltage

The HCLV section of the board is in the upper left-hand corner of PWA (see Figure F.50). The upper left-hand portion of this quadrant contains PTH components with SMT components immediately beneath.

Purpose of the HCLV Experiment

Performance of high-current circuits is affected by series resistance. Resistance of a conductor (including solder joints) is determined by the following equation:

$$R = \frac{\rho L}{A_c} ohms(\Omega) \qquad \text{(F.7)}$$

where ρ = resistivity, the proportionality constant
L = length of the conductor
A_C = cross-sectional area of the conductor (solder joints)

Resistance is most likely to change due to cracking or corrosion of the solder joint that may be related to the soldering process. These conditions decrease the cross-sectional area of the solder joints, thus increasing resistance as shown in Equation F.7. Use of high current to test solder joint resistance makes detection of a change in resistance easier. A 5 Amperes (A) current was selected as a value that would cover most military applications. A change of resistance is most conveniently determined by measuring the steady state performance of the circuit, which will now be discussed.

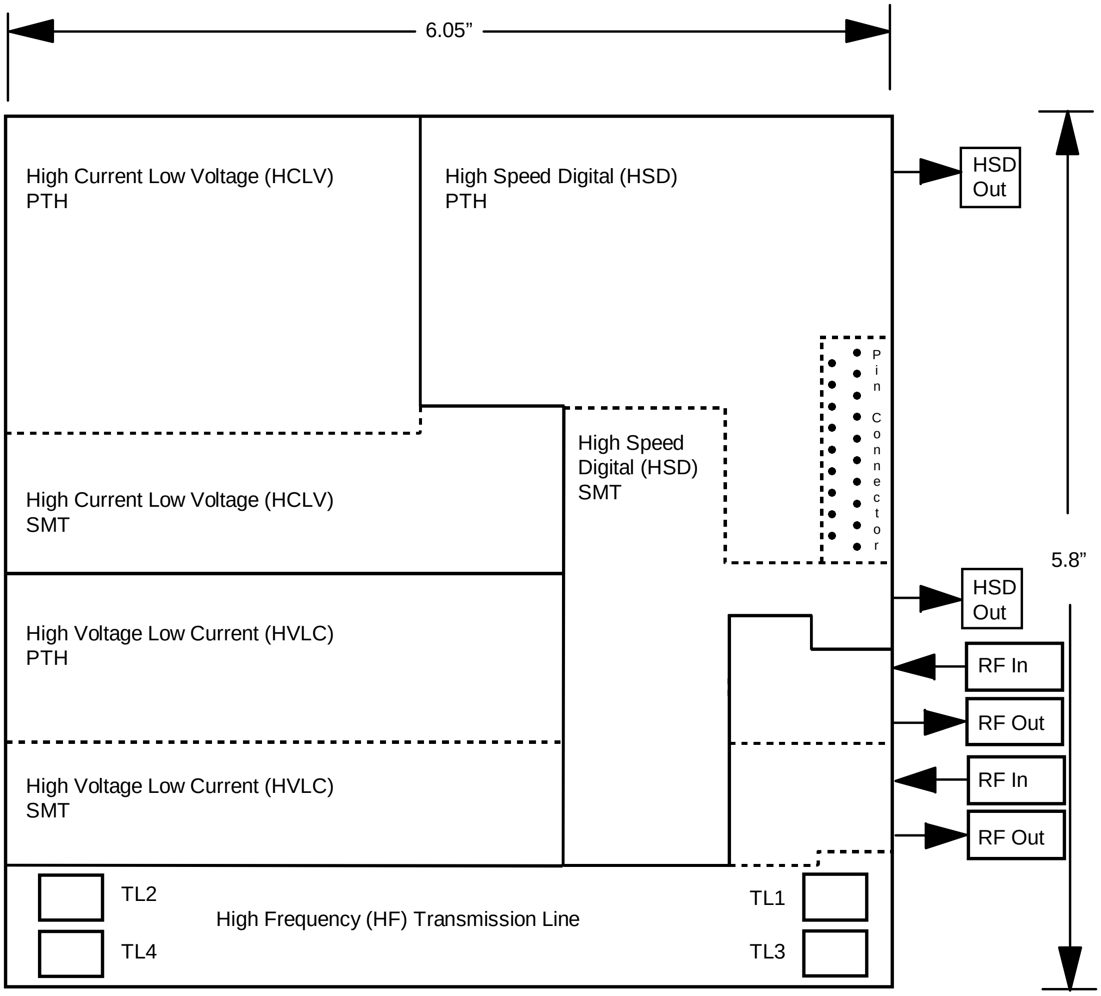

Figure F.50 Layout of the PWA Illustrating the Four Major Sections and Subsections

Steady State Circuit Performance

Overall circuit resistance, R_{total}, is the parallel combination of the seven resistors, R_1, R_2, ..., R_7, (all resistors = 10Ω) used in the HCLV circuit:

$$\frac{1}{R_{total}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_2} + \cdots + \frac{1}{R_7} = \frac{7}{10\Omega} \tag{F.8}$$

$$R_{total} = \frac{10\Omega}{7} \tag{F.9}$$

Since a current (I) of 5A will be applied to the circuit, the resulting voltage (V), according to Ohm's Law, is

$$V = IR = 5A \times \frac{10\Omega}{7} = 7.14V \tag{F.10}$$

Changes in resistance are thus detected by changes in voltage. However, a pulse width had to be chosen that would not overstress the circuit components. With current equally divided among the seven parallel resistors, the power (P) dissipated in each resistor, according to Joule's Law, is:

$$P = I^2 R = \left(\frac{5A}{7}\right)^2 \times 10\Omega = 5.1 Watts(W) \tag{F.11}$$

Since the power rating for the PTH wire-wound resistor is 3W, the rating is exceeded by a factor of 1.7 for steady state (5.1 / 3). Design curves from the resistor manufacturer indicate the PTH wire-wound resistors could tolerate the excess power for about 100*ms*. The SMT resistors are rated at 1W, so the steady state rating is exceeded by a factor of five. With the manufacturer unable to provide the pulse current capability of the SMT resistors, a pulse derating factor could not be determined. A pulse width of 100μ*s* was selected, which is three orders of magnitude less than the capability of the wire-wound resistors. This width is also sufficiently long for the circuit to achieve steady state before the measurement is taken.

Circuit Board Design

Traces carrying the 5A current were placed on an inner layer of the circuit board because: (1) the primary concern was the possible degradation of the solder connections as discussed above and (2) the bulk electrical characteristics (resistivity) of the traces should not be affected by flux residues. High-current trace widths were designed to be 250 mils whenever possible (following MIL-STD-275). This width with a 5A current should cause no more than a $30^{o}C$ temperature rise under steady-state conditions.

The resistor and capacitor values were selected to be readily available. If other values are used, care should be taken to not over-stress the parts, as discussed above.

Baseline Testing Results for HCLV

A gauge repeatability and reproducibility (GR&R) study (Iman et al, 1998) was conducted for the CCAMTF ATS as part of the CCAMTF program. The LRSTF PWA was utilized in this study. In particular, 120 LRSTF PWAs were tested for each of the following four surface finishes: OSP, immersion Ag, immersion Au/Pd and HASL with solder mask. Half the PWAs in each surface finish group were processed with low-residue (LR) flux and the other half with water soluble (WS) flux. Data modeling showed that surface finish and flux type did not significantly affect the voltage measurements for HCLV PTH and HCLV SMT. Figures F.51 and F.52 provide dotplot displays of 4 × 120 = 480 voltage measurements for HCLV PTH and 480 voltage measurements for HCLV SMT, respectively. The summary statistics HCLV PTH and HCLV SMT voltages are given in Table F.31.

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---+---------+---------+---------+---------+---------+---Volts
6.60      6.72      6.84      6.96      7.08      7.20
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Figure F.51. Dotplot for 480 HCLV PTH Voltage Measurements (each dot represents up to 10 points)

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  -+---------+---------+---------+---------+---------+-----Volts
6.90      7.00      7.10      7.20      7.30      7.40
```

Figure F.52. Dotplot for 480 HCLV SMT Voltage Measurements (each dot represents up to 16 points)

Table F.31. Summary Statistics for HCLV Circuitry Test Measurements

Circuitry	**Mean**	**Median**	**St. Dev.**	**Min**	**Max**
HCLV PTH	6.88V	6.96	0.163	6.60	7.20
HCLV SMT	7.20V	7.20	0.106	6.88	7.44

F.10.3 High Voltage Low Current

The HVLC circuitry is immediately below the HCLV circuitry and above the high frequency transmission lines in Figure F.50. The PTH circuitry is in the upper part of this subsection and the SMT circuitry is in the lower part.

Purpose of the HVLC Experiment

Flux residues could decrease the insulation resistance between conductors. The impact of this decrease could be significant in circuits with a high voltage gradient across the insulating region. Decreased resistance can be detected by an increase in current when a high voltage is applied to the circuit. A voltage of 250V was selected as the high potential for this test. The change in leakage current is determined by measuring the steady-state performance of the circuit, which will now be discussed.

Steady State Circuit Performance

Steady-state operation of the HVLC circuit can be determined by considering only the resistors. The total resistance of the series combination is the sum of the resistances.

$$R_{total} = R_1 + R_2 + R_3 + R_4 = R_5 = 50\,M\Omega \qquad \text{(F.12)}$$

since all resistors are 10MΩ each. From Ohm's law, the current flowing into the circuit with 250V applied is

$$I = \frac{V}{R} = \frac{250V}{50\,M\Omega} = 5\mu A \qquad \text{(F.13)}$$

Care was taken to not overstress the individual components in the circuits. The voltage stress across each resistor-capacitor pair is one-fifth of the applied 250V, or 50V. The voltage ratings are 250V for the PTH resistors, 200V for the SMT resistors, and 250V for all the capacitors. Power rating is not a concern due to the low current.

Circuit Board Design

High voltage traces were placed next to ground potential traces by design. The spacings between the high voltage and intermediate traces were selected using MIL-STD-275.

Voltage	Spacing Between Traces (mils)
0 – 100	5
101 – 300	15
301 – 500	30

These guidelines were followed except the 5-mil spacing, where 10 mils was used to facilitate board fabrication. Table F.32 lists the voltage on various board circuit traces and the spacing to the adjacent ground trace.

Resistors and capacitors were selected to have readily available values—different values could have been used to achieve particular experimental goals. For instance, higher resistance values could be used with lower value capacitors. Reverse biased, low-leakage diodes could also be used for higher sensitivity to parasitic leakage resistance.

Baseline Testing Results for HVLC

Data modeling showed that surface finish and flux type had very little effect on the voltage measurements for HVLC PTH and HVLC SMT. Figures F.53 and F.54 provide dotplot displays of 480 voltage measurements for HVLC PTH and HVLC SMT, respectively. The summary statistics for HVLC PTH and HVLC SMT voltages are given in Table F.33. Note that two slight outliers for HVLC PTH are identified in Table F.33, but are not included in Figure F.53.

Table F.32 HVLC Circuit Board Trace Potentials

Technology	Trace Connected to: Resistor	Capacitor	Potential (V)	Trace Length at Potential (in)	Spacing (mils)
PTH	R15	C21	250	0.8	30
			200	0.4	15
	R16	C22	200	0.4	15
			150	NA	
	R17	C23	150	NA	
			100	0.4	10
	R18	C24	100	0.4	10
			50	NA	
	R19	C25	50	NA	
SMT	R20	C26	250	5.0	30
			200	1.0	15
	R21	C27	200	1.0	15
			150	NA	
	R22	C28	150	NA	
			100	0.9	10
	R23	C29	100	0.9	10
			50	NA	
	R24	C30	50	NA	

NA = not applicable since no 50V or 150V traces were adjacent to ground potential

Table F.33 Summary Statistics for HVLC Circuitry Test Measurements (sans outliers)

Circuitry	Mean	Median	St. Dev.	Min	Max	Outliers	
HVLC PTH	5.04µA	5.04	0.024	4.972	5.148	5.203	5.232
HVLC SMT	4.95µA	4.95	0.011	4.914	4.976		

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4.970     5.005     5.040     5.075     5.110     5.145
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Figure F.53 Dotplot of 478 Voltage Measurements for HVLC PTH
(each dot represents up to 2 points)

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   4.920     4.932     4.944     4.956     4.968     4.980
```

Figure F.54 Dotplot of 480 Voltage Measurements for HVLC SMT (each dot represents up to 2 points)

F.10.4 High Speed Digital

The HSD circuitry is in the upper right-hand corner of the LRSTF PWA shown in Figure F.50. This subsection contains the PTH circuitry and consists of two 14-pin Dual In-line Package (DIP) integrated circuits (ICs). The SMT subsection IC is a single 20-pin leadless chip carrier (LCC) package. Each of these ICs is a “Fast” bi-polar digital ”QUAD-DUAL-INPUT-NAND-GATE.” Both subsections contain two ceramic capacitors that bypass spurious noise on the power input line (VCC) to the ICs and an output high-frequency connector. Inputs to both subsections are applied through the edge-connector on the right side of the board. Figure F.55 shows a simplified schematic of the ICs.

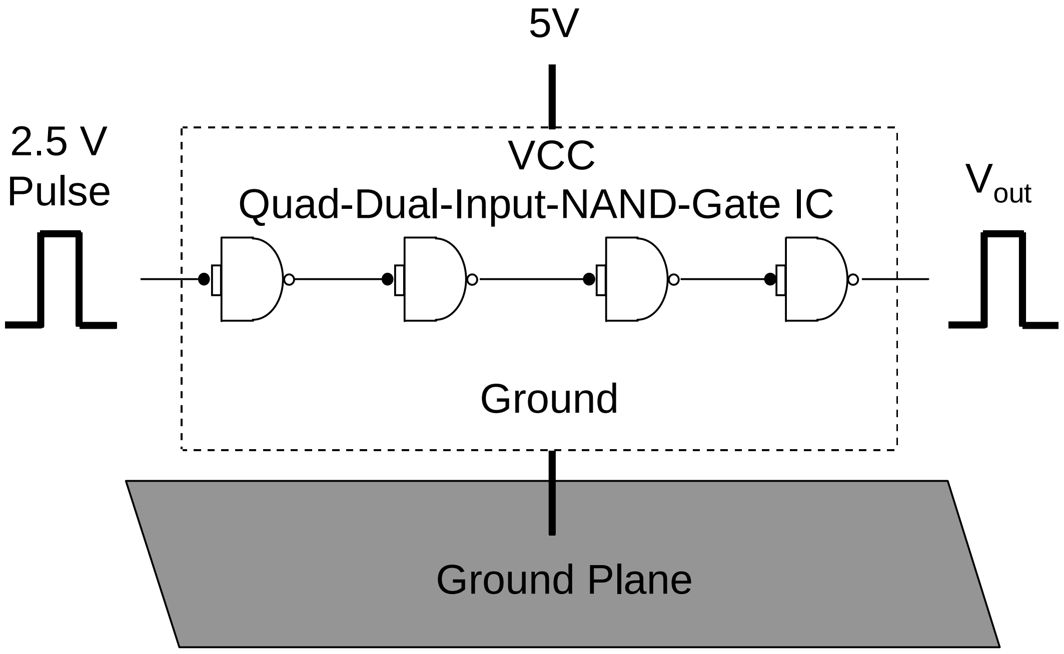

Figure F.55 Simplified Schematic of the ICs in the HSD Subsection

Purpose of the HSD Experiment

The output signal of each gate in Figure F.55 is opposite in polarity to the input signal. If the traces of these two signals are in close proximity on the printed circuit board (capacitively coupled), the gate switching speed might be affected by the presence of flux residues. A 5VDC bias is applied to the VCC inputs during environmental testing to accelerate aging. One PTH IC (U02) is hand soldered during assembly to introduce hand solder flux residue in the experiment.

Circuit Description

The schematic in Figure F.55 represents the ICs in the PTH and SMT subsections. The ICs are random logic circuits that are NAND (Not AND) gates. An AND gate's output is high only when all inputs are high. The logic of a NAND gate is opposite the logic of an AND gate. Therefore, the output of a NAND gate is low only when all inputs are high, otherwise the output is high. With the two connected inputs, the output of each gate is opposite the input. Since the four gates are connected in series, the output of the last gate is the same logic level (high or low) as the input, with a slight lag.

The output pulse does not change logic levels instantaneously, but the switching times from low to high (rise time) and from high to low (fall time) should be less than 7*ns*. ICs should perform within these criteria if the VCC input is 5±0.5V DC, the output load does not exceed specifications, and the circuit has a proper ground plane as shown in Figure F.55. The HSD circuits also provide an intermediate test for high frequencies, with switching time dictating a high frequency spectrum. The frequency spectrum of switching circuits can be expressed in terms of bandwidth (BW). For a switching circuit, the respective BWs (in Hertz) for rise (t_r) and fall (t_f) times are:

$$BW_r = \frac{0.35}{t_r} Hz \qquad and \qquad BW_f = \frac{0.35}{t_f} Hz \tag{F.14}$$

Bipolar technology was used rather than a complementary metal oxide semiconductor (CMOS) since it is not as vulnerable to electrostatic discharge (ESD) damage. Available military bipolar technologies have the following typical switching speeds and bandwidths:

Technology	**Typical $t_{r\ or\ f}$ (ns)**	**Bandwidth (MHz)**
5404 TTL	12	29
54LS04 Low Power Schottky	9	39
54S04 Schottky	3	117
54F04 Advanced Schottky (Fast)	2.5	140

The Fast technology was selected since it had the shortest switching time and largest bandwidth, which provides the widest frequency spectrum for this test.

Circuit Board Design

Ground planes were provided for proper circuit operation of the ICs. The PTH subcircuit utilized the large common ground plane on layer 3 since most of the input and output traces are on layer 4. Since the SMT circuit traces are on the top layer, a smaller ground plane was added on layer 2. The "QUAD-DUAL-INPUT-NAND-GATE" was selected since other solder studies of national attention have used that particular type of IC, which makes direct comparisons with these studies possible.

Baseline Testing Results for HSD

Data modeling showed that surface finish and flux type had very little effect on the total propagation delay measurements (msec) for HSD PTH and HSD SMT. Figures F.56 and F.57 provide dotplot displays of 480 voltage measurements for HSD PTH and HSD SMT, respectively. The summary statistics HSD PTH and HSD SMT total propagation delay are given in Table F.34 (Note one slight outlier for HSD PTH).

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 12.64     12.80     12.96     13.12     13.28     13.44
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Figure F.56 Dotplot of 480 Measurements of Total Propagation Delay for HSD PTH (each dot represents up to 2 points)

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  4.80      4.92      5.04      5.16      5.28      5.40
```

Figure F.57 Dotplot of 480 Measurements of Total Propagation Delay for HSD SMT (each dot represents up to 2 points)

Table F.34 Summary Statistics for HSD Circuitry Total Propagation Delay (µsec) Test Measurements (sans outliers)

Circuitry	**Mean**	**Median**	**St. Dev.**	**Min**	**Max**	**Outliers**	
HSD PTH	13.04µ sec	13.04	0.124	12.56	13.44	14.40	
HSD SMT	5.02µ sec	5.02	0.086	4.75	5.39	4.20	4.29

F.10.5 High Frequency

The HF section shown in the lower right-hand corner of Figure F.50 contains two major subsections, the low-pass filters (LPF) and the transmission line coupler (TLC). The TLC traces on layer 4 of the board are on the backside of the board. The LPF/PTH subsection is above the LPF/SMT subsection. Each of these subsections has discrete ceramic capacitors and three inductor-capacitor (LC) filters, with the inductor printed on the circuit board in a spiral pattern. The HF circuits allow evaluation of circuit performance up to 1G*Hz* (1000*MHz*).

Purpose of the High Frequency Experiment

Flux residues may affect the performance of LPF printed circuit inductors and transmission lines due to parasitic resistances and parasitic capacitances. Since the transmission lines are separated by only 10 mils, flux residues between the lines may affect their performance.

LPF Circuit Description

An inductor-capacitor (LC) LPF consists of a series inductor followed by a shunt capacitor. A low-frequency signal passes through the LPF without any loss since the inductor acts as a short circuit and the capacitor acts as an open circuit for such signals. Conversely, a high-frequency signal is blocked by the LPF since the inductor acts as an open circuit and the capacitor acts as a short circuit for such signals.

When a sine wave test signal is passed through an LPF, its amplitude is attenuated as a function of frequency. The relationship between the output and input voltage amplitudes can be expressed as a transfer function. The transfer function, V_{out} / V_{in}, was measured to determine any effects of the l ow-residue fluxes.

The transfer function is measured in decibels (dB) as a function of frequency. A decibel can be expressed in terms of voltage as follows:

$$dB = 20\log_{10}\left(\frac{|V_{out}|}{|V_{in}|}\right) \tag{F.15}$$

The PTH transfer function differs from the SMT transfer function due to the self inductance of the capacitor through-hole leads.

LPF Circuit Board Design

The three LC LPFs for each of the SMT and PTH circuits were designed to have the following cutoff frequencies: 800, 400, and 200 *MHz*. Cutoff frequency is that frequency for which the transfer function is -3 *dB*. The respective component values chosen for the LC filters are 16 *nH* (nano-Henries) and 6.4 *pF* (pico-Farads), 32 *nH* and 13 *pF*, and 65 *nH* and 24 *pF*. Most LPF circuitry was placed on Layer 1, with Layer 2 used as a ground plane. Crossovers needed to connect the LPF circuits are on Layer 4.

The LPF circuits were designed to operate with a 50Ω test system, so all interconnect traces longer than 0.10 *in* were designed as 50Ω transmission lines to avoid signal distortion. The LPF circuits were predicted to have less than 2 *dB* loss below 150 *MHz*, approximately 6 *dB* loss near 235

MHz, and greater than 40 *dB* loss at 550 *MHz* and beyond. The measured response of the LPF/SMT circuit is close to that predicted except that the transfer function decreases more rapidly than predicted above 350 *MHz*. As stated previously, the PTH circuit transfer function did not perform similarly to the SMT, particularly at frequencies above 150 *MHz*.

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     +---------+---------+---------+---------+---------+-------dB
-0.325    -0.300    -0.275    -0.250    -0.225    -0.200
```

Figure F.58 Dotplot of 473 Measurements of the Response for HF PTH at 50 MHz (each dot represents up to 2 points)

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    .  :  :::::::: :: :: :: :: :: :: :: :: :: :: :: :: :.
   -+---------+---------+---------+---------+---------+-----MHz
240.0     244.0     248.0     252.0     256.0     260.0
```

Figure F.59 Dotplot of 472 Measurements of the Frequency for HF PTH at –3dB (each dot represents up to 2 points)

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      ..::..:::::::::::::::::::::::::::..:     .       .
   -+---------+---------+---------+---------+---------+-----MHz
424.0     432.0     440.0     448.0     456.0     464.0
```

Figure F.60 Dotplot of 474 Measurements of the Frequency for HF PTH at –40dB (each dot represents up to 2 points)

Baseline Testing Results for HF LPF

Data modeling showed that surface finish and flux type had slights effects on the HF LPF frequencies and responses for HF PTH 50 MHz, HF PTH f(–3dB), HF PTH f(–40dB), HF SMT 50 MHz, and HF SMT f(-3dB). The response, HF SMT f(-40dB), was 5 to 12 MHz lower for PWA with OSP, immersion Ag, or immersion Au/Pd surface finishes. However, the range of frequencies for this response was only from 630.7 MHz to 680.60 MHz, so the changes in frequency are relatively small. Figures F.58 to F.59 provide dotplot displays of 480 measurements for the six HF LPF responses. The summary statistics for these responses are given in Table F.35 (Note there are several outliers identified in this table).

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-----+---------+---------+---------+---------+---------+-dB
-0.315    -0.280    -0.245    -0.210    -0.175    -0.140
```

Figure F.61 Dotplot of 473 Measurements of the Response for HF SMT at 50 MHz (each dot represents up to 2 points)

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     .   .   .   .  :   :   :   :  :   :   :   :  .   .   .
   -+---------+---------+---------+---------+---------+-----MHz
273.6     275.2     276.8     278.4     280.0     281.6
```

Figure F.62 Dotplot of 469 Measurements of the Frequency for HF SMT at –3dB (each dot represents up to 7 points)

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 -+---------+---------+---------+---------+---------+-----MHz
630       640       650       660       670       680
```

Figure F.63 Dotplot of 469 Measurements of the Frequency for HF SMT at –40dB (each dot represents up to 2 points)

The distribution in Figure F.59 is different from the other 22 electrical responses in that it displays a bimodal distribution for HF PTH f(-3dB) with one group of frequencies centered at approximately 245MHz and the other group at 256MHz. Data modeling showed that the differences between these two groups were not related to any of the experimental parameters (surface finish or flux) nor were they related to fixture or time of test. A possible explanation for the bimodal distribution is differences in date lots for the components. However, date lot information were not recorded prior to processing and thus, the date lot hypothesis cannot be confirmed. Since the JTP acceptance criterion is based on change after exposure to environmental conditions, the bimodal distribution could potentially be important if the measurements were not repeatable. Twenty board serial numbers were randomly selected for retest to see if the measurements were repeatable with 10 boards from the distribution centered at 245MHz and 10 boards from the distribution centered at 256MHz. These two groups of 10 were equally split between fixtures A and B on the CCAMTF ATS. Table F.36 gives the differences between the initial baseline measurements and those from the repeat test. The differences in this table are all quite small. The correlation of the measurements on fixture A is 0.995 and on fixture B it is 0.982, which indicates excellent repeatability. Thus, other than being a curiosity, the bimodal distribution for HF PTH f(-3dB) will have no practical effect on the test results.

Table F.35 Summary Statistics for 393 Test Measurements for Response (dB) or Frequency (MHz) for HF LPF (sans outliers)

Circuitry	**Mean**	**Median**	**St. Dev.**	**Min**	**Max**	**Outliers**
HF PTH 50 MHz	-0.254 dB	-0.252	0.022	-0.319	-0.194	-0.351 -0.150 -0.148 -0.138 -0.130 -0.107 -0.096
HF PTH –3dB	250.6 MHz	250.7	5.65	240.0	260.8	227.4 230.5 305.3 306.5 307.1 307.7 308.3 308.9
HF PTH –40dB	440.7 MHz	440.1	6.01	425.3	464.4	506.6 507.2 507.8 513.1 513.7 514.3
HF SMT 50 MHz	-0.242 dB	-0.242	0.023	-0.329	-0.144	-0.447 -0.074 -0.066 -0.062 -0.061
HF SMT –3dB	278.3 MHz	278.6	1.20	273.8	282.2	225.2 295.8 299.4 301.8 302.9 302.9 355.2 381.9 383.1 384.3 389.6
HF SMT –40dB	660.2 MHz	661.0	7.66	630.7	680.6	694.8 701.9 708.5 719.8 721.5 758.3 862.8 872.3 877.7 890.2 924.6

Table F.36 Results from Repeat Testing of the HF PTH f(-3dB) Circuit

	Fixture A			Fixture B		
Test	**Baseline**	**Repeat**	**Difference**	**Baseline**	**Repeat**	**Difference**
1	244.2	243.0	1.23	242.4	243.0	-0.57
2	245.3	244.8	0.55	244.2	245.3	-1.14
3	246.5	246.5	-0.03	245.3	245.9	-0.64
4	247.1	247.1	-0.03	246.5	244.2	2.34
5	253.1	254.3	-1.15	248.9	250.1	-1.19
6	255.4	255.4	-0.04	253.7	255.4	-1.74
7	256.0	256.0	-0.03	254.8	255.4	-0.64
8	257.2	257.8	-0.61	256.0	258.4	-2.41
9	259.0	259.0	0.00	257.8	258.4	-0.61
10	259.6	259.0	0.60	259.0	259.0	0.00

TLC Circuit Description

Figure F.64 shows a diagram of the TLC subsection. The LPFs described above are *lumped element* circuits since the capacitors are discrete components. The TLC lines are *distributed element* circuits with the resistors, inductors, and capacitors distributed along the lines. A circuit model for the lines is shown in Figure F.65.

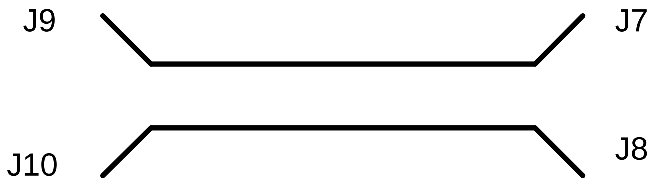

Figure F.64 Diagram of the HF/TLC Subsection

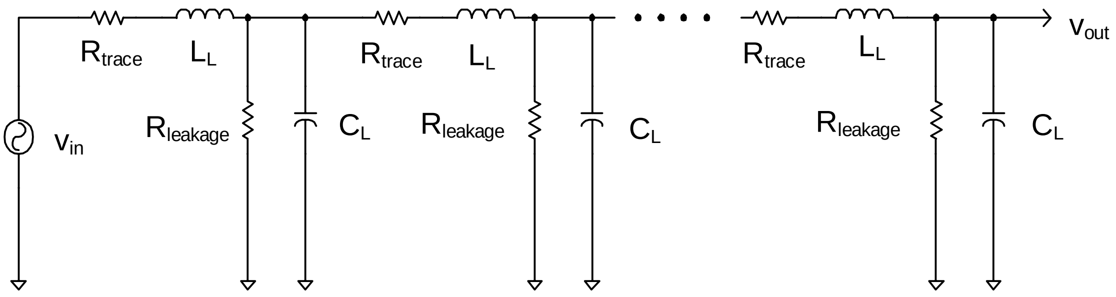

Figure F.65 HF/TLC Distributed Element Model

The inductance and capacitance for a transmission line with a ground plane are, respectively:

$$L_L = 0.085 R_0 \sqrt{\varepsilon_r}\, nH / in \tag{F.16}$$

$$C_L = \frac{85}{R_0} \sqrt{\varepsilon_r}\, pF / in \tag{F.17}$$

where R_0 = characteristic resistance and ε_r = dielectric constant of the board material.

The TLC R_o was designed to be 50Ω for operation with a 50Ω test system. For FR-4 epoxy (board substrate material), L_L is about 9.6 *nH*/*in* and C_L is about 3.8 *pF*/*in*.

The TLC was tested with a sine wave signal similar to the one used in testing the LPFs. The source resistance was 50Ω and the three output terminals were connected to 50Ω loads.

TLC Circuit Board Design

The transmission line coupler (TLC) circuit has a pair of coupled 50Ω transmission lines with required measurable performance frequencies less than 1000 *MHz*. Layer 4 of the printed wiring board (PWB) was used to route the TLC circuit, with Layer 3 used as the ground plane. The TLC circuit is a 5 *in* long pair of 0.034 *in* wide 50Ω transmission lines spaced 0.010 *in* apart. The circuit design incorporated the board dielectric constant of about 3.8 and the .020 *in* spacing between copper layers. A computer-aided circuit design tool (Libra) was used to model the TLC circuit. Performance measured on a test PWB agreed very closely with the forward and reverse coupling predictions between 45 *MHz* and 1000 *MHz*.

Baseline Testing Results for HF TLC

Data modeling showed that surface finish and flux type had very slight effect on the HF TLC frequencies and responses for HF TLC 50 MHz, HF TLC 500 MHz, HF TLC 1000 MHz, HF TLC Reverse Null Frequency, and HF TLC Reverse Null Response. Figures F.66 to F.70 provide dotplot displays of 480 measurements for the five HF TLC responses. Summary statistics for these responses are given in Table F.37 (Note the outliers identified in this table).

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   -42.0     -40.0     -38.0     -36.0     -34.0     -32.0
```

Figure F.66 Dotplot of 479 Measurements of the Response for HF TLC at 50 MHz (each dot represents up to 4 points)

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-------+---------+---------+---------+---------+---------dB
  -18.90    -18.20    -17.50    -16.80    -16.10    -15.40
```

Figure F.67 Dotplot of 479 Measurements of the Response for HF TLC at 500 MHz (each dot represents up to 3 points)

```
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            :::::::::::::::::::
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    -+---------+---------+---------+---------+---------+-----dB
-13.20    -12.80    -12.40    -12.00    -11.60    -11.20
```

Figure F.68 Dotplot of 478 Measurements of the Response for HF TLC at 1000 MHz (each dot represents up to 2 points)

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            .. :::::::::::::::::::::::::..
     .  . ..::.::::::::::::::::::::::::::::..: .  .  .
 ---+---------+---------+---------+---------+---------+---MHz
636.0     642.0     648.0     654.0     660.0     666.0
```

Figure F.69 Dotplot of 479 Measurements of the HF TLC Reverse Null Frequency (each dot represents up to 2 points)

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      .   .. ..:..::...:::::.:::::::::::::::::::::::::....
   -+---------+---------+---------+---------+---------+-----dB
-66.0     -60.0     -54.0     -48.0     -42.0     -36.0
```

Figure F.70 Dotplot of 479 Measurements of the HF TLC Reverse Null Response (each dot represents up to 2 points)

Table F.37 Summary Statistics for 480 Test Measurements for Response (dB) or Frequency (MHz) for HF TLC (sans outliers)

Circuitry	Mean	Median	St. Dev.	Min	Max	Outliers
HF TLC 50 MHz	-37.57 dB	-37.34	0.974	-42.74	-33.05	-6.13
HF TLC 500 MHz	-18.34 dB	-18.43	0.403	-19.29	-15.57	-6.90
HF TLC 1000 MHz	-12.56 dB	-12.60	0.258	-13.15	-11.07	-7.05 -8.94
HF TLC RNF	649.6 MHz	649.1	4.77	636.6	665.1	935.3
HF TLC RNR	-44.82 dB	-44.01	5.25	-64.89	-34.12	-9.67

F.10.6 Other Networks (Leakage Currents)

The test PWA also contains three test patterns to provide tests for current leakage: (1) the pin grid array (PGA), (2) the gull wing (GW), and (3) 10-mil spaced pads. A 100V source was used to generate leakage currents.

Purpose of the Experiments

The PGA, GW, and 10-mil pads allow leakage currents to be measured on test patterns that are typical in circuit board layouts. These patterns contain several possible leakage paths and the leakage could increase with the presence of flux residues and environmental exposure. In addition, solder mask was applied to portions of the PGA and GW patterns to evaluate its effect on leakage currents and the formation of solder balls.

Pin Grid Array

The PGA hole pattern has four concentric squares that are electrically connected by traces on the top layer of the board as shown in Figure F.71. The pattern also has four vias just inside the corners of the innermost square that are connected to that square. Four vias were placed inside the innermost square to trap flux residues. Two leakage current measurements were made: (1) between the two inner squares (PGA-A) and (2) between the two outer squares (PGA-B), as shown in Figure F.71. Solder mask covers the holes of the two outer squares on the bottom layer, 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.

Gull Wing

The upper half of the topmost GW lands and the lower half of the bottom most GW lands were covered with solder mask to create a region that is susceptible to the formation of solder balls. The lands were visually inspected to detect the presence of solder balls. A nonfunctional GW device is installed with every other lead connected to a circuit board trace forming two parallel paths around the device. Total leakage current measurements were made on adjacent lands of the GW device

10-mil Pads

The 10-mil pads were laid out in two rows of five pads each. The pads within each row were connected on the bottom layer of the board and leakage between the rows was measured.

Baseline Testing Results for Leakage Currents

The leakage currents are converted to resistance (ohms) through the basic equation $R = V/I$. Since the applied voltage is 100 V and the current is measured in nanoamps, this equation can be expressed as $\log_{10} R = 11 - \log_{10} I$.

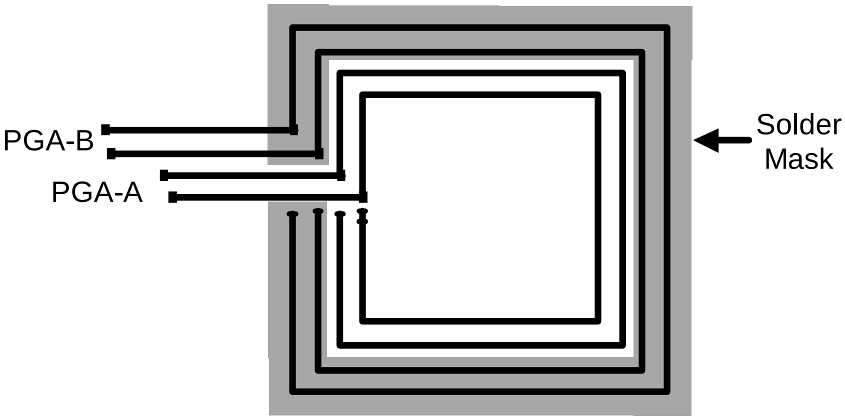

Figure F.71 PGA Hole Pattern with Solder Mask

Table F.38 Significant Coefficients for the GLM Analyses of Leakage Currents

Experimental Variables	10-Mil Pad	PGA A	PGA B	Gull Wing
Constant	11.43	10.63	9.88	11.57
OSP	0.68	0.92	1.22	0.61
Immersion Ag	0.59	0.84	1.22	0.67
Immersion Au/Pd	0.28	0.49	1.52	0.40
Flux	1.61	1.77	2.74	0.89
OSP*Flux	-0.33		-0.60	
Ag*Flux	-0.37	-0.26	-0.90	
Au/Pd*Flux			-0.90	-0.31
Model R^2	60.99	74.52	88.12	35.04
Standard Deviation	0.606	0.542	0.432	.681

General linear modeling (GLM) results for $\log_{10}$ R are given in Table F.38. The GLM results show that surface finish and flux type strongly affect leakage currents. To illustrate these effects, dotplot displays of 480 measurements for the four leakage responses are given by surface finish and flux in Figures F.72 to F075 and by flux in Figure F.76. The summary statistics for these responses are given in Tables F.39 and F.40.

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-----+---------+---------+---------+-------OSP WS
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-----+---------+---------+---------+-------Ag LR
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                              : : ::::::
-----+---------+---------+---------+-------Ag WS
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          .    .:.:::::::::..: :.. .
-----+---------+---------+---------+-------Au/Pd LR
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                              . :....: :
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-----+---------+---------+---------+-------Au/Pd WS
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-----+---------+---------+---------+-------HASL LR
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-----+---------+---------+---------+-------HASL WS
  10.0      11.0      12.0      13.0      14.0
```

Figure F.72 Dotplots for 480 Measurements of Leakage on 10-Mil Pads by Surface Finish and Flux

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                          .     ..:.::::
-----+---------+---------+---------+-------OSP WS
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-----+---------+---------+---------+-------Ag LR
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-----+---------+---------+---------+-------Ag WS
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-----+---------+---------+---------+-------Au/Pd LR
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-----+---------+---------+---------+-------Au/Pd WS
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-----+---------+---------+---------+-------HASL LR
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                  ...: .:::: :::::::::::
-----+---------+---------+---------+-------HASL WS
  10.0      11.0      12.0      13.0      14.0
```

Figure F.73 Dotplots for 480 Measurements of Leakage on PGA A by Surface Finish and Flux

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-----+---------+---------+---------+-------OSP LR
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-----+---------+---------+---------+-------OSP WS
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-----+---------+---------+---------+-------HASL LR
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-----+---------+---------+---------+-------HASL WS
  10.0      11.0      12.0      13.0      14.0
```

Figure F.74 Dotplots for 480 Measurements of Leakage on PGA B by Surface Finish and Flux

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-----+---------+---------+---------+-------OSP WS
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-----+---------+---------+---------+-------Ag LR
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-----+---------+---------+---------+-------Ag WS
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-----+---------+---------+---------+-------Au/Pd LR
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-----+---------+---------+---------+-------Au/Pd WS
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-----+---------+---------+---------+-------HASL LR
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-----+---------+---------+---------+-------HASL WS
  10.0      11.0      12.0      13.0      14.0
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Figure F.75 Dotplots for 480 Measurements of Leakage on the Gull Wing by Surface Finish and Flux

Table F.39 Summary Statistics for Leakage Currents Test Measurements by Surface Finish and Flux

Circuitry	Surface Finish	Flux	Mean	Median	St. Dev.	Min	Max
10-Mil Pads	**OSP**	**LR**	12.11	11.94	0.77	10.91	15.00
		WS	13.39	13.52	0.55	11.12	14.00
	Immersion Ag	**LR**	12.02	11.90	0.76	10.73	15.00
		WS	13.26	13.30	0.38	12.48	14.00
	Immersion Au/Pd	**LR**	11.81	11.73	0.54	10.47	14.00
		WS	13.22	13.22	0.60	11.91	15.00
	HASL	**LR**	11.29	11.29	0.33	10.34	12.30
		WS	13.15	13.40	0.67	11.57	15.00
PGA A	**OSP**	**LR**	11.59	11.62	0.67	10.38	13.15
		WS	13.28	13.30	0.26	12.12	13.70
	Immersion Ag	**LR**	11.47	11.39	0.66	10.16	13.22
		WS	12.98	12.94	0.33	12.18	14.00
	Immersion Au/Pd	**LR**	11.23	11.20	0.56	10.18	13.15
		WS	12.78	12.80	0.62	11.67	15.00
	HASL	**LR**	10.45	10.46	0.28	9.94	11.10
		WS	12.56	12.66	0.58	11.29	13.40
PGA B	**OSP**	**LR**	11.10	11.11	0.43	9.91	12.09
		WS	13.23	13.30	0.25	11.85	13.52
	Immersion Ag	**LR**	11.10	11.12	0.47	10.13	12.40
		WS	12.94	13.00	0.27	12.19	13.30
	Immersion Au/Pd	**LR**	11.47	11.44	0.50	10.09	13.15
		WS	13.16	13.10	0.39	12.51	15.00
	HASL	**LR**	9.74	9.75	0.29	9.11	10.35
		WS	12.70	12.70	0.35	11.65	13.40
Gull Wing	**OSP**	**LR**	12.15	12.40	0.90	9.01	13.52
		WS	13.10	13.22	0.65	11.44	16.00
	Immersion Ag	**LR**	12.23	12.32	0.60	10.66	13.52
		WS	13.14	13.46	0.70	10.91	14.00
	Immersion Au/Pd	**LR**	11.99	12.02	0.57	10.35	13.22
		WS	12.53	12.66	0.64	10.69	14.00
	HASL	**LR**	11.57	11.52	0.39	10.26	12.62
		WS	12.44	12.70	0.86	9.48	13.52

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     -----+---------+---------+---------+-------PGA A WS
       10.0      11.0      12.0      13.0      14.0
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Figure F.76 Dotplots for 480 Leakage Measurements by Flux

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      -----+---------+---------+---------+-------PGA B LR

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Each dot represents up to 3 points        ::
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      -----+---------+---------+---------+-------GullWing WS
        10.0      11.0      12.0      13.0      14.0
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Figure F.76 Continued

F.10.7 Stranded Wires

Two 22-gauge stranded wires were hand soldered just to the left of the edge connector. One wire was soldered directly into the board through holes and the other were soldered to two terminals, E17 and E18. Each wire is 1.5 *in* long, is silver coated, and has white PTFE insulation. All wires were stripped, tinned, and cleaned in preparation for the soldering process.

Purpose of the Stranded Wire Experiment

Stranded wires were used to evaluate flux residues and subsequent corrosion.

Table F.40 Summary Statistics for Leakage Currents Test Measurements by Flux

Circuitry	Flux	Mean	Median	St. Dev.	Min	Max
10-Mil Pads	**LR**	11.80	11.68	0.70	10.34	15.00
	WS	13.25	13.30	0.56	11.12	15.00
PGA A	**LR**	11.18	11.10	0.72	9.94	13.22
	WS	12.90	13.00	0.54	11.29	15.00
PGA B	**LR**	10.85	11.00	0.79	9.11	13.15
	WS	13.01	13.07	0.38	11.65	15.00
Gull Wing	**LR**	11.99	12.02	0.68	9.01	13.52
	WS	12.80	12.94	0.78	9.48	16.00

Circuit Description

The 5A 100μs pulse used to test the HCLV circuit was injected into each of the stranded wires for electrical test. A separate PWB trace was connected to each end of the stranded wire. Test wires were connected to the separate traces allowing to provide the means to measure the voltage drop across the stranded wires. In this manner, the voltage drop was measured independently from any voltage drop in the test wires conducting the 5A pulse to the stranded wires.

Baseline Testing Results for Stranded Wires

Surface finish and flux type had very little effect on the HF TLC frequencies and responses for HF TLC 50 MHz, HF TLC 500 MHz, HF TLC 1000 MHz, HF TLC Reverse Null Frequency, and HF TLC Reverse Null Response. Figures F.77 and F.78 provide dotplot displays of 480 measurements for the two stranded wire voltages. The summary statistics for these responses are given in Table F.41.

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---+---------+---------+---------+---------+---------+---mV
 8.0      10.0      12.0      14.0      16.0      18.0
```

Figure F.77 Dotplots for 480 Voltage Measurements for Stranded Wire 1
(each dot represents up to 11 points)

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-----+---------+---------+---------+---------+---------+-mV
   20.0      22.0      24.0      26.0      28.0      30.0
```

Figure F.80 Dotplots for 476 Voltage Measurements for Stranded Wire 2 (each dot represents 8 points)

Table F.41 Summary Statistics for Stranded Wires Voltage Test Measurements

Circuitry	Mean	Median	St. Dev.	Min	Max	Outliers
Stranded Wire 1	11.75mV	12.00	1.60	8.00	18.00	
Stranded Wire 2	24.82mV	25.00	2.41	19.00	30.00	42,43, 45, 45

F.10.8 Summary Statistics for All Baseline Measurements

For ease of reference, Table F.42 gives the summary statistics for all 23 electrical responses from the test PWA.

F.10.9 Listing of Components

All functional component types conformed to commercial specifications and were ordered pre-tinned (to the extent possible). Components were not pre-cleaned before use. A listing of all components is given in the Table F.43.

Table F.42 Summary Statistics for All Baseline 480 Measurements (sans outliers)

Circuitry	Mean	Median	St. Dev.	Min	Max	Outliers
High Current Low Voltage						
HCLV PTH	6.88V	6.92	0.16	6.60	7.20	
HCLV SMT	7.20V	7.20	0.10	6.88	7.44	
High Voltage Low Current						
HVLC PTH	5.04µA	5.04	0.024	4.972	5.148	5.203 5.232
HVLC SMT	4.95µA	4.95	0.011	4.914	4.976	
High Speed Digital						
HSD PTH	13.04µ sec	0.12	13.04	12.56	13.44	14.40
HSD SMT	5.02µ sec	0.08	5.02	4.75	5.39	
High Frequency Low Pass Filter						
HF PTH 50 MHz	-0.254 dB	-0.253	0.024	-0.319	-0.194	-0.351 -0.150 -0.148 -0.138 -0.130 -0.107 -0.096
HF PTH –3dB	250.5 MHz	249.2	5.74	230.5	260.8	227.6 230.5 305.3 306.5 307.2 307.7 308.3 308.9
HF PTH –40dB	440.5 MHz	440.1	5.96	425.3	464.4	506.6 507.2 507.8 513.1 513.7 514.3
HF SMT 50 MHz	-0.242 dB	-0.241	0.022	-0.329	-0.173	-0.447 -0.164 -0.144 -0.074 -0.066 -0.062 -0.061
HF SMT –3dB	278.4 MHz	278.6	1.21	273.8	282.2	225.2 295.8 299.4 301.8 302.9 302.9 355.2 381.9 383.1 384.3 389.6
HF SMT –40dB	660.7 MHz	661.6	7.46	639.0	680.6	694.8 701.9 708.5 719.8 721.5 758.3 862.8 872.3 877.7 890.2 924.6
High Frequency Transmission Line Coupler						
HF TLC 50 MHz	-37.61 dB	-37.38	0.957	-42.74	-33.05	-6.13
HF TLC 500 MHz	-18.31 dB	-18.40	0.389	-19.29	-15.57	-6.90
HF TLC 1000 MHz	-12.55 dB	-12.58	0.254	-13.15	-11.07	-7.05 -8.94
HF TLC RNF	649.5 MHz	649.1	4.87	636.6	665.1	935.3
HF TLC RNR	-44.68 dB	-43.96	5.208	-64.89	-34.12	-9.67
Leakage (resistance in log 10 ohms)						
10-Mil Pads (LR)	11.79	11.69	0.64	10.63	15.00	
10-Mil Pads (WS)	13.27	13.40	0.56	11.12	15.00	
PGA A (LR)	11.17	11.11	0.70	10.01	13.15	
PGA A (WS)	12.89	13.05	0.52	11.29	14.00	
PGA B (LR)	10.84	11.04	0.80	9.11	12.46	
PGA B (WS)	13.01	13.10	0.34	11.65	13.52	
Gull Wing (LR)	12.03	12.05	0.66	10.15	13.52	
Gull Wing (WS)	12.81	12.96	0.71	10.52	14.00	
Stranded Wire						
Stranded Wire 1	11.75mV	12.00	1.50	8.00	18.00	
Stranded Wire 2	24.71mV	25.00	2.38	19.00	30.00	42, 43, 45, 45

Table F.43 Listing of Components for the Test PWA

MFG P/N	Description	Quantity per Assembly	Supplier
ACC916228-2	PGA Socket, 18X18 (223 PINS)	1	AMP
350-60-2	6 Split washer	3	Barnhill Bolt
402-632-38-0110	6-32 UNC Mach Screw	3	Barnhill Bolt
231-632-A-2	6-32 UNC Mach Screw Nut	3	Barnhill Bolt
RWR89N10R0FR	Resistor, 10 Ohm, Axial	7	Dale
M55342M09B10MOM	Resistor, 10 Ohm, Surface Mnt	7	Dale
RLR07C1005FR	Resistor,10Meg Axial	5	Dale
M55342M09B10POM	Resistor,10Meg Surface Mount	5	Dale
2309-2-00-44-00-07-0	Swage pin	17	Harrison HEC
KA29/127BPMCTH	29 Pin Connector,Pretin	1	Hypertonics
C1825N474K5XSCxxxx	CAP, .47 UF, Surf Mnt	7	Kemet
C0627104K1X5CS7506	CAP, 0.1 UF, Radial	7	Kemet
C1825N104K1XRC	CAP, 0.1 UF, Surf Mnt	7	Kemet
C062T105K5X5CSxxxx	CAP, 1 UF, Radial	7	Kemet
C052G130J2G5CR	CAP, 13 PF, Radial	1	Kemet
CDR31BP130BJWR	CAP, 13 PF, Surf Mnt	1	Kemet
C052G240J2G5CRxxxx	CAP, 24 PF, Radial	1	Kemet
C0805N240J1GRC37317537	CAP, 24 PF, Surf Mnt	1	Kemet
C0805N629B1GSC37317535	CAP, 6.2 PF ±0.5%, Surf Mnt	1	Kemet
C052G629D2G5CR7535	CAP, 6.2 PF, ±0.5%, Radial	1	Kemet
JM38510/33001B2A	20 Pin LCC	1	TI (808810.1001)
JM38510/33001BCA	14 Pin Dual-In-Line	2	TI (808810.1)
QFP80T25	80 Pin SQ Flat Pack	1	Top Line
CS1	Cap	1	Top Line
CKR06	Cap	2	Top Line
SC1210E7Axxxx	Cap	13	Top Line
D034	Diode	13	Top Line
RN65	Resistor	1	Top Line
RN55(sub for CS1, Qty 800)	Resistor	5	Top Line
SR1210E7A	Resistor	18	Top Line
T05	Transistor	4	Top Line
TO220M-3	Transistor	3	Top Line
5162-5013-09	Connector, RF, OMNI Spec	10	TTI
131-3701-201	Sub for 5162-5013-09	10	Penstock

F.11 Design for the Environment Printed Wiring Board Project Performance Demonstration Methodology for Alternative Surface Finishes

Note: This methodology is based on input from members of a Performance Demonstration Technical Workgroup, which includes representatives of the printed wiring board (PWB) industry manufacturers, assemblers, and designers; industry suppliers; public interest group; Environmental Protection Agency (EPA); the University of Tennessee Center for Clean Products and Clean Technologies; and other stakeholders. As the testing continues, there may be slight modifications to this methodology.

I. OVERVIEW

A. Goals

The U.S. Environmental Protection Agency’s (EPA=s) Design for the Environment (DfE) Printed Wiring Board (PWB) Project is a cooperative partnership among EPA, the PWB industry, public interest groups, and other stakeholders. The project encourages businesses to incorporate environmental concerns into their decision-making processes, along with the traditional parameters of cost and performance, when choosing which technologies and processes to implement. To accomplish this goal, the DfE PWB Project collects detailed data on the performance, cost, and risk aspects of one Ause cluster@ or manufacturing operation, and makes it available to all interested parties. This use cluster focuses on surface finishes used in PWB manufacturing. Analyses on the performance, cost, and risk of several alternative surface finishes will be conducted throughout this project, and the results will be documented in the final project report, titled the *Cleaner Technologies Substitutes Assessment* or CTSA. This methodology provides the general protocol for the performance demonstration portion of the DfE PWB Project. The CTSA is intended to provide manufacturers and designers with detailed information so that they can make informed decisions, taking environmental and health risks into consideration, on what process is best suited for their own facility.

Surface finishes are applied to PWBs to prevent oxidation of exposed copper on the board, thus ensuring a solderable surface when components are added at a later processing stage . Specifically, the goals of the DfE PWB Surface Finishes Project are:

1) to standardize existing information about surface finish technologies;
2) to present information about surface finish technologies not in widespread use, so PWB manufacturers and designers can evaluate the environmental and health risks, along with the cost and performance characteristics, among different technologies; and
3) to encourage PWB manufacturers and designers to follow the example of this project and evaluate systematically other technologies, practices, and procedures in their operations that affect the environment.

B. General Performance Demonstration Plan

The most widely used process for applying surface finishes in commercial PWB shops is hot air solder leveling (HASL). In this process, tin-lead is fused onto exposed copper surfaces. This process was selected as the focus of the Design for the Environment Project because HASL is a source of lead waste in the environment and because there are several alternative surface finishes available on the market. A comprehensive evaluation of these technologies, including performance, cost, and risk, however, has not been conducted. In addition, a major technical concern is that the HASL process

does not provide a level soldering surface for components.
The general plan for the performance demonstration portion of the Project is to collect data on alternative surface finish processes during actual production runs at sites where the processes are already in use. Demonstration facilities will be nominated by suppliers. These sites may be customer production facilities, customer testing facilities (beta sites), or supplier testing facilities, in that order of preference. Each demonstration site will receive standardized test boards which they will run through their surface finish operation during their normal production operation.

The test vehicle design will be tested on the test board designed by the Sandia National Laboratory Low-Residue Soldering Task Force (LRSTF). The same test vehicle was used by the Circuit Card Assembly and Materials Task Force (CCAMTF). CCAMTF is a joint industry and military program evaluating several alternative technologies including Organic Solderability Preservative (OSP), Immersion Silver, Electroplated Palladium/Immersion Gold, Electroless Nickel/Immersion Gold, and Electroplated Palladium. CCAMTF conducted initial screening tests on coupons for each of these surface finishes, however, they will conduct functionality tests only for the OSP (thick), Electroplated Palladium/Immersion Gold, and Immersion Silver technologies.

II. PERFORMANCE DEMONSTRATION PROTOCOL

A. Technologies to be Tested

The technologies that the DfE Project plans to test include:

1. HASL (baseline)
2. OSP – Thick
3. Immersion Tin
4. Immersion Silver
5. Electroless Nickel/Immersion Gold
6. Nickel/Palladium/Gold

B. Step One: Identify Suppliers and Test Sites/Facilities

Performance Demonstration Technical Workgroup members identified suppliers of the above product lines. Any supplier of these technologies who wanted to participate was eligible to submit its product line, provided that it agreed to comply with the testing methodology and submit the requested information, including chemical formulation data. All proprietary information submitted is bring handled as Confidential Business Information. For each product line submitted, the supplier completed a Supplier Data Sheet detailing information on the chemicals used, equipment requirements, waste treatment recommendations, any limitations of the technology, and other information on the product line.

Performance demonstration sites were nominated by suppliers. They identified sites that are currently using their alternative surface finish product line in the following order of preference:
- customer production facilities (first preference)
- beta sites – customer testing facilities (second preference)
- supplier testing facilities (third preference)

The final number of product lines evaluated for each type of alternative surface finish was determined based on the number of suppliers interested in participating and on the resources available. Each accepted product line was tested at one or two sites. If a supplier has more than one substantially different product line within a technology, the supplier was allowed to submit names of test facilities for each of the products.

C. Step Two: Fabricate Test Vehicles

Test board were fabricated based on the Sandia National Laboratory Low-Residue Soldering Task Force (LRSTF) test board design. This general design was also used in the CCAMTF testing. For the DfE Project, uncoated test boards with comb pattern spacing of 8 mil, 12 mil, 16 mil, and 20 mil will be used.

All test boards are of the same design, and were fabricated at a single shop to minimize the variables associated with board production. All manufacturing steps, up to but not including the soldermask application, were completed by the test board fabricator. For each supplier's product line, 24 boards were shipped to the demonstration site where the alternative surface finish was applied, beginning with the soldermask application step.

The design of the LRSTF PWB was based on input from a large segment of the manufacturing community, and thus reflects the multiple requirements of the commercial sector. Each quadrant of the LRSTF PWA contain one of the following types of circuity:

High-current low-voltage (HCLV)
High-voltage low current (HVLC)
High speed digital (HSD)
High frequency (HF)

The components in each quadrant represent two principal types of soldering technology:

Plated through hole (PTH) – leaded components are soldered through vias in the circuit board by means of a wave soldering operation.
Surface mount technology (SMT) – components manufactured with solder tips on two of their opposite ends are temporarily attached to the substrate with an adhesive and then they are soldered to pads on the circuit board by passing the circuit board through a reflow oven to reflow the solder tips.

The LRSTF PWA also has two stranded wires (SW) that are secured to the circuit board with hand soldering, such as used in repair operations. This assembly also contains other networks that are used to monitor current leakage.

D. Step Three: Collect Background Information

After the suppliers identified appropriate test facilities and completed a supplier data sheet, an independent observer contacted the designated facilities. The observer scheduled a date for the on-site performance demonstration. A questionnaire was sent to each facility prior to the site visit to collect information on the surface finish technology used and background information on the facility, such as the size and type of product produced. On the day of the performance demonstration, the observer reviewed the background questionnaire and discussed any ambiguities with the facility contect.

E. Step Four: Conduct the Surface Finish Performance Demonstration

After test boards were distributed to the demonstration sites, the surface finish performance demonstrations were conducted. The surface finish was applied to the test boards as part of the normal production run at the facility. The test boards were placed in the middle of the run to reflect actual production conditions. The facility applied the solder mask it normally uses in production. The usual process operator operated the line to minimize error due to unfamiliarity with the technology. All test boards were processed in the same production run.

On the day of the performance demonstration, the observer collected data on the surface finish process. During the demonstration, the observer recorded information on surface finish technology performance, including information on chemicals, equipment, and waste treatment methods used. In addition, other information needed for the performance, cost, or risk analyses, as described below, was collected.

1. **Product Cost:** A cost per square foot of panel processed will be calculated. This number will be based on information provided by product suppliers, such as purchase price, recommended bath life and treatment/disposal methods, and estimated chemical and equipment costs per square foot panel per day. Any “real world” information from PWB manufacturers, such as actual dumping frequencies, treatment/disposal methods, labor requirements, and chemical and equipment costs, will be collected during performance demonstrations, as required for use in the cost analysis. The product cost may differ for difference shop throughput categories.
2. **Product Constraints:** Information on any incompatibilities such as soldermask, flux, substrate type, or assembly process will be included. This information will be submitted by the suppliers and may also be identified as a result of the performance demonstrations.
3. **Special storage, safety, and disposal requirements:** Information on flammability or special storage requirements of the chemicals used in the process will be requested from the suppliers. Suppliers will provide recommendations on disposal or treatment of wastes associated with the use of their product lines. Information on these issues was also collected from participating facilities during the performance demonstrations. The storage and disposal costs will be a factor in determining the adjusted cost of the product. This project does not entail a life cycle analysis for disposal of the boards.
4. **Ease of use:** During the performance demonstration, the physical effort required to use the various surface finishes effectively will be qualitatively assessed based on the judgement of the operator in comparison to the baseline technology, HASL. Specific questions such as the following will be asked: What process operating parameters are needed to ensure good performance? What are the ranges of those parameters, and is there much flexibility in the process steps? How many hours of training are required to use this type of surface finish?
5. **Duration of Production Cycle:** The measured time of the surface finish application process and the number of operators required will be recorded during the performance demonstration. This information will be used to measure the labor costs associated with the use of the product line. Labor costs will be based on the operator time required to run the process using an industry standard worker wage. The process cycle has been defined as the activities following soldermask application up to, but not including, gold tab plating. The facilities participating in the performance demonstration will use the same soldermask they typically use in production conditions. The observer recorded the type of soldermask used, and information on the facilities’ experiences with other soldermasks to determine if any known incompatibilities exist.

6. **Effectiveness of Technology, Product Quality:** The performance characteristics of the assembled boards will be tested after all demonstrations are complete and the boards are assembled with the functional components. Circuit electrical Performance will be tested to assess the circuit performance of the functional test vehicle under applicable environmental stress. Circuit Reliability Testing (functional tests) conditions will include Thermal Shock and Mechanical Shock. These tests are described in greater detail in Step 5. Qualitative information on shelf life considerations were collected through the performance demonstrations, where applicable.
7. **Energy and Natural Resource Data:** Information will be collected from the suppliers and during the performance demonstrations to evaluate the variability of energy consumption for the use of different surface finishes. The analysis will also address material use rates and how the rates vary with the different surface finishes.
8. **Exposure Data:** Exposure data will be used to characterize chemical exposures associated with the technologies. Exposure information collected during the performance demonstration may be supplemented with data from other sources, where available.

F. Step Five: Assemble and Test the Boards

After the surface finish was applied to the test boards at each demonstration facility, the facility sent the processed boards to one site for assembly. Two different assembly processes were used: a halide-free, low-residue flux and a halide-containing, water-soluble flux. Table 1 shows the different assembly methods, and number of test vehicles used for each method. The boards were not assembled as originally planned, resulting in the uneven distribution of assembly methods.

Table 1: Test Vehicle Distribution by Site and Flux

Site #	Surface Finishes*	# of Boards Assembled with Low Residue Flux	# of Boards Assembled with Water Soluble Flux	Total Boards by Site and by Surface Finish
1	HASL	8	8	16
2	HASL	0	8	8
6	HASL	8	0	8
	HASL Totals	16	16	32
3	OSP-Thick	4	8	12
13	OSP-Thick	8	8	16
16	OSP-Thick	8	0	8
	OSP Totals	20	16	36
4	Immersion Tin	0	8	8
5	Immersion Tin	4	8	12
10	Immersion Tin	8	0	8
11	Immersion Tin	8	0	8
	Immersion Tin Totals	20	16	36
8	Immersion Silver	0	8	8
9	Immersion Silver	8	4	12
	Immersion Silver Totals	8	12	20
7	Electroless Ni/Immersion Au	0	8	8
12	Electroless Ni/Immersion Au	8	0	8
14	Electroless Ni/Immersion Au	4	8	12
	NI/Au Totals	12	16	28
	Subtotals	84	80	
		Total test boards: 164		

* Corresponding board identification numbers are listed in Appendix A.

Following assembly, the performance characteristics of the assembled boards will be tested. Testing will include Circuit Electrical Performance testing and Circuit Reliability Testing.

Circuit Electrical Performance

This test assesses the circuit performance of a functional test vehicle under applicable environmental stress. The assembled test vehicles will be exposed to 85 ^{o} C at 85% relative humidity for 3 weeks. The assemblies will be tested prior to exposure, and at the end of three weeks of exposure. Good experimental design practices will be followed to control extraneous sources of variation. For example, the assemblies will be placed randomly in the test chamber. If all assemblies cannot be accommodated in the test chamber at the same time, they will be randomized to maintain balance among the experimental factors at each test time. A staggered ramp will be used to prevent condensation (during ramp-up, the temperature will be raised to test level before the humidity is raised and the procedure will be reversed during ramp-down). The pre-tests and post-tests will be identical.

Circuit Reliability Testing
The same test vehicles used to test circuit electrical performance will be used for the circuit reliability tests, which include:

- Thermal Shock
- Mechanical Shock

The electrical functionality of the LRSTF PWA will be evaluated through 23 electrical responses, as follows:

HCLV PTH voltage
HCLV SMT voltage
Stranded wire 1 voltage
Stranded wire 2 voltage
HVLC PTH current
HVLC SMT current
10-mil spaced pads current leakage
PGA A current leakage
PGA B current leakage
Gull wing current leakage
HSD PTH total propagation delay
HSD SMT total propagation delay
HF LPF PTH 50 MHz response
HF LPF PTH frequency response at –3 dB
HF LPF PTH frequency response at –40 dB
HP LPF SMT 50 MHz response
HF LPF SMT frequency response at –3 dB
HF LPF SMT frequency response at –40 dB
HF TLC 50 MHz forward response
HF TLC 500 MHz forward response
HF TLC 1000 MHz forward response
HF TLC reverse null frequency
HF TLC reverse null response

Table 2 shows the total number of electrical responses that will be measured.

Table 2. Number of Tests to be Conducted

Test Environment	Number of PWBs	Number of Test Times	Number of Tests	Number of Electrical Responses Measured
85/85	164	2	164 x 2 = 328	164 x 2 x 23 = 7,544
Thermal Shock		1	164 x 1 = 164	164 x 1 x 23 = 3,772
Mechanical Shock		1	164 x 1 = 164	164 x 1 x 23 = 3,722
Totals	**164**	**4**	**656**	**15,088**

G. Analyze Data and Present Results

The details of the data analysis and results are presented in the "Technical Proposal for this project, in Appendix B.

III. PERFORMANCE DEMONSTRATION PARTICIPANT REQUIREMENTS

A. From the Facilities/Process Operators:

1. Participating facilities were contacted by the project observer to arrange a convenient data for the performance demonstration. The observer sent a fact sheet describing the facility's role in the project.
2. Each facility was asked to complete a background questionnaire prior to the scheduled date of the performance demonstration and return it to the observer.
3. Each facility was asked to make its process line/process operators available to run the 24 test boards on the agreed upon date.
4. The process operator met with the independent observer before running the test boards through the line to explain the unique aspects of the line to the observer. The process operator was asked to be available to assist the independent observer in collecting information about the line.

B. From the Suppliers of the Process Line Alternatives:

1. Suppliers were asked to submit product data sheets, on which they provided information on product formulations, product constraints, recommended disposal/treatment etc. The information, including chemical formulation information, was requested prior to testing. Any proprietary information was submitted to the University of Tennessee as Confidential Business Information.
2. Suppliers were asked to identify and contact the demonstration sites.
3. Suppliers were asked to attend the on-site performance demonstration if they wishes to do so, but they were not required to attend.

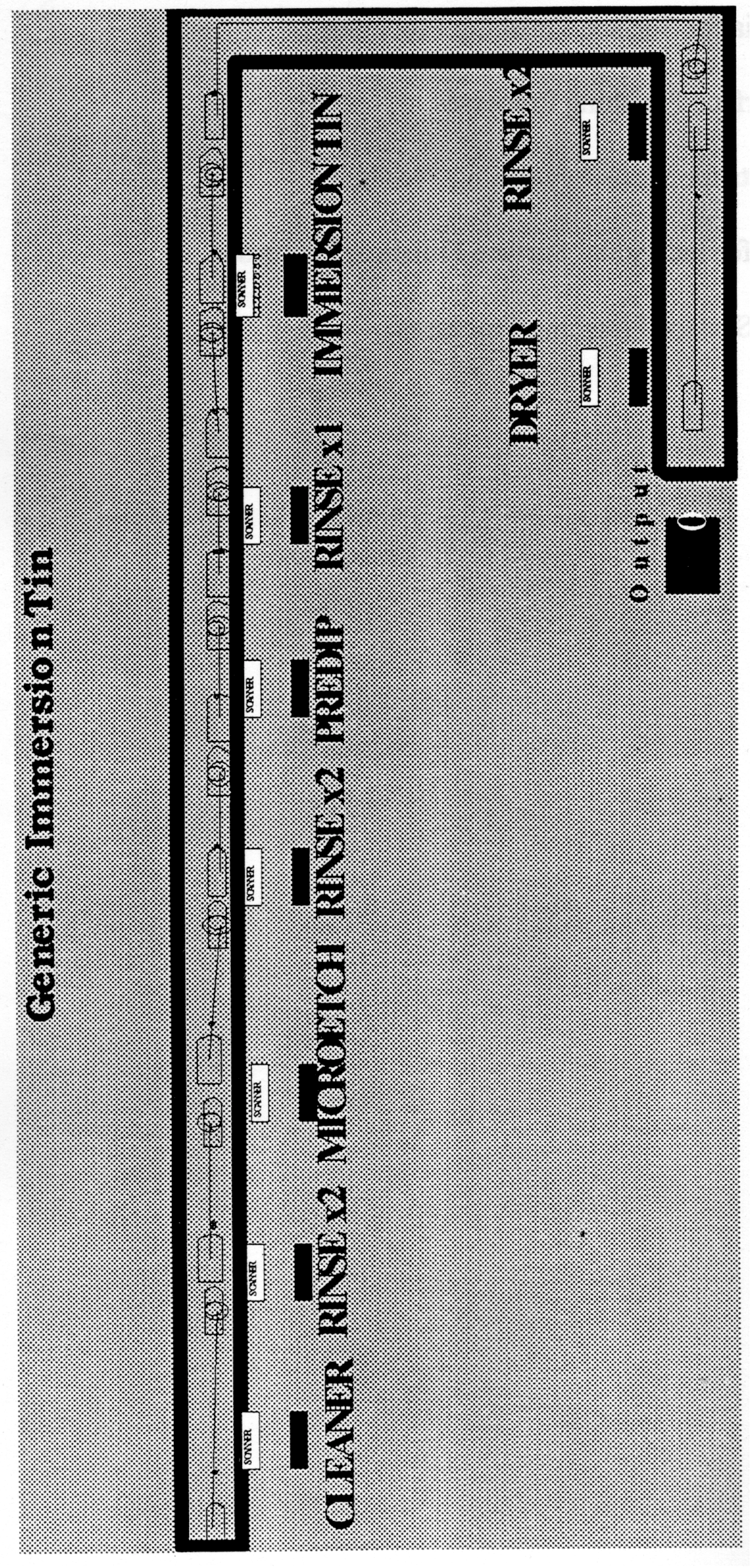
Attachment A to this Methodology lists "Identification Numbers for Assembled Boards." To conserve space this information as not been reprinted as part of the CTSA.

Attachment B to this Methodology is the "Technical/Management Proposal for Validation of Alternatives to Lead Containing Surface Finishes." This Attachment contains the testing and analysis methodology submitted by Dr. Ronald L. Inman, President, Southwest Technology Consultants in Albuquerque, MN. Dr. Inman's methodology and results are presented in Chapter 6 of the CTSA and in Appendix F, and therefore, Attachment B of the Methodology is not repeated here.

Appendix G

Supplemental Cost Analysis Information

G-1. Example Graphic Representation of Cost Simulation Model



G-2 Bath Replacement Criteria for Surface Finishing Processes

Process: HASL

Chemical Bath	Bath Replacement Criteria[a] (ssf/gal)
Cleaner	750
Microetch	570
Flux	NA[b]
Solder	NA[b]

[a] Values were selected by averaging the replacement criteria for similar bath types from other alternatives.

[b] This bath is refilled or continuously maintained through chemical additions rather than replaced. The number of bath replacements was set at one to reflect the initial bath make-up for the purposes of the computer simulation.

Process: Electroless Nickel/Immersion Gold

Chemical Bath	Bath Replacement Criteria[a] (ssf/gal)
Cleaner	750
Microetch	570
Catalyst	830
Acid Dip	1,500
Electroless Nickel	130
Immersion Gold	890

[a] Values were determined from data provided by two electroless nickel/immersion gold suppliers. To convert to units of racks per bath replacement for non-conveyorized processes, multiply by 51.1 gallons and divide by 84.4 ssf/rack.

Process: Electroless Nickel/Electroless Palladium/Immersion Gold

Chemical Bath	Bath Replacement Criteria[a] (ssf/gal)
Cleaner	750
Microetch	570
Catalyst	830
Acid Dip	1,500
Electroless Nickel	130
Preinitiator	1,200
Electroless Palladium	150
Immersion Gold	890

[a] Values were determined from data provided by two electroless nickel/immersion gold suppliers and one electroless nickel/palladium/immersion gold supplier. To convert to units of racks per bath replacement for non-conveyorized processes, multiply by 51.1 gallons and divide by 84.4 ssf/rack.

Process: OSP

Chemical Bath	Bath Replacement Criteria[a] (ssf/gal)
Cleaner	750
Microetch	570
OSP	NA[b]

[a] Values were determined from data provided by two OSP suppliers. To convert to units of racks per bath replacement for non-conveyorized processes, multiply by 51.1 gallons and divide by 84.4 ssf/rack. To convert to units of panels per bath replacement for conveyorized process, multiply by the size of the bath in gallons and divide by 5.66 ssf/panel.

[b] This bath is refilled or continuously maintained through chemical additions rather than replaced. The number of bath replacements was set at one to reflect the initial bath make-up for the purposes of the computer simulation.

Process: Immersion Silver

Chemical Bath	Bath Replacement Criteria[a] (ssf/gal)
Cleaner	750
Microetch	570
Predip	1,000
Immersion Silver	NA[b]

[a] Values were determined from data provided by two OSP suppliers. To convert to units of panels per bath replacement for conveyorized process, multiply by the size of the bath in gallons and divide by 5.66 ssf/panel.

[b] This bath is refilled or continuously maintained through chemical additions rather than replaced. The number of bath replacements was set at one to reflect the initial bath make-up for the purposes of the computer simulation.

Process: Immersion Tin

Chemical Bath	Bath Replacement Criteria[a] (ssf/gal)
Cleaner	750
Microetch	570
Predip	1,250
Immersion Tin	NA[b]

[a] Values were determined from data provided by two OSP suppliers. To convert to units of racks per bath replacement for non-conveyorized processes, multiply by 51.1 gallons and divide by 84.4 ssf/rack. To convert to units of panels per bath replacement for conveyorized process, multiply by the size of the bath in gallons and divide by 5.66 ssf/panel.

[b] This bath is refilled or continuously maintained through chemical additions rather than replaced. The number of bath replacements was set at one to reflect the initial bath make-up for the purposes of the computer simulation.

G-3 Bills of Activities for Surface Finishing Processes

Activities Associated with the Bath Setup

Activity Description	Cost Driver	Cost/Activity
Wear masks, goggles, rubber gloves, and suitable clothing	**$/bath setup**	**$2.50**
Go to storage area	labor	
Locate protective equipment	labor	
Put on protective equipment	labor	
	protective equipment	
Return to tank	labor	
Put in base liquid (usually water)	**$/bath setup**	**$2.60**
Open water valve	labor	
Wait for measured amount	labor	
Close water valve	labor	
Document water amount/level	labor	
Mix the bath solution	**$/bath setup**	**$5.00**
Open the chemical containers	labor	
Add the chemicals to the bath	labor	
Turn on the agitator	labor	
Wait for mixing	labor	
Turn off the agitator	labor	
Titrate sample	labor	
Document	labor	
Repeat as necessary	labor	
Flush containers	**$/bath setup**	**$3.00**
Turn on water valve	labor	
Spray containers	labor	
Turn off water valve	labor	
Place empty container in storage area	**$/bath setup**	**$2.00**
Take container to storage	labor	
Documentation	labor	
Return to tank	labor	
Total =	**$per testing**	**$15.10**

Activities Associated with the Tank Cleanup

Activity Description	Cost Driver	Cost/Activity
Rinse with water	**$/cleanup**	**$25.00**
Obtain spray/rinse equipment	labor	
Turn water on	labor	
Spray equipment	labor	
Turn water off	labor	
Obtain scrubbing and cleaning tools	**$/cleanup**	**$1.00**
Go to storage area	labor	
Find necessary tools	labor	
Return to tank	labor	
Hand scrub tank	**$/cleanup**	**$30.00**
Put on gloves, choose tool	labor	
Scrub tank	labor	
	cleaning supplies	
Return cleaning tools	**$/cleanup**	**$1.25**
Go to the storage area	labor	
Place tools in correct place	labor	
Return to tank	labor	
Spray according to schedule	**$/cleanup**	**$5.00**
Wait for time to elapse before spraying	labor	
Obtain spray equipment	labor	
Turn spray on	labor	
Spray all cleaning solution from tank	labor	
Turn spray off	labor	
Operator opens control valve	**$/cleanup**	**$1.00**
Find correct control valve	labor	
Open valve	labor	
Water goes to treatment facility	**$/cleanup**	**$2.75**
Wait for water to drain	labor	
Operator closes control valve	**$/cleanup**	**$1.00**
Locate correct control valve	labor	
Close valve	labor	
Total =	**$per testing**	**$67.00**

Activities Associated with Sampling and Testing

Activity Description	Cost Driver	Cost/Activity
Get sample	**$/testing**	**$1.35**
Go to the line	labor	
Titrate small sample into flask	labor	
	materials	
Transfer to lab	labor	
Test sample	**$/testing**	**$1.35**
Request testing chemicals	labor	
Document request	labor	
Locate chemicals	labor	
Add chemicals to sample	labor	
	materials	
Mix	labor	
Document the results	labor	
Return testing chemicals	labor	
Relay information to line operator	**$/testing**	**$1.00**
Return to line	labor	
Inform operator of results	labor	
Document	labor	
Total =	**$per testing**	**$3.70**

Activities Associated with Filter Replacement

Activity Description	Cost Driver	Cost/Activity
Check old filter	**$/replacement**	**$1.50**
Pull canister from process	labor	
Inspect filter	labor	
Decide if replacement is necessary	labor	
Get new filer	**$/replacement**	**$1.75**
Go to storage area	labor	
Locate new filters	labor	
Fill out paper work	labor	
Return to tank	labor	
Change filter	**$/replacement**	**$12.25**
Pull old filter from canister	labor	
Replace with new filter	labor	
	filter	
Replace canister	labor	
Fill out paper work	labor	
Dispose of old filter	**$/replacement**	**$2.00**
Take old filter to disposal bin/area	labor	
Dispose of filter	labor	
Return to tank	labor	
Fill out paper work	labor	
Total =	**$per replacement**	**$17.50**

Activities Associated with Transportation

Activity Description	Cost Driver	Cost/Activity
Paperwork and maintenance	**$/transportation**	**$1.10**
Request for chemicals	labor	
Updating inventory logs	labor	
Safety and environmental record keeping	labor	
Move forklift to chemical storage area	**$/transportation**	**$3.22**
Move to forklift parking area	labor	
Prepare forklift to move chemicals	labor	
Move to line container storage area	labor	
Prepare forklift to move line container	labor	
Move forklift to chemical storage area	labor	
Locate chemicals in storage area	**$/transportation**	**$1.15**
Move forklift to appropriate areas	labor	
Move chemical containers from storage to staging	labor	
Move containers from staging to storage	filter	
Preparation of chemicals for transfer	**$/transportation**	**$1.78**
Open chemical container(s)	labor	
Utilize correct tools to obtain chemicals	labor	
Place obtained chemicals in line container(s)	labor	
Close chemical container(s)	labor	
Place line container(s) on forklift	labor	
Transport chemicals to line	**$/transportation**	**$1.15**
Move forklift to line	labor	
Unload line container(s) at line	labor	
Move forklift to parking area	labor	
Transport chemicals from line to bath	**$/transportation**	**$.88**
Move line container(s) to bath	labor	
Clean line container(s)	labor	
Store line container(s) in appropriate area	labor	
Total =	**$per testing**	**$9.28**

G-4 Simulation Model Outputs for Surface Finishing Processes

NAME: HASL, non-conveyorized
Throughput: 260,000K ssf

ARENA Simulation Results

Replication ended at time: 17831.4 min.

Tally Variables

Identifier	Average	Half Width	Minimum	Maximum	Observations
Takt Time	5.7866	(Corr)	1.4700	141.10	3080
Time in system	19.957	4.8613	7.9560	168.71	3081

Counters

Identifier	Count	Limit
Parts Done	3081	Infinite

Frequencies

Identifier	Category	Number	AvgTime	Percent	Percent
STATE (Microetch3_R)	BUSY	3075	1.4728	25.40	25.40
	IDLE	3075	3.9279	67.74	67.74
	FAILED	9	136.00	6.86	6.86
STATE (Cleaner3_R)	BUSY	2251	4.7494	59.96	59.96
	IDLE	2250	2.7503	34.70	34.70
	FAILED	7	136.00	5.34	5.34
STATE (flux3_R)	BUSY	3081	.18000	3.11	3.11
	IDLE	3082	5.5615	96.13	96.13
	FAILED	1	136.00	0.76	0.76
STATE (solder3_R)	BUSY	3081	.12600	2.18	2.18
	IDLE	3082	5.6155	97.06	97.06
	FAILED	1	136.00	0.76	0.76

NAME: HASL, non-conveyorized
Throughput: 60,000K ssf

ARENA Simulation Results

Replication ended at time: 2876.64 min.

Tally Variables

Identifier	Average	Half Width	Minimum	Maximum	Observations
Takt Time	3.8531	.69813	3.4700	139.47	710
Time in system	89.058	(Corr)	7.9560	279.95	711

Counters

Identifier	Count	Limit
Parts Done	711	Infinite

Frequencies

Identifier	Category	Number	AvgTime	Percent	Percent
STATE (Microetch3_R)	BUSY	577	1.8113	36.33	36.33
	IDLE	575	2.4756	49.48	49.48
	FAILED	3	136.00	14.18	14.18
STATE (Cleaner3_R)	BUSY	3	822.39	85.77	85.77
	IDLE	1	137.47	4.78	4.78
	FAILED	2	136.00	9.46	9.46
STATE (flux3_R)	BUSY	711	.18000	4.45	4.45
	IDLE	712	3.6694	90.82	90.82
	FAILED	1	136.00	4.73	4.73
STATE (solder3_R)	BUSY	711	.12600	3.11	3.11
	IDLE	712	3.7233	92.16	92.16
	FAILED	1	136.00	4.73	4.73

NAME: HASL, conveyorized
Throughput: 60,000K ssf

ARENA Simulation Results

Replication ended at time: 2348.82 min.

Tally Variables

Identifier	Average	Half Width	Minimum	Maximum	Observations
Takt time	.19281	.02704	.16654	136.00	10600
Time in system	19.009	(Corr)	4.9888	140.82	10601

Counters

Identifier	Count	Limit
Depart 33_C	10601	Infinite

Frequencies

Identifier	Category	Number	AvgTime	Percent	Percent
STATE (Cleaner_R)	BUSY	9825	.00539	2.59	2.59
	IDLE	9823	.17549	84.14	84.14
	FAILED	2	136.00	13.28	13.28
STATE (solder_R)	BUSY	10601	.00500	2.59	2.59
	IDLE	10601	.17544	90.77	90.77
	FAILED	1	136.00	6.64	6.64
STATE (flux_R)	BUSY	10601	.00500	2.59	2.59
	IDLE	10601	.17544	90.77	90.77
	FAILED	1	136.00	6.64	6.64
STATE (Microetch_R)	BUSY	10601	.00500	2.59	2.59
	IDLE	10601	.17544	90.77	90.77
	FAILED	1	136.00	6.64	6.64

NAME: HASL, conveyorized
Throughput: 260,000K ssf

ARENA Simulation Results

Replication ended at time: 8908.24 min.

Tally Variables

Identifier	Average	Half Width	Minimum	Maximum	Observations
Time in system	21.188	10.277	4.9888	140.91	45936
Takt time	.18000	(Corr)	.16654	136.00	45935

Counters

Identifier	Count	Limit
Depart 33_C	45936	Infinite

Frequencies

Identifier	Category	Number	AvgTime	Percent	Percent
STATE (Cleaner_R)	BUSY	42056	.00546	2.73	2.73
	IDLE	42051	.17506	87.56	87.56
	FAILED	6	136.00	9.71	9.71
STATE (solder_R)	BUSY	45936	.00500	2.73	2.73
	IDLE	45936	.17506	95.65	95.65
	FAILED	1	136.00	1.62	1.62
STATE (Microetch_R)	BUSY	45936	.00500	2.73	2.73
	IDLE	45932	.16027	87.56	87.56
	FAILED	6	136.00	9.71	9.71
STATE (flux_R)	BUSY	45936	.00500	2.73	2.73
	IDLE	45937	.17506	95.65	95.65
	FAILED	1	136.00	1.62	1.62

NAME: Nickel/Palladium/Gold, non-conveyorized
Throughput: 260,000K ssf

ARENA Simulation Results

Replication ended at time: 114576.0 min.

Tally Variables

Identifier	Average	Half Width	Minimum	Maximum	Observations
Time in system	116.79	1.0484	106.86	278.21	308
Takt Time	38.848	(Corr)	17.830	131.33	3080

Counters

Identifier	Count	Limit
Parts Done	3081	Infinite

Frequencies

Identifier	Category	Number	AvgTime	Percent	Percent
STATE (Acid Dip_R)	BUSY	3073	1.6342	4.19	4.19
	IDLE	3070	37.226	95.43	95.43
	FAILED	4	113.00	0.38	0.38
STATE (Catalyst_R)	BUSY	3075	3.7372	9.60	9.60
	IDLE	3070	35.045	89.84	89.84
	FAILED	6	113.00	0.57	0.57
STATE (Cleaner_R)	BUSY	3069	3.4835	8.93	8.93
	IDLE	3062	35.362	90.41	90.41
	FAILED	7	113.00	0.66	0.66
STATE (Electroless Palla	BUSY	3008	4.7321	11.89	11.89
	IDLE	2975	34.179	84.91	84.91
	FAILED	34	113.00	3.21	3.21
STATE (Immersion Gold_R	BUSY	2803	19.598	45.87	45.87
	IDLE	2798	22.926	53.56	53.56
	FAILED	6	113.00	0.57	0.57
STATE (Preinitiator_R)	BUSY	3081	2.3000	5.92	5.92
	IDLE	3082	36.375	93.61	93.61
	FAILED	5	113.00	0.47	0.47
STATE (Electroless Nicke	BUSY	2872	19.663	47.16	47.16
	IDLE	2833	20.743	49.07	49.07
	FAILED	40	113.00	3.77	3.77
STATE (Microetch_R)	BUSY	3064	1.4781	3.78	3.78
	IDLE	3056	37.373	95.37	95.37
	FAILED	9	113.00	0.85	0.85

NAME: Nickel/Palladium/Gold, non-conveyorized
Throughput: 60,000K ssf

ARENA Simulation Results

Replication ended at time: 25807.8 min.

Tally Variables

Identifier	Average	Half Width	Minimum	Maximum	Observations
Time in system	115.87	1.7495	106.86	199.39	711
Takt Time	38.929	(Corr)	17.830	131.33	710

Counters

Identifier	Count	Limit
Parts Done	711	Infinite

Frequencies

Identifier	Category	Number	AvgTime	Percent	Percent
STATE (Acid Dip_R)	BUSY	711	1.6300	4.17	4.17
	IDLE	712	37.269	95.43	95.43
	FAILED	1	113.00	0.41	0.41
STATE (Cleaner_R)	BUSY	709	3.4797	8.87	8.87
	IDLE	707	35.522	90.32	90.32
	FAILED	2	113.00	0.81	0.81
STATE (Catalyst_R)	BUSY	707	3.7511	9.54	9.54
	IDLE	706	35.311	89.65	89.65
	FAILED	2	113.00	0.81	0.81
STATE (Electroless Palla	BUSY	695	4.7263	11.81	11.81
	IDLE	688	34.329	84.94	84.94
	FAILED	8	113.00	3.25	3.25
STATE (Immersion Gold_R	BUSY	652	19.443	45.59	45.59
	IDLE	651	22.895	53.60	53.60
	FAILED	2	113.00	0.81	0.81
STATE (Preinitiator_R)	BUSY	711	2.3000	5.88	5.88
	IDLE	711	36.651	93.71	93.71
	FAILED	1	113.00	0.41	0.41
STATE (Electroless Nicke	BUSY	670	19.451	46.87	46.87
	IDLE	663	20.751	49.48	49.48
	FAILED	9	113.00	3.66	3.66
STATE (Microetch_R)	BUSY	707	1.4783	3.76	3.76
	IDLE	706	37.427	95.02	95.02
	FAILED	3	113.00	1.22	1.22

NAME: Nickel/Gold, non-conveyorized
Throughput: 260,000K ssf

ARENA Simulation Results

Replication ended at time: 86437.5 min.

Tally Variables

Identifier	Average	Half Width	Minimum	Maximum	Observations
Takt Time	27.062	1.2220E-14	17.830	134.33	3080
Time in system	98.948	2.0602	86.100	286.16	3081

Counters

Identifier	Count	Limit
Parts Done	3081	Infinite

Frequencies

Identifier	Category	Number	AvgTime	Percent	Percent
STATE (Microetch2_R)	BUSY	3056	1.4820	5.43	5.43
	IDLE	3048	25.546	93.32	93.32
	FAILED	9	116.00	1.25	1.25
STATE (Acid Dip2_R)	BUSY	3068	1.6369	6.02	6.02
	IDLE	3065	25.432	93.42	93.42
	FAILED	4	116.00	0.56	0.56
STATE (Electroless Nickel)	BUSY	2448	23.069	67.69	67.69
	IDLE	2409	9.2664	26.75	26.75
	FAILED	40	116.00	5.56	5.56
STATE (Cleaner2_R)	BUSY	3063	3.4903	12.81	12.81
	IDLE	3056	23.538	86.21	86.21
	FAILED	7	116.00	0.97	0.97
STATE (Catalyst2_R)	BUSY	3067	3.7470	13.77	13.77
	IDLE	3062	23.268	85.39	85.39
	FAILED	6	116.00	0.83	0.83
STATE (Immersion Gold2_	BUSY	2966	18.521	65.84	65.84
	IDLE	2961	9.3911	33.33	33.33
	FAILED	6	116.00	0.83	0.83

NAME: Nickel/Palladium/Gold, non-conveyorized
Throughput: 60,000K ssf

ARENA Simulation Results

Replication ended at time: 19427.7 min.

Tally Variables

Identifier	Average	Half Width	Minimum	Maximum	Observations
Takt Time	27.150	(Corr)	17.830	134.33	710
Time in system	95.321	4.1505	86.100	193.43	711

Counters

Identifier	Count	Limit
Parts Done	711	Infinite

Frequencies

Identifier	Category	Number	AvgTime	Percent	Percent
STATE (Electroless Nicke	BUSY	605	21.541	67.08	67.08
	IDLE	597	8.9632	27.54	27.54
	FAILED	9	116.00	5.37	5.37
STATE (Acid Dip2_R)	BUSY	711	1.6300	5.97	5.97
	IDLE	712	25.495	93.44	93.44
	FAILED	1	116.00	0.60	0.60
STATE (Microetch2_R)	BUSY	705	1.4825	5.38	5.38
	IDLE	704	25.617	92.83	92.83
	FAILED	3	116.00	1.79	1.79
STATE (Cleaner2_R)	BUSY	708	3.4847	12.70	12.70
	IDLE	706	23.694	86.11	86.11
	FAILED	2	116.00	1.19	1.19
STATE (Catalyst2_R)	BUSY	711	3.7300	13.65	13.65
	IDLE	710	23.300	85.16	85.16
	FAILED	2	116.00	1.19	1.19
STATE (Immersion Gold2_	BUSY	684	18.533	65.25	65.25
	IDLE	683	9.5440	33.55	33.55
	FAILED	2	116.00	1.19	1.19

NAME: OSP, non-conveyorized
Throughput: 260,000K ssf

ARENA Simulation Results

Replication ended at time: 14371.9 min.

Tally Variables

Identifier	Average	Half Width	Minimum	Maximum	Observations
Takt Time	4.7599	.59985	4.6200	150.67	3080
Time in System	399.53	(Corr)	21.330	513.90	3081

Counters

Identifier	Count	Limit
Depart 7_C	3081	Infinite

Frequencies

Identifier	Category	Number	AvgTime	Percent	Percent
STATE (Cleaner_R)	BUSY	2301	4.6462	72.82	72.82
	IDLE	2294	1.2850	20.08	20.08
	FAILED	7	149.00	7.10	7.10
STATE (Osp_R)	BUSY	3081	1.6700	35.04	35.04
	IDLE	3081	3.0469	63.94	63.94
	FAILED	1	149.00	1.01	1.01
STATE (Microetch_R)	BUSY	2711	1.6706	30.85	30.85
	IDLE	2703	3.2600	60.02	60.02
	FAILED	9	149.00	9.13	9.13

NAME: OSP, non-conveyorized
Throughput: 60,000K ssf

ARENA Simulation Results

Replication ended at time: 3731.92 min.

Tally Variables

Identifier	Average	Half Width	Minimum	Maximum	Observations
Takt Time	5.0236	.57885	4.6200	150.47	710
Time in System	172.58	(Corr)	21.330	322.15	711

Counters

Identifier	Count	Limit
Depart 7_C	711	Infinite

Frequencies

Identifier	Category	Number	AvgTime	Percent	Percent
STATE (Cleaner_R)	BUSY	581	4.2464	66.11	66.11
	IDLE	579	1.6696	25.90	25.90
	FAILED	2	149.00	7.99	7.99
STATE (Osp_R)	BUSY	711	1.6700	31.82	31.82
	IDLE	711	3.3692	64.19	64.19
	FAILED	1	149.00	3.99	3.99
STATE (Microetch_R)	BUSY	619	1.6884	28.01	28.01
	IDLE	618	3.6241	60.02	60.02
	FAILED	3	149.00	11.98	11.98

NAME: OSP, conveyorized
Throughput: 260,000K ssf

ARENA Simulation Results

Replication ended at time: 6568.83 min.

Tally Variables

Identifier	Average	Half Width	Minimum	Maximum	Observations
Takt time	.14724	.01562	.13961	149.00	45936
Time in system	30.442	14.465	5.1777	154.12	45937

Counters

Identifier	Count	Limit
Depart 22_C	45937	Infinite

Frequencies

Identifier	Category	Number	AvgTime	Percent	Percent
STATE (Microetch2_R)	BUSY	45937	.00500	3.39	3.39
	IDLE	45932	.12290	83.40	83.40
	FAILED	6	149.00	13.21	13.21
STATE (Cleaner2_R)	BUSY	40587	.00566	3.39	3.39
	IDLE	40582	.13910	83.40	83.40
	FAILED	6	149.00	13.21	13.21
STATE (osp_R)	BUSY	45937	.00500	3.39	3.39
	IDLE	45937	.13911	94.41	94.41
	FAILED	1	149.00	2.20	2.20

NAME: OSP, conveyorized
Throughput: 60,000K ssf

ARENA Simulation Results

Replication ended at time: 2002.0 min.

Tally Variables

Identifier	Average	Half Width	Minimum	Maximum	Observations
Takt Time	.15805	.03019	.1356	149.00	1060
Time in System	27.077	(Corr)	5.1777	154.07	10600

Counters

Identifier	Count	Limit
Depart 22_C	10601	Infinite

Frequencies

Identifier	Category	Number	AvgTime	Percent	Percent
STATE (Microetch2_R)	BUSY	10601	.00500	2.65	2.65
	IDLE	10601	.16979	89.91	89.91
	FAILED	1	149.00	7.44	7.44
STATE (Cleaner2_R)	BUSY	9531	.00556	2.65	2.65
	IDLE	9530	.17324	82.47	82.47
	FAILED	2	149.00	14.89	14.89
STATE (OSP_R)	BUSY	10601	.00500	2.65	2.65
	IDLE	10601	.16979	89.91	89.91
	FAILED	1	149.00	7.44	7.44

NAME: Immersion Silver, conveyorized
Throughput: 60,000K ssf

ARENA Simulation Results

Replication ended at time: 5425.08 min.

Tally Variables

Identifier	Average	Half Width	Minimum	Maximum	Observations
Time in System	14.998	5.9815	11.189	125.07	10601
Takt time	.51074	(Corr)	.48953	113.99	10600

Counters

Identifier	Count	Limit
depart 44_C	10601	Infinite

Frequencies

Identifier	Category	Number	AvgTime	Percent	Percent
STATE (Microetch3_R)	BUSY	10601	.00500	0.98	0.98
	IDLE	10601	.49600	96.92	96.92
	FAILED	1	114.00	2.10	2.10
STATE (Cleaner3_R)	BUSY	10372	.00511	0.98	0.98
	IDLE	10370	.49605	94.82	94.82
	FAILED	2	114.00	4.20	4.20
STATE (Immersion Silver)	BUSY	10601	.00500	0.98	0.98
	IDLE	10601	.49600	96.92	96.92
	FAILED	1	114.00	2.10	2.10
STATE (prodip_R)	BUSY	10601	.00500	0.98	0.98
	IDLE	10600	.48529	94.82	94.82
	FAILED	2	114.00	4.20	4.20

NAME: Immersion Silver, conveyorized
Throughput: 260,000K ssf

ARENA Simulation Results

Replication ended at time: 26206.7 min.

Tally Variables

Identifier	Average	Half Width	Minimum	Maximum	Observations
Time in System	18.921	4.1632	11.189	238.69	45937
Takt Time	.50495	(Corr)	.48995	114.03	45936

Counters

Identifier	Count	Limit
depart 44_C	45937	Infinite

Frequencies

Identifier	Category	Number	AvgTime	Percent	Percent
STATE (Microetch3_R)	BUSY	45937	.00500	0.99	0.99
	IDLE	45932	.48535	96.06	96.06
	FAILED	6	114.00	2.95	2.95
STATE (Cleaner3_R)	BUSY	44792	.00513	0.99	0.99
	IDLE	44786	.49777	96.06	96.06
	FAILED	6	114.00	2.95	2.95
STATE (Immersion Silver)	BUSY	45937	.00500	0.99	0.99
	IDLE	45937	.49770	98.52	98.52
	FAILED	1	114.00	0.49	0.49
STATE (prodip_R)	BUSY	45021	.00510	0.99	0.99
	IDLE	45017	.49775	96.55	96.55
	FAILED	5	114.00	2.46	2.46

NAME: Immersion Tin, non-conveyorized
Throughput: 260,000K ssf

ARENA Simulation Results

Replication ended at time: 30669.2 min.

Tally Variables

Identifier	Average	Half Width	Minimum	Maximum	Observations
Takt Time	9.8516	(Corr)	8.5500	93.550	3080
Time in System	40.215	4.5278	26.010	185.18	3081

Counters

Identifier	Count	Limit
Depart 7_C	3081	Infinite

Frequencies

Identifier	Category	Number	AvgTime	Percent	Percent
STATE (Cleaner_R)	BUSY	3009	3.5530	35.20	35.20
	IDLE	3002	6.3568	62.84	62.84
	FAILED	7	85.000	1.96	1.96
STATE (predip_R)	BUSY	3049	1.1822	11.87	11.87
	IDLE	3045	8.6500	86.73	86.73
	FAILED	5	85.000	1.40	1.40
STATE (Immersion Tin_R)	BUSY	2003	13.151	86.74	86.74
	IDLE	2003	1.9678	12.98	12.98
	FAILED	1	85.000	0.28	0.28
STATE (Microetch_R)	BUSY	3008	1.5056	14.91	14.91
	IDLE	3000	8.3583	82.57	82.57
	FAILED	9	85.000	2.52	2.52

NAME: Immersion Tin, non-conveyorized
Throughput: 60,000K ssf

ARENA Simulation Results

Replication ended at time: 7144.18 min.

Tally Variables

Identifier	Average	Half Width	Minimum	Maximum	Observations
Takt Time	9.9108	.36935	8.5500	88.470	710
Time in System	36.380	7.8297	26.010	104.68	711

Counters

Identifier	Count	Limit
Depart 7_C	711	Infinite

Frequencies

Identifier	Category	Number	AvgTime	Percent	Percent
STATE (Cleaner_R)	BUSY	699	3.5295	34.53	34.53
	IDLE	697	6.4663	63.09	63.09
	FAILED	2	85.000	2.38	2.38
STATE (Predip_R)	BUSY	711	1.1700	11.64	11.64
	IDLE	712	8.7462	87.17	87.17
	FAILED	1	85.000	1.19	1.19
STATE (Immersion Tin_R)	BUSY	527	11.535	85.09	85.09
	IDLE	527	1.8598	13.72	13.72
	FAILED	1	85.000	1.19	1.19
STATE (Microetch_R)	BUSY	693	1.5081	14.63	14.63
	IDLE	692	8.4451	81.80	81.80
	FAILED	3	85.000	3.57	3.57

NAME: Immersion Tin, conveyorized
Throughput: 260,000K ssf

ARENA Simulation Results

Replication ended at time: 43501.6 min.

Tally Variables

Identifier	Average	Half Width	Minimum	Maximum	Observations
Takt Time	.95367	(Corr)	.93728	85.005	45936
Time in System	21.375	(Corr)	12.350	160.23	45937

Counters

Identifier	Count	Limit
Depart 22_C	45937	Infinite

Frequencies

Identifier	Category	Number	AvgTime	Percent	Percent
STATE (Microetch2_R)	BUSY	45936	.00500	0.54	0.54
	IDLE	45931	.91794	98.28	98.28
	FAILED	6	85.000	1.19	1.19
STATE (Cleaner2_R)	BUSY	45487	.00505	0.54	0.54
	IDLE	45481	.92702	98.28	98.28
	FAILED	6	85.000	1.19	1.19
STATE (Predip_R)	BUSY	45576	.00504	0.54	0.54
	IDLE	45572	.92704	98.47	98.47
	FAILED	5	85.000	0.99	0.99
STATE (Immersion Tin_R)	BUSY	45937	.00500	0.54	0.54
	IDLE	45937	.92707	99.27	99.27
	FAILED	1	85.000	0.20	0.20

NAME: Immersion Tin, conveyorized (Tin h 60)
Throughput: 60,000K ssf

ARENA Simulation Results

Replication ended at time: 10029.78 min.

Tally Variables

Identifier	Average	Half Width	Minimum	Maximum	Observations
Takt Time	.95796	(Corr)	.93728	85.260	10600
Time in Systemm	23.910	(Corr)	12.364	110.71	10601

Counters

Identifier	Count	Limit
Depart 22_C	10601	Infinite

Frequencies

Identifier	Category	Number	AvgTime	Percent	Percent
STATE (Microetch2_R)	BUSY	10601	.26000	27.69	27.69
	IDLE	10601	.67102	71.46	71.46
	FAILED	1	85.000	0.85	0.85
STATE (Cleaner2_R)	BUSY	10476	.26310	27.69	27.69
	IDLE	10475	.67098	70.60	70.60
	FAILED	2	85.000	1.71	1.71
STATE (Predip_R)	BUSY	10601	.26000	27.69	27.69
	IDLE	10600	.66307	70.60	70.60
	FAILED	2	85.000	1.71	1.71
STATE (Immersion Tin_R)	BUSY	10601	.26000	27.69	27.69
	IDLE	10601	.67102	71.46	71.46
	FAILED	1	85.000	0.85	0.85

G-5 Chemical Costs by Bath for Individual Surface Finish Processes

Process: Hot Air Solder Leveling (HASL)[a]

Bath	Volume in Bath (in gallons) Horizontal	Volume in Bath (in gallons) Vertical	Supplier ID	Unit Vol. Chemical Cost	Avg. Chemical Cost	Total Cost of the Bath (Horizontal)	Total Cost of the Bath (Vertical)
Cleaner	66.5	51.1	#1	$14.4/gal	$3.67/gal	$244	$188
			#2	$5.42/gal			
			#3	$1.38/gal			
			#4	$1.13/gal			
			#5	$2.50/gal			
			#6	$1.00/gal			
			#7	$1.02/gal			
			#8	$2.50/gal			
Microetch	86.6	51.1	#1	$1.43/gal	$3.86/gal	$344	$197
			#2	$2.14/gal			
			#3	$0.757/gal			
			#4	$9.88/gal			
			#5	$5.20/gal			
			#6	$5.20/gal			
			#7	$1.05/gal			
			#8	$5.20/gal			
Flux	NA	NA		$12.50/gal		$12.50/gal[b]	$12.50/gal [b]

[a] No suppliers of HASL were identified. Chemical costs for baths similar to other alternatives were calculated by averaging the individual bath costs from other alternatives.

[b] Flux is refilled as it is consumed. The flux cost per gallon was obtained by industry estimate. (Personal communication with Mark Carey, February, 2000.)

Process: Immersion Silver
Supplier #1

Bath	Volume in Bath (in gallons) Horizontal	Volume in Bath (in gallons) Vertical	Chemical Name	Percentage of Chemical in Bath	Cost of Chemicals	Multiplying Factor	Total Cost of the Bath (Horizontal)	Total Cost of the Bath (Vertical)
Cleaner	66.5	No data	A	100	$14.4/gal	1	$958	No data
Microetch	86.6	No data	B	5	$26.6/gal	1	$124	No data
			C	0.25	$1.20/gal	1		
			D	10	$1.00/gal	1		
Predip	46.2	No data	E	100	$26.0/gal	1	$1,200	No data
Immersion Silver	NA	No data	F	90	$26.0/gal	1	$30.9/gal[a]	No data
			G	10	$75.0/gal	1		

[a] The silver bath is not replaced, but rather maintained as it becomes depleted. The total material cost of the silver bath required to produce 260,000 ssf of PWB will be calculated directly from the price per gallon of bath solution and the total gallons of bath solution required.

Process: Immersion Tin
Supplier #2

Bath	Volume in Bath (in gallons) Horizontal	Volume in Bath (in gallons) Vertical	Chemical Name	Percentage of Chemical in Bath	Cost of Chemicals	Multiplying Factor	Total Cost of the Bath (Horizontal)	Total Cost of the Bath (Vertical)
Cleaner	66.5	51.1	A	7	$20.0/L	1	$360	$277
			B	10	$1.20/gal	1		
Microetch	86.6	51.1	C	1.25 lb/gal	$1.70/lb	1	$185	$109
			D	1	$1.20/gal	1		
Predip	46.2	51.1	E	0.5	$40.0/L	1	$34.9	$38.7
Immersion Tin	NA	NA	F	5	$1.20/gal	1	$166/gal[a]	$166/gal[a]
			G	200 g/L	$40.0/kg	2.24		
			H	10	$40.0/L	3.48		
			I	5	$40.0/L	5.94		

[a] The tin bath is not replaced, but rather maintained as it becomes depleted. The total material cost of the tin bath required to produce 260,000 ssf of PWB will be calculated directly from the price per gallon of bath solution and the total gallons of bath solution required.

Process: Immersion Tin
Supplier #3

Bath	Volume in Bath (in gallons) Horizontal	Volume in Bath (in gallons) Vertical	Chemical Name	Percentage of Chemical in Bath	Cost of Chemicals	Multiplying Factor	Total Cost of the Bath (Horizontal)	Total Cost of the Bath (Vertical)
Cleaner	66.5	51.1	A	12.5	$11.0/gal	1	$91.4	$70.3
Microetch	86.6	51.1	B	60 g/L	$1.49/lb	1	$65.6	$38.7
			C	1	$1.20/gal	1		
Predip	46.2	51.1	D	25	$100/gal	1	$1,160	$1,280
Immersion Tin	NA	NA	E	100	$100/gal	1	$100/gal[a]	$100/gal[a]

[a] The tin bath is not replaced, but rather maintained as it becomes depleted. The total material cost of the tin bath required to produce 260,000 ssf of PWB will be calculated directly from the price per gallon of bath solution and the total gallons of bath solution required.

Process: Electroless Nickel/Immersion Gold
Supplier #4

Bath	Volume in Bath (in gallons) Horizontal	Volume in Bath (in gallons) Vertical	Chemical Name	Percentage of Chemical in Bath	Cost of Chemicals	Multiplying Factor	Total Cost of the Bath (Horizontal)	Total Cost of the Bath (Vertical)
Cleaner	No data	51.1	A	15	$7.50/gal	1	No data	$57.5
Microetch	No data	51.1	B	1.88 lb/gal	$5.25/lb	1	No data	$505
			C	1	$1.20/gal	1		
Catalyst	No data	51.1	D	10	$40.0/gal	1	No data	$467
			E	17	$8.00/L	1		
Acid Dip	No data	51.1	F	40	$8.00/L	1	No data	$619
Electroless Nickel	No data	51.1	G	5	$14.5/gal	5	No data	$574
			H	15	$20.0/gal	1		
			J	5	$23.0/gal	4		
Immersion Gold	No data	51.1	K	0.250 unit/gal (225 mL/gal)	$344/unit	1	No data	$58,500[a]
			L	8 oz/gal	$3.25/lb	1		

[a] Immersion gold replacement cost was calculated differently than other baths because of the wide disparity in costs and throughput between product lines. The overall cost for the gold bath was calculated for each product line and then averaged together to give the gold cost for the process.

Process: Electroless Nickel/Immersion Gold
Supplier #5

Bath	Volume in Bath (in gallons) Horizontal	Volume in Bath (in gallons) Vertical	Chemical Name	Percentage of Chemical in Bath	Cost of Chemicals	Multiplying Factor	Total Cost of the Bath (Horizontal)	Total Cost of the Bath (Vertical)
Cleaner	No data	51.1	A	10	$25.0/gal	1	No data	$128
Microetch	No data	51.1	B	3	$5.66/gal	1	No data	$266
			C	3	$9.39/gal	1		
			D	45 g/L	$27.3/kg	1		
			E	8.5	$1.20/gal	1		
Catalyst	No data	51.1	F	30	$127/gal	1	No data	$2,810
			G	20	$54.0/gal	1		
			H	12	$51.0/gal	1		
Acid Dip	No data	51.1	I	2 g/L	$29.1/kg	1	No data	$11.3
Electroless Nickel	No data	51.1	J	6.6	$24.1/gal	6	No data	$2,390
			K	15	$30.9/gal	6		
			L	6.6	$28.4/gal	5		
Immersion Gold	No data	51.1	M	50	$21.4/gal	1	No data	$57,350[a]
			N	3 g/L	$40.0/g	3		

[a] Immersion gold replacement cost was calculated differently than other baths because of the wide disparity in costs and throughput between product lines. The overall cost for the gold bath was calculated for each product line and then averaged together to give the gold cost for the process.

Process: OSP
Supplier #6

Bath	Volume in Bath (in gallons) Horizontal	Volume in Bath (in gallons) Vertical	Chemical Name	Percentage of Chemical in Bath	Cost of Chemicals	Multiplying Factor	Total Cost of the Bath (Horizontal)	Total Cost of the Bath (Vertical)
Cleaner	66.5	51.1	A	10	$10.0/gal	1	$66.5	$51.1
Microetch	86.6	51.1	B	3	$5.66/gal	1	$451	$261
			C	3	$9.39/gal	1		
			D	45.0 g/L	$27.3/kg	1		
			E	8.5	$1.20/gal	1		
OSP	NA	NA	F	6	$324/gal	1	$93.6/gal[a]	$93.6/gal[a]
			G	23	$321/gal	1		

[a] The OSP bath is not replaced, but rather maintained as it becomes depleted. The total material cost of the OSP bath required to produce 260,000 ssf of PWB will
be calculated directly from the price per gallon of bath solution and the total gallons of bath solution required.

Process: OSP
Supplier #7

Bath	Volume in Bath (in gallons) Horizontal	Volume in Bath (in gallons) Vertical	Chemical Name	Percentage of Chemical in Bath	Cost of Chemicals	Multiplying Factor	Total Cost of the Bath (Horizontal)	Total Cost of the Bath (Vertical)
Cleaner	66.5	51.1	A	10	$10.2/gal	1	$67.8	$52.1
Microetch	86.6	51.1	B	2.5	$7.62/gal	1	$91.0	$53.7
			C	7	$9.12/gal	1		
			D	18.5	$1.20/gal	1		
OSP	NA	NA	E	100	$117/gal	1	$117/gal[a]	$117/gal[a]

[a] The OSP bath is not replaced, but rather maintained as it becomes depleted. The total material cost of the OSP bath required to produce 260,000 ssf of PWB will
be calculated directly from the price per gallon of bath solution and the total gallons of bath solution required.

Process: Electroless Nickel/Electroless Palladium/Immersion Gold
Supplier #8

Bath	Volume in Bath (in gallons) Horizontal	Volume in Bath (in gallons) Vertical	Chemical Name	Percentage of Chemical in Bath	Cost of Chemicals	Multiplying Factor	Total Cost of the Bath (Horizontal)	Total Cost of the Bath (Vertical)
Cleaner	No data	51.1	A	10	$25.0/gal	1	No data	$128
Microetch	No data	51.1	B	3	$5.66/gal	1	No data	$266
			C	3	$9.39/gal	1		
			D	45 g/L	$27.3/kg	1		
			E	8.5	$1.20/gal	1		
Catalyst	No data	51.1	F	30	$127/gal	1	No data	$2,810
			G	20	$54.0/gal	1		
			H	12	$51.0/gal	1		
Acid Dip	No data	51.1	I	2 g/L	$29.1/kg	1	No data	$11.3
Electroless Nickel	No data	51.1	J	6.6	$24.1/gal	6	No data	$2,390
			K	15	$30.9/gal	6		
			L	6.6	$28.4/gal	5		
Preinitiator	No data	51.1	M	20	$160/gal	1	No data	$2,430
			N	10	$152/gal	1		
			O	1.4	$8.00/L	1		
Electroless Palladium	No data	51.1	P	2.5	$943/gal	3	No data	$3,980
			Q	20	$23.8/gal	1		
			R	2.5	$48.2/gal	2		
			S	0.05	$13.3/gal	3		
Immersion Gold	No data	NA	T	50	$21.4/gal	1	No data	$57,900[a]
			U	3 g/L	$40.0/g	3		

[a] Immersion gold replacement cost was calculated differently than other baths because of the wide disparity in costs and throughput between product lines. The overall cost for the gold bath was calculated for each product line and then averaged together to give the gold cost for the process.

G-6 Total Materials Cost for Surface Finishing Processes

Process: HASL, non-conveyorized
Throughput: 260K ssf of PWB

Bath	Chemical Cost/Bath Replacement [a]	Number of Bath Replacements [b]	Total Chemical Cost
Cleaner	$188	7	$1,320
Microetch	$197	9	$1,770
Flux	$16,250 [c]	1	$16,250
Solder	$55,460 [d]	1	$55,460
Total Materials Cost			**$74,800**

[a] Reported chemical cost per bath replacement reflects the average bath cost of all processes submitted for evaluation in this surface finishing category.
[b] Number of bath replacements required to process 260,000 ssf as determined by process simulation.
[c] Flux bath is not replaced, but rather refilled as flux is consumed. Cost of flux was calculated at $12.50/gal and is consumed at 200 ssf/gal.
[d] Solder is not replaced, but rather refilled as solder is consumed. Cost of solder was calculated using a solder cost of $2.57/lb and an average solder consumption rate, including solder wastage, of 0.083 lb/ssf which was obtained from three PWB facilities.

Process: HASL, conveyorized
Throughput: 260K ssf of PWB

Bath	Chemical Cost/Bath Replacement [a]	Number of Bath Replacements [b]	Total Chemical Cost
Cleaner	$244	6	$1,460
Microetch	$344	6	$2,060
Flux	$16,250 [c]	1	$16,250
Solder	$55,460 [d]	1	$55,460
Total Materials Cost			**$75,200**

[a] Reported chemical cost per bath replacement reflects the average bath cost of all processes submitted for evaluation in this surface finishing category.
[b] Number of bath replacements required to process 260,000 ssf as determined by process simulation.
[c] Flux bath is not replaced, but rather refilled as flux is consumed. Cost of flux was calculated at $12.50/gal and is consumed at 200 ssf/gal.
[d] Solder is not replaced, but rather refilled as solder is consumed. Cost of solder was calculated using a solder cost of $2.57/lb and an average solder consumption rate, including solder wastage, of 0.083 lb/ssf which was obtained from three PWB facilities.

Process: Electroless Nickel/Immersion Gold, non-conveyorized
Throughput: 260K ssf of PWB

Bath	Chemical Cost/Bath Replacement [a]	Number of Bath Replacements [b]	Total Chemical Cost
Cleaner	$92.8	7	$649
Microetch	$386	9	$3,470
Catalyst	$1,640	6	$9,830
Acid Dip	$315	4	$1,260
Electroless Nickel	$890	40	$35,500
Immersion Gold	NA [c]	6	$57,900
Total Materials Cost			**$108,600**

[a] Reported chemical cost per bath replacement reflects the average bath cost of all processes submitted for evaluation in this surface finishing category.

[b] Number of bath replacements required to process 260,000 ssf as determined by process simulation.

[c] Immersion gold replacement cost was calculated differently than other baths because of the wide disparity in costs and throughput between product lines. The overall cost for the gold bath was calculated for each product line and then averaged together to give the gold cost for the process.

Process: Electroless Nickel/Electroless Palladium/Immersion Gold, non-conveyorized
Throughput: 260K ssf of PWB

Bath	Chemical Cost/Bath Replacement [a]	Number of Bath Replacements [b]	Total Chemical Cost
Cleaner	$128	7	$900
Microetch	$266	9	$2,390
Catalyst	$2,810	6	$16,860
Acid Dip	$11.3	4	$45
Electroless Nickel	$2,390	40	$95,600
Preinitiator	$2,430	5	$12,150
Electroless Palladium	$3,980	34	$135,300
Immersion Gold	NA [c]	6	$57,900
Total Materials Cost			**$321,000**

[a] Reported chemical cost per bath replacement reflects the average bath cost of all processes submitted for evaluation in this surface finishing category.

[b] Number of bath replacements required to process 260,000 ssf as determined by process simulation.

[c] Immersion gold replacement cost was calculated differently than other baths because of the wide disparity in costs and throughput between product lines. The overall cost for the gold bath was calculated for each product line and then averaged together to give the gold cost for the process.

Process: OSP, non-conveyorized
Throughput: 260K ssf of PWB

Bath	Chemical Cost/Bath Replacement [a]	Number of Bath Replacements [b]	Total Chemical Cost
Cleaner	$51.6	7	$361
Microetch	$157	9	$1,420
OSP	$16,750 [c]	1	$16,750
Total Materials Cost			**$18,500**

[a] Reported chemical cost per bath replacement reflects the average bath cost of all processes submitted for evaluation in this surface finishing category.

[b] Number of bath replacements required to process 260,000 ssf as determined by process simulation.

[c] OSP bath is not replaced, but rather refilled as the OSP is consumed. Cost of OSP was calculated at $105/gal and is consumed at 1,630 ssf/gal.

Process: OSP, conveyorized
Throughput: 260K ssf of PWB

Bath	Chemical Cost/Bath Replacement [a]	Number of Bath Replacements [b]	Total Chemical Cost
Cleaner	$67.2	6	$403
Microetch	$271	6	$1,630
OSP	$16,750 [c]	1	$16,800
Total Materials Cost			**$18,800**

[a] Reported chemical cost per bath replacement reflects the average bath cost of all processes submitted for evaluation in this surface finishing category.

[b] Number of bath replacements required to process 260,000 ssf as determined by process simulation.

[c] OSP bath is not replaced, but rather refilled as the OSP is consumed. Cost of OSP was calculated at $105/gal and is consumed at 1,630 ssf/gal.

Process: Immersion Silver, conveyorized
Throughput: 260K ssf of PWB

Bath	Chemical Cost/Bath Replacement [a]	Number of Bath Replacements [b]	Total Chemical Cost
Cleaner	$958	6	$5,750
Microetch	$124	6	$744
Predip	$1,200	5	$6,000
Immersion Silver	$40,170 [c]	1	$40,200
Total Materials Cost			**$52,700**

[a] Reported chemical cost per bath replacement reflects the average bath cost of all processes submitted for evaluation in this surface finishing category.

[b] Number of bath replacements required to process 260,000 ssf as determined by process simulation.

[c] Silver bath is not replaced, but rather maintained as the silver bath is depleted. The cost of the silver bath was calculated at $30.9/gal and is consumed at 200 ssf/gal.

Process: Immersion Tin, non-conveyorized
Throughput: 260K ssf of PWB

Bath	Chemical Cost/Bath Replacement [a]	Number of Bath Replacements [b]	Total Chemical Cost
Cleaner	$174	7	$1,220
Microetch	$74	9	$665
Predip	$659	5	$3,300
Immersion Tin	$23,850 [c]	1	$23,850
Total Materials Cost			**$29,000**

[a] Reported chemical cost per bath replacement reflects the average bath cost of all processes submitted for evaluation in this surface finishing category.

[b] Number of bath replacements required to process 260,000 ssf as determined by process simulation.

[c] Tin bath is not replaced, but rather maintained as the tin bath is depleted. The cost of the tin bath was calculated at $133/gal and is consumed at 1,450 ssf/gal.

Process: Immersion Tin, conveyorized
Throughput: 260K ssf of PWB

Bath	Chemical Cost/Bath Replacement [a]	Number of Bath Replacements [b]	Total Chemical Cost
Cleaner	$226	6	$1,350
Microetch	$125	6	$752
Predip	$597	5	$2.990
Immersion Tin	$23,850 [c]	1	$23,850
Total Materials Cost			**$28,900**

[a] Reported chemical cost per bath replacement reflects the average bath cost of all processes submitted for evaluation in this surface finishing category.

[b] Number of bath replacements required to process 260,000 ssf as determined by process simulation.

[c] Tin bath is not replaced, but rather maintained as the tin bath is depleted. The cost of the tin bath was calculated at $133/gal and is consumed at 1,450 ssf/gal.

Appendix H

Environmental Hazard Assessment and Ecological Risk Assessment Methodology

H-1. HAZARD PROFILE

The environmental hazard assessment of chemicals consists of the identification of the effects that a chemical may have on organisms in the environment. An overview of this assessment process has been reported by, for example, Smrchek and Zeeman (1998) and by Zeeman and Gilford (1993). The effects are expressed in terms of the acute and chronic toxicity of a chemical on the exposed organisms. These are generally given as either the lethal concentration (LC) or as the effective concentration (EC) that describe the type and seriousness of the effect for a known concentration of a chemical. When the effective concentrations for a range of species for a chemical are tabulated, the tabulation is called a hazard profile or toxicity profile. A more detailed discussion of a comprehensive hazard profile has been presented by Nabholz (1991). The most frequently used hazard profile for the aquatic environment consists of a set of six effective concentrations as reported by Nabholz et al. (1993a). These are:

- Fish acute value (usually a fish 96-hour LC_{50} value)
- Aquatic invertebrate acute value (usually a daphnid 48-hour LC_{50} value)
- Green algal toxicity value (usually an algal 96-hour EC_{50} value)
- Fish chronic value (usually a fish 28-day chronic value [ChV])
- Aquatic invertebrate chronic value (usually a daphnid 21-day ChV)
- Algal chronic value (usually an algal 96-hour NEC or GMATC value for biomass)

For the acute values, the LC_{50} (lethality or mortality) (EC_{50}) (non-lethal/lethal effects) refers to the concentration that results in 50 percent of the test organisms affected at the end of the specified exposure period in a toxicity test. The chronic values represent the concentration of the chemical that results in no statistically significant sublethal effects on the test organism following an extended or chronic exposure.

The hazard profile can be constructed using effective concentrations based on toxicity test data (with measured test chemical concentrations) or estimated toxicity values based on structure activity relationships (SARs). The measured values are preferred because they are based on actual test data, but in the absence of test data SAR estimates, if available for the chemical class, can be used. Thus the hazard profile may consist of only measured data, only predicted values, or a combination of both. Also, the amount of data in the hazard profile may range from a minimum of one acute or chronic value to the full compliment of three acute values and three chronic values.

In the absence of measured toxicity values, estimates of these values can be made using SARs. SAR methods include quantitative structure activity relationships (QSARs), qualitative SARs, or use of the chemical analogs. The use of SARs by OPPT has been described (Clements, 1988; Clements, 1994). The use and application of QSARs specifically for the hazard assessment of TSCA new chemicals has been presented (Clements et al., 1993a). The development, validation, and application of SARs in OPPT have been presented by OPPT staff (Zeeman et al., 1993b; Boethling, 1993; Clements et al., 1993b; Nabholz et al., 1993b; Newsome et al., 1993 and Lipnick, 1993).

The predictive equations (QSARs) are used in lieu of actual test data to estimate a toxicity value for aquatic organisms within a specific chemical class. A total of 140 have been listed (Clement et al., 1995; Smrchek and Zeeman, 1998). Although the equations are derived from correlation and linear regression analysis based on measured data, the confidence intervals associated with the equation are not used to provide a range of toxicity values. Even with measured test data, the use of the confidence limits to determine the range of values is not used.

H-2. DETERMINATION OF CONCERN CONCENTRATION

Upon completion of a hazard profile, a concern concentration (CC) is determined. A concern concentration is that concentration of a chemical in the aquatic environment, which, if exceeded, may cause a significant risk to aquatic organisms. Conversely, if the CC is not exceeded, the assumption is made that probability of a significant risk occurring is low and no regulatory action is required. The CC for each chemical is determined by applying assessment factors (AsF) (U.S. EPA, 1984) or uncertainty factors (UF) (Smrchek et al., 1993) to the effect concentrations in the hazard profile.

These factors incorporate the concept of the uncertainty associated with: 1) toxicity data, laboratory tests versus field tests, and measured versus estimated data; and 2) species sensitivity. For example, if only a single LC_{50} value for a single species is available, there are several uncertainties to consider. First, how reliable is the value itself? If the test were to be done again by the same laboratory or a different laboratory, would the value differ and, if so, by how much? Second, there are differences in sensitivity (toxicity) among and between species that have to be considered. If the species tested the most or the least sensitive? In general, if only a single toxicity value is available, there is a large uncertainty about the applicability of this value to other organisms in the environment and a large assessment factor, i.e., 1000, is applied to cover the breadth of sensitivity known to exist among and between organisms in the environment. Conversely, the more information that is available results in more certainty concerning the toxicity values and requires the use of smaller factors. For example, if toxicity values are derived from field tests, then an assessment factor of 1 is used because tests measure chemical effects on field organisms.

Four factors are used by OPPT to set a CC for chronic risk: 1, 10, 100, and 1000. The factor used is dependent on the amount and type of toxicity data contained in the hazard profile and reflects the amount of uncertainty about the potential effects associated with a toxicity value. In general, the more complete the hazard profile and the higher the quality of the generated toxicity data, the smaller a factor that is used. The following discussion describes the use and application of uncertainty or assessment factors.

1. If the hazard profile only contains one or two acute toxicity values, the concern concentration is set at 1/1000 of the acute value.

2. If the hazard profile contains three acute values (called the base set), the concern concentration is set at 1/100 of the lowest acute value.

3. If the hazard profile contains one chronic value, the concern concentration is set at 1/10 of the chronic value if the value is for the most sensitive species. Otherwise, it is 1/100 of the acute value for the most sensitive species.

4. If the hazard profile contains three chronic values, the concern concentration is set at 1/10 of the lowest chronic value.

5. If the hazard profile contains a measured chronic value from a field study, then an assessment factor of 1 is used.

H-3. HAZARD RANKING

Chemicals can be also ranked by their hazard concern levels for the aquatic environment. This ranking can be based upon the acute toxicity values expressed in milligrams per liter (mg/L). The generally accepted scoring used by OPPT is as follows (Smrchek et al., 1993; Wagner et al., 1995):

High Concern (H)	≤ 1
Moderate (or Medium) Concern (M)	> 1 and ≤ 100
Low Concern (L)	> 100

This ranking can also be expressed in terms of chronic values as follows:

High Concern (H)	≤ 0.1
Moderate (or Medium) Concern (M)	> 0.1 and ≤ 10.0
Low Concern (L)	> 10.0

Chronic toxicity ranking takes precedent over the acute ranking.

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