

TECHNICAL PAPER ≡

IPC Cleaning and Cleanliness Test Program Phase 3 Water Soluble Fluxes Part 2

By Douglas Pauls
Department Of The Navy
Naval Air Warfare Center
Indianapolis, IN

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2215 Sanders Road
Northbrook, Illinois
60062-6135
Tel 847 509.9700
Fax 847 509.9798





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IPC Cleaning and Cleanliness Test Program Phase 3 Water Soluble Fluxes Part 2: B-36 Comparison to Phase 1 Rosin Benchmark September 21, 1992

A joint program sponsored by the EPA/DOD/IPC/Industry Ad Hoc Solvents Working Group. This evaluation was performed at the Naval Air Warfare Center, Aircraft Division, Indianapolis, Indiana (formerly the Naval Avionics Center). This testing was performed in November and December, 1991.

IPC
2215 Sanders Road
Northbrook, Illinois
60062-6135
Tel 847 509.9700
Fax 847 509.9798

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IPC Cleaning and Cleanliness Test Program

Phase 3 Water Soluble Fluxes Part 2

1.0 SCOPE

This document presents the results of the IPC Cleaning and Cleanliness Test Program, Phase 3, Water Soluble Flux, Part 2, B-36 Test, as performed by the Naval Air Warfare Center, Aircraft Division, Indianapolis (NAWC AD Indianapolis), November 8-9, 1991. The Phase 3 test was designed by the EPA/DoD/IPC Ad Hoc Solvents Working Group as a test for evaluating manufacturing materials and processes as alternatives to present manufacturing practices which require the use of chlorofluorocarbons (CFCs). This Phase 3 test is a repeat of the Phase 1 benchmark testing, substituting water soluble fluxes and deionized (DI) water cleaning for rosin fluxes and CFC-113/methanol cleaning. The details of the Phase 1 testing are given in References 1 and 2. The details of the Phase 3 Water Soluble Flux (WSF) testing are given in Reference 3.

The WSF evaluation was split into two parts. Part 1, detailed in Reference 5, examined the interaction between water soluble fluxes and the metal/laminate of a standard circuit board. In Part 1, three water soluble fluxes, and three water soluble pastes were evaluated. Based on the results of Part 1, one flux and one paste were chosen to be evaluated in Part 2.

2.0 REFERENCES

Institute for Interconnecting and Packaging Electronic Circuits (IPC)

1. IPC Cleaning and Cleanliness Test Program: A Joint Industry/Military/EPA Program to Evaluate Alternative to Chlorofluorocarbons (CFCs) for Printed Wiring Board Assembly Cleaning. March 30, 1989.
2. IPC-TR-580, Cleaning and Cleanliness Test Program: Phase I Test Results, October, 1989.
3. IPC Cleaning and Cleanliness Test Program: A Joint Industry/Military/EPA Program to Evaluate Alternative to Chlorofluorocarbons (CFCs) for Printed Wiring Board Assembly Cleaning. Phase 3 - Water Soluble Fluxes. September 1, 1990.
4. NAC-TR-2447: Cleaning and Cleanliness Test Program, Phase I, Surface Insulation Test: Procedures for Test Preparation, Testing, Data Acquisition, Data Reporting, and Data Analysis. December 1, 1989.
5. IPC-TP-1043, Cleaning and Cleanliness Test Program, Phase 3, Water Soluble Fluxes, Part 1: B-24, Interactions of Water Soluble Fluxes with Metal/Substrates. October, 1992.
6. Turbini, L.J., "Characterizing Water Soluble Fluxes: Surface Insulation Resistance vs. Electrochemical Migration," Proceedings, IEEE International Electronics Manufacturing Technology Symposium, Baltimore, MD, September 22-30, 1992.

3.0 DEFINITIONS

3.1 Phase 1 Test

A test defined by the IPC Cleaning and Cleanliness Testing Program using a MIL-F-14256 Type RA (Rosin) flux and a batch cleaning operation, and employing as the cleaning agent the nitromethane-stabilized azeotrope of CFC-113 and methanol. See References 1 and 2.

3.2 Phase 3 Test

An evaluation of alternative manufacturing processes which eliminate the need for CFC cleaning. See Reference 3.

3.3 EPA/DoD/IPC Ad Hoc Solvents Working Group

A committee comprised of people drawn from the EPA, the military, and industry, whose chief concern was to define and specify both a suitable printed wiring assembly test board and detailed test procedures for the IPC Cleaning and Cleanliness Test Program. Phase 3 of this test program is chaired by Dr. Laura Turbini, Georgia Institute of Technology.

3.4 Test Monitoring and Validation Team (TMVT)

A group of people drawn from the Ad Hoc Solvents Working Group whose chief duties consist of (1) data analysis from all phases of the test program, (2) determining whether a test site is fully compliant with the requirements of the IPC Cleaning and Cleanliness Test Program, (3) monitoring a specific test site during testing to make sure it fully complies with the test procedures, and (4) review of all test data and approval of the test report and conclusions.

3.5 Polyglycols

Materials with polyether linkages, such as those found in polyethylene glycol, or material derived by reaction of organic acids, amines, alcohols, phenols, or water with either ethylene oxide or propylene oxide. This family includes, but is not limited to: polyethylene glycol; polypropylene glycol; and a wide range of polyglycol surfactants. This family of materials does not include glycols (e.g. ethylene glycol), polyols (e.g. glycerin), or glycol ethers.

4.0 GENERAL REQUIREMENTS

4.1 Applicable Documents

The test methods are outlined in the Phase 3 Water Soluble Flux Test Plan (Reference 3). This document was developed during the course of several IPC meetings. The test plan was adhered to, with the exception of some items which required changes due to information gathered during process development at NAWC AD Indianapolis. Those changed elements are included in this report.

4.2 Purpose

The purpose of the Phase 3 test was to determine whether a standard IPC-B-36 test assembly, processed with water soluble pastes and flux, and cleaned with deionized water, could achieve cleanliness levels comparable to the Phase 1 benchmark process. The Phase I process was based on rosin (RA) fluxed boards which were batch cleaned with a nitromethane-stabilized, CFC-113/methanol azeotrope.

4.3 Process Sequences

An illustration of the process sequences used in the test plan is shown as Figure 1. The following is a brief summary of the process sequences. All IPC-B-36 test boards received the same precleaning and drying steps (as detailed in 4.4).

4.3.1 Process A1

Boards in this process received no subsequent processing. They acted as a control.

4.3.2 Process A2

Boards in this process were subjected only to the aqueous cleaner. These boards acted as controls to determine if any contamination was contributed by the aqueous cleaner.

4.3.3 Process B1

These boards had solder paste applied and were then subjected to infrared (IR) reflow. They were not cleaned. These boards represented the dirtiest conditions to be expected from an IR operation with WSF solder paste.

4.3.4 Process B2

These boards were solder pasted, IR reflowed, cleaned, dried, wave fluxed, and wave soldered. The boards were not cleaned after wave soldering. These boards represented the dirtiest conditions to be expected from a wave solder operation. Aqueous cleaning was employed after the IR reflow step to remove contamination attributable to the solder paste.

4.3.5 Process C

These boards had solder paste applied, leadless ceramic chip carriers (LCCCs) mounted in two quadrants, IR reflowed, and cleaned. These boards represented a typical assembly with cleaning challenges, subjected to IR reflow with a subsequent cleaning operation.

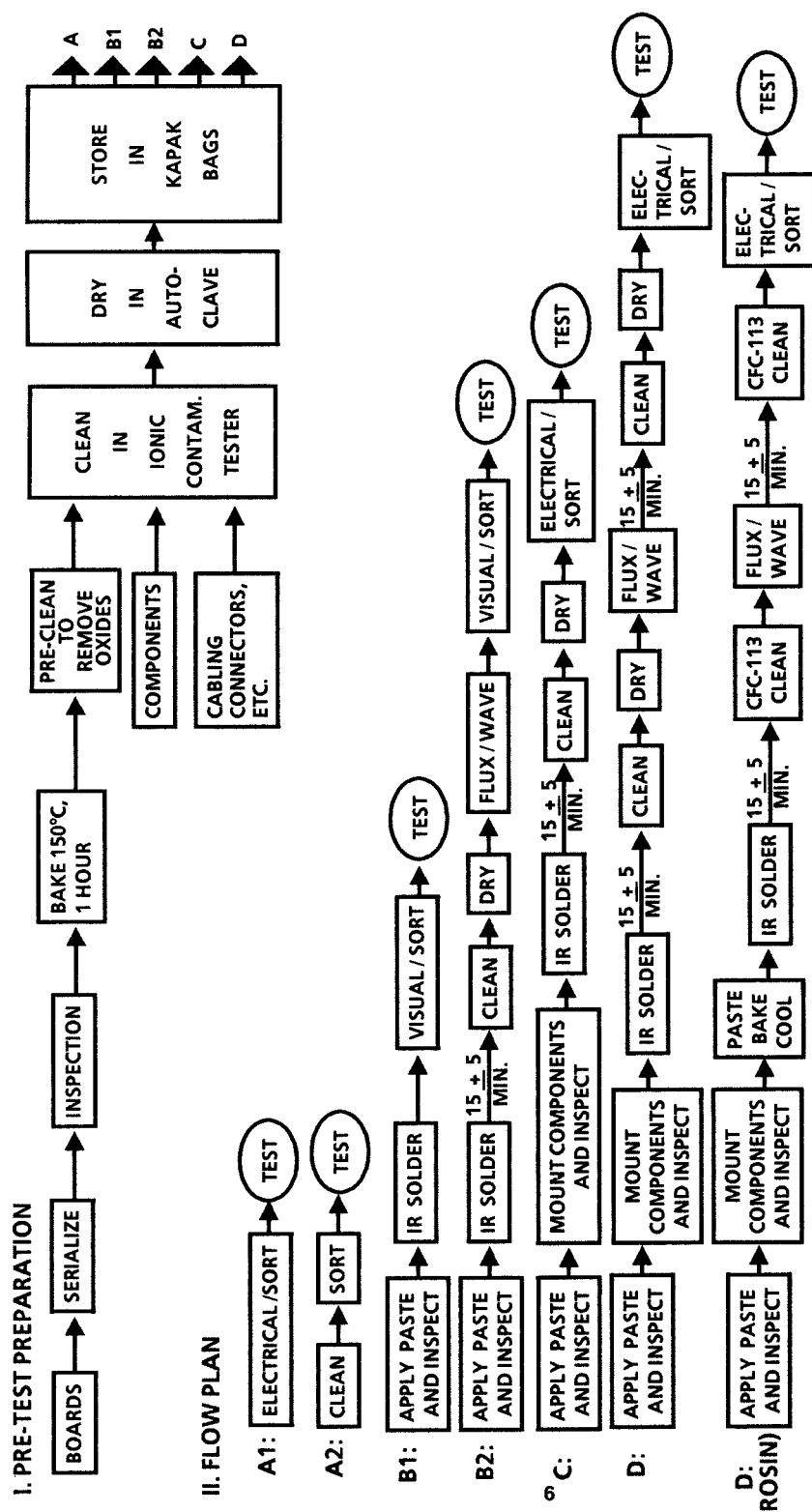
4.3.6 Process D

These boards had solder paste applied, components (LCCCs) mounted in two quadrants, IR reflowed, cleaned, wave fluxed, wave soldered, and cleaned. These boards represented a typical assembly with cleaning challenges, subjected to both IR reflow and wave soldering, with subsequent cleaning operations.

4.3.7 Rosin Process D

This is the same process as described in 4.3.6, with the process materials being rosin-based and two cleaning steps utilizing a nitromethane-stabilized, CFC-113/methanol azeotrope. Materials and parameters were the same as in Phase 1, but this process was not intended as a repeat or confirmation of the Phase 1 test. Rosin processed D boards were included in the test.

PHASE III TEST PROGRAM / WATER SOLUBLE FLUX RESIDUE REMOVAL



III. TEST SERIES

- 1: IONIC CONTAMINATION BY OMEGAMETER 600SMD
- 2: IONIC CONTAMINATION BY ION CHROMATOGRAPHY (DELCO)
- 3: SIR (85°C/85%RH) - CONDENSATION FREE PROFILE
- 4: ORGANIC CONTAMINATION BY HPLC (ALLIANT TECHSYSTEMS)
- 5: SIR ASSEMBLIES TESTED USING ION CHROMATOGRAPHY (DELCO)
- 6: SIR ASSEMBLIES TESTED USING HPLC (ALLIANT TECHSYSTEMS)



Figure 1

Figure 1

testing to compare the Phase 1 temperature-humidity profile with an alternate “condensation-free” profile, which had been developed in Part 1. The process instruction which defined the rosin defluxing operation is included in Appendix A.

4.4 Board Preparation Processes

The following process was used at NAWC AD Indianapolis to prepare all B-36 test boards.

4.4.1 Oven Bake

All boards were baked in a forced air oven at 150°C for one hour. This bake step was done to fully polymerize the epoxy matrix of the boards and to liberate as much free bromine from the boards as possible.

4.4.2 Microetch Process

The oven bake procedure caused a heavy layer of oxide to develop on the copper circuitry of the test boards. A microetch procedure was needed to remove the oxide layer. Boards were processed in accordance with Table 1.

Table 1

Step	Solution	Temperature	Dwell Time
1	Enplate PC-499*	160°F	5 Minutes
2	Tap Water Spray Rinse	Room Temperature	30 Seconds
3	1st Stage Tap Water Cascade Rinse	Room Temperature	30 Seconds
4	2nd Stage Tap Water Cascade Rinse	Room Temperature	30 Seconds
5	3rd Stage Tap Water Cascade Rinse	Room Temperature	30 Seconds
6	Deionized Water Overflow Rinse	Room Temperature	1 Minute
7	Enplate AD-485	Room Temperature	15 Seconds
8	Tap Water Spray Rinse	Room Temperature	30 Seconds
9	1st Stage Tap Water Cascade Rinse	Room Temperature	30 Seconds
10	2nd Stage Tap Water Cascade Rinse	Room Temperature	30 Seconds
11	3rd Stage Tap Water Cascade Rinse	Room Temperature	30 Seconds
12	Deionized Water Overflow Rinse	Room Temperature	1 Minute
13	10% v/v Sulfuric Acid	Room Temperature	2 Minutes
14	Tap Water Spray Rinse	Room Temperature	30 Seconds
15	1st Stage Tap Water Cascade Rinse	Room Temperature	30 Seconds
16	2nd Stage Tap Water Cascade Rinse	Room Temperature	30 Seconds
17	3rd Stage Tap Water Cascade Rinse	Room Temperature	30 Seconds
18	Deionized Water Overflow Rinse	Room Temperature	1 Minute

*Enplate PC-499 (an alkaline cleaner) and Enplate AD-485 (a mild copper microetch) were prepared according to the manufacturer's (i.e., Enthone's) directions. The deionized water used for rinsing was a minimum one megohm-cm resistivity.

4.4.3 IPA/Water Clean

Immediately following the microetch procedure, all boards were subjected to cleaning in an Omegameter 600SMD until the ionic levels had not changed for five minutes. This differs from the test plan method of cleaning to lower than two micrograms per square inch. Boards were cleaned in batches of six boards. Boards were separated to allow full solution access. Solution resistivity values were not recorded during this operation. This step was included to insure that all boards were free of ionic residues prior to any test processing. All boards were cleaned until no further ionic residues could be removed.

4.4.4 Board Drying

After removal from the Omegameter, the boards were placed in clean aluminum racks and batch-dried in a nitrogen autoclave at room temperature. After nitrogen-drying, the boards were sealed in Kapak bags (6.5" x 8") until ready for testing. The Kapak bags had been tested thoroughly by Terry Munson, and were determined as noncontaminating. A source for Kapak bags is listed in Appendix F.

4.5 Post-Reflow Aqueous Clean Cycle

Applicable to processes A2, C, and D. A diagram of the aqueous cleaner, with all of the temperatures and spray pressures, is shown as Figure 2.

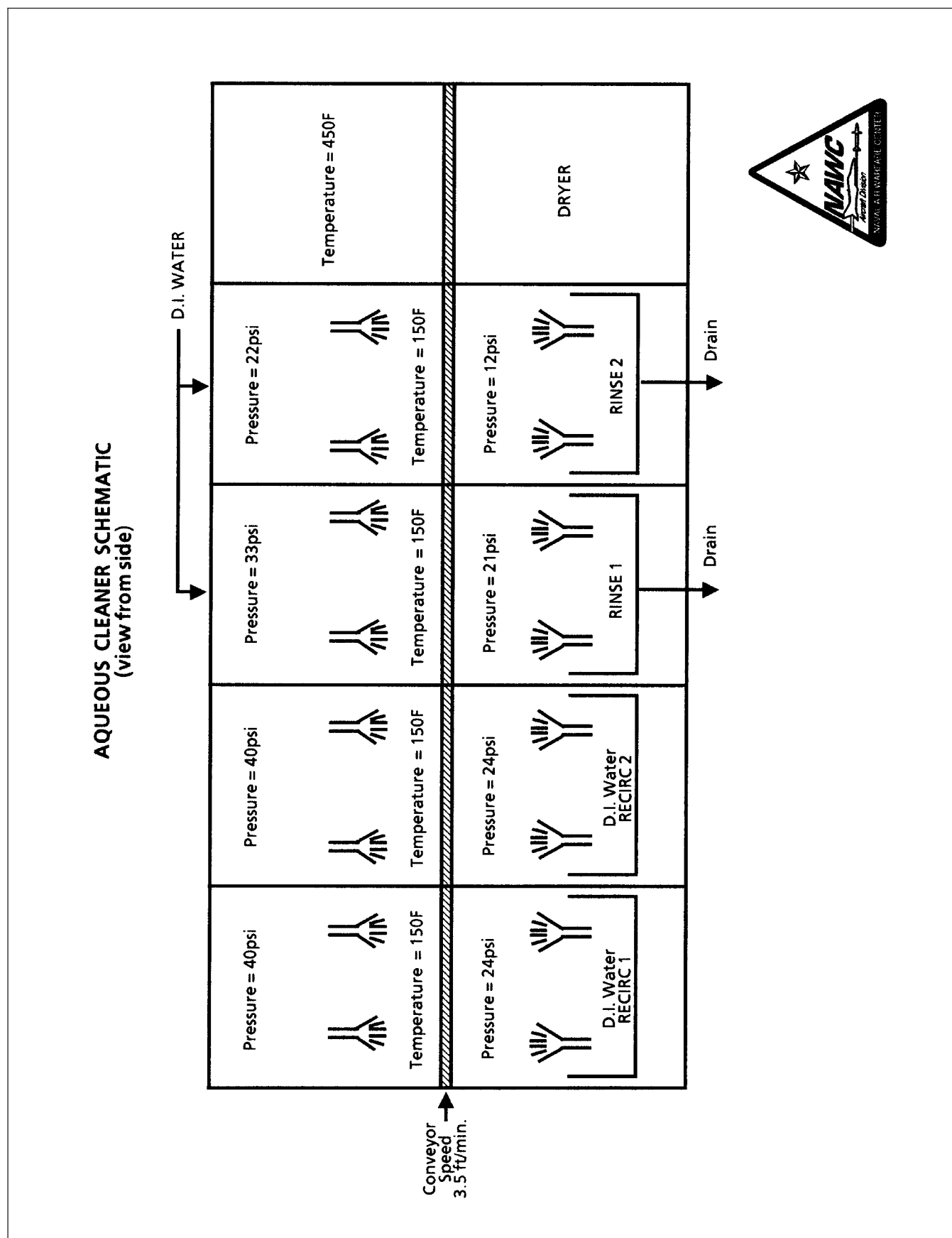


Figure 2

4.5.1 Fixturing During Cleaning

The boards were not placed in a fixture for the cleaning cycle. The pressure differential between the top and bottom spray nozzles were sufficient to keep the boards in place on the conveyor.

4.5.2 Cleaning Medium

The cleaning medium was deionized water with no detergents, saponifiers, or surfactants added. The aqueous cleaner was a multiple stage cleaner. The overflow water from the final two rinse stages went to the drains. The overflow water from the second wash stage fed into the first wash stage. The water in the first wash stage was recirculated, with overflow going to the drains. The water was sampled periodically during the testing to determine the resistivity and quality of the water. The resistivity of the water was measured at 200 kilohm-cm (0.2 megohm-cm) as drawn from the recirculating rinse tanks of the cleaner. The resistivity of the water could not be measured as it entered the cleaner, but industrial deionizing columns had been set up to provide water with a one megohm-cm resistivity. The water quality tests indicated that the water did not contain detectable levels of metals or minerals.

4.6 Other Process Materials

The following is a list of process materials utilized for the Phase 3 test.

Table 2

Material	Manufacturing Operation
Paste Application	WSF Paste #2
Wave Flux/Wave Solder	WS Flux #2
Rosin Paste Application	Alpha Metals RA321 90-2-70 Paste
Rosin Flux - Wave Fluxer	Kester 1585-MIL RA Rosin Flux
Rosin Defluxing	Freon TMS

The water soluble flux and water soluble pastes were chosen from the fields of materials tested in Part 1 (Reference 5) of the experiment. The fluxes tested in Part 1 were Alpha Metals 857, Kester 2331 ZX, and Lonco 3355-HB. The pastes tested in Part 1 were Alpha Metals WS601, Multicore HX21A88, and Kester R577T. The codes for each material were assigned randomly and are not associated with the order presented here.

4.6.1 Process Material Application Weights

The weights of materials applied to each test board (35 in²) in this test were as follows:

Paste: 0.4 - 0.6 grams Flux: 0.2 - 0.3 grams

4.7 Equipment

The following is a list of equipment utilized for the Phase 3 test at NAWC AD Indianapolis.

Table 3

Manufacturing Operation	Equipment Used
Paste Application	Crystal Mark Model 1224 ISD Screen Printer
Ovens	Blue M Model DC-256
	Blue M Model OV-490A-2
Infrared Reflow	Electrovert Infraflow 500C Turb Air (on loan from Electrovert)
Wave Solder	Electrovert 2000
Aqueous Cleaner	Electrovert 2000C
Rosin Defluxing	Baron Blakeslee MLR-120LE Vapor Degreaser
Ionic Cleanliness Tester	Alpha Metals 600SMD
Ion Chromatography Testing ¹	Dionex 4000i System, AS4A Columns, Conductivity Detector
High Pressure Liquid Chromatography (HPLC) Testing ²	Waters HPLC System, HP photodiode array detector, Brownlee Labs Polypore H column
Surface Insulation Resistance (SIR) Testing	Despatch 16512 microprocessor controlled humidity chamber
	Keithley Data Acquisition System (Models 706, 230, 617, 7158)
	IBM XT microcomputer
Thermal Profiler	ECD SuperMOLE
Bag Sealer	KAPAK Bag Sealer

1 - All Ion Chromatography work was performed by Terry Munson, formerly of Delco Electronics, Kokomo, Indiana. Mr. Munson now with CSL, Inc., Kokomo, IN.

2 - All High Pressure Liquid Chromatography (HPLC) testing was performed by Tom Barrett, Alliant Tech Systems, Hopkins, Minnesota.

4.8 Donated Equipment and Support

The following companies donated materials, equipment, or analytical test services to this evaluation. Their contributions are gratefully acknowledged.

Table 4

Phototooling and Stencils	Magnavox
Components (LCCCs)	Intel
Pastes	Alpha Metals, Kester Solder, Multicore
Fluxes	Alpha Metals, Kester Solder, London Chemical (Lonco)
Glass Boards	Texas Instruments
Thermal Profiling System	ECD
Connectors	AMP, Inc.
Titanium Solder Boots	Electrovert
Levchecks	Hexacon
IPC-B-36 Test Boards	Hughes Aircraft Company
Vinyl Gloves	Delco Electronics
Ion Chromatography Testing	Delco Electronics, Terry Munson
HPLC Testing	Alliant Techsystems, Tom Barrett

4.9 Test Monitoring

In order to verify that NAWC AD Indianapolis was fully compliant with the Phase 3 test plan, the test was monitored by a Test Monitoring and Validation Team (TMVT). The TMVT was lead by Dr. Turbini and Mr. Bergman. The TMVT members and affiliations were:

Table 5

Dr. Laura Turbini, Georgia Tech	David Maitland, NASA/Unisys
David Bergman, IPC	Lt. Jim Mattila, USAF
Tom Barrett, Alliant Techsystems	Bill Vuono, EMPF
Terry Munson, CSL, Inc.	Mike Oborny, Sandia National Labs
Phil Wittmer, Magnavox	David Dodgen, Interflux USA
Tom Carroll, Hughes Aircraft	Dick Contos, London Chemical
Bob Burress, Texas Instruments	Dr. Jack Brous, Alpha Metals
Les Hymes, Plexus	Dennis Bernier, Kester Solder

4.10 Internal Support

The following personnel were instrumental in the development and performance of this evaluation. Such a project as this could not be completed without a dedicated support staff. Their contributions are gratefully acknowledged.

Table 6

Ed Ostack	Dave Lob	Frank Renfro	David Pond
Sharon Wagner	Dusty Herrings	Barbara Malburg	Gerald Rhoades
Barbara Belt	John O'Connor	Linda Luber	Malcom Griner
Teresa Birdsong	Peggy Plymate	Tim Berg	Laura Stocker
Melissa Pirtle	Jim Hovelsrud	Gary Moore	Tom Tierne
Michael Bratcher	Joe Kurek	Ed Arvin	Robin Sellers

The project at NAWC AD Indianapolis was co-managed by Douglas Pauls and Michael Hook. The IPC extends its thanks to NAWC's management for their support of this water soluble flux evaluation.

4.11 Other Processing Issues

Various changes in the test method were made to accommodate information gained in process development. These included:

- (1) As in Part 1, a microetch step was added after the 150°C bake step, to remove oxides.
- (2) The stencil used was eight mils. This was the same stencil used in Phase 1 testing.
- (3) The paste-bake step of the plan was removed at the recommendation of the paste vendors.
- (4) A single infrared thermal profile was used to reflow all pastes, regardless of the presence of LCCCs on the test boards. The LCCCs acted as heat sinks. In order to get the board surface to reflow temperatures under the LCCCs, the temperature would have been high enough to destroy those test boards without LCCCs.

4.12 Sample Sizes

The following table shows the sample sizes for each of the process sequences.

Process	600SMD	IC/HPLC	SIR	Photo	Extra	Total
A1 Control	5	5	5	1	4	20
A2 Control	5	5	2	1	4	17
B1	3	3	2	1	4	13
B2	3	3	2	1	4	13
C	5	5	5	1	4	20
D	5	5	5	1	4	20
D-Rosin	0	2	5	0	5*	10

* = 2 Boards from the Extra set were analyzed by ion chromatography.

4.13 Processing Conditions

A set of detailed process instructions was developed for each operation in the evaluation. These process instructions are included as Appendix A. In order to fully document the processing conditions for each test board, a process traveler sheet was filled out for each set of processed boards. Samples of these process traveler sheets are included in Appendix C. The following is a summary of the critical machine settings for the B-36 test:

Table 7

Wave Solder ¹	Conveyor Speed	3.0 Ft/minute
	Flux Application Method	Wave Fluxer
	Preheat Temperature	120°C
	Solder Temperature	250°C
IR Reflow ²	Belt Speed	12 inches/minute
	Preheat Temperature	190°C
	Reflow Temperature	260°C
Aqueous Cleaning ³	Medium	Deionized Water (1 megohm-cm)
	Water Temperature	150°F
	Conveyor Speed	3.5 ft/minute
	Wash Pressures (top/bottom)	40 psi/24 psi
	Wash Flow Rate	3 gallons/minute
	Rinse Pressures (top/bottom)	33 psi/21 psi
	Rinse Flow Rate	4 gallons/minute
Solvent Cleaning ⁴	Media	CFC-113/Methanol Azeotrope
	Vapor Dwell/Boiling Sump	1 minute/3 minutes
	Vapor Dwell/Rinse Sump/Vapor	30 sec/1 min/30 sec

1 = The thermal profile for Wave Soldering is included as Appendix B, Profile #1.

2 = The thermal profile for IR Reflow operations is included as Appendix B, Profile #2.

3 = The thermal profile for the aqueous cleaner is included as Appendix B, Profile #3.

4 = No thermal profile was done for the batch vapor degreaser.

4.14 Cleanliness Characterization Tests

In order to characterize cleanliness, several tests were conducted to examine the residues remaining after processing. The following is a description of the tests used and the operating parameters of each.

4.14.1 Ionic Contamination by Omegameter 600SMD

This test measures the electrical resistivity (in megohm-cm) of an alcohol/water solution used to clean the test boards in a controlled process. The Omegameter 600SMD used a heated, agitated, 75% isopropyl alcohol (IPA) and 25% deionized water solution. The resulting change in electrical conductivity was a measure of the ionic residues remaining on the board surface. Testing was performed at NAWC AD Indianapolis within two hours of the final assembly process. The following were the 600SMD operating parameters.

Table 8

Calibration	Chemical and Electrical - Daily
Solution Temperature	41 - 43°C
Solution Volume	4000 ml
Surface Board Area	35.0 square inches
Test Time	15 Minutes
Pass/Fail Limit	None

The Omegameter 600SMD has a set zero-point cleanliness of 60.35 megohm-cm. Continuous circulation of the test solution (between contamination tests) can clean the solution to much higher resistivities, requiring some amount of contamination to bring the instrument back to the zero point. In order to avoid this “dead-band” problem, one milliliter of 750 ppm NaCl solution was added to the solution prior to the start of testing. The 600SMD was then put through a single CLEAN/FILL cycle to bring the solution to the 60.35 megohm-cm starting point. Due to the steady supply of test boards throughout the day, this step was not required between boards.

4.14.2 Ionic Contamination by Ion Chromatography

Ion chromatography determines the amount of chlorides, bromides, nitrates, and weak organic acids (WOAs). The extraction was done with a solution of 75% IPA and 25% DI water. The extraction technique is listed in Appendix D. The extract solution was divided into two aliquots; one aliquot for IC testing and one aliquot for HPLC testing. The Delco ion chromatography system and operating parameters were:

Table 9

Equipment	Dionex 4000i, AS4A columns, AMMS chemical suppression unit, conductivity detector
Effluent	0.0018N Sodium Bicarbonate
Temperature	25°C
Chemical Suppression	0.005N Sulfuric Acid
Injection Loop	100 microliters
Flow Rate	2 ml/minute

4.14.3 Organic Residues by HPLC

High Pressure Liquid Chromatography (HPLC) was used to determine the total amount of organic residues remaining on a board. The analytical technique used is included as Appendix E. Due to the proprietary nature of the fluxes, the constituent information on flux composition was not available for standards development. Therefore, the contamination was determined as total organics present. The Alliant Techsystems HPLC system and operating parameters were:

Table 10

Equipment	Waters HPLC Unit, Hewlett Packard photodiode array
Columns	Brownlee Labs Polypore H
Wavelength	210 nm
Bandwidth	30 nm
Reference Wavelength	350 nm
Column Temperature	35°C
Mobile Phase	0.01 N Sulfuric Acid
Flow Rate	0.4 ml/minute
Sample Size	10 microliters

4.14.4 Surface Insulation Resistance Testing

Surface Insulation Resistance (SIR) testing examines the change in insulation qualities of a printed circuit assembly when exposed to elevated temperatures and humidity for a period of time. Testing was performed at NAWC AD Indianapolis. The following is a summary of the SIR test conditions:

Table 11

Equipment	Despatch 16512 microprocessor controlled humidity chamber, Keithley data acquisition system, custom fixtures
Test Length	Seven days
Ambient Conditions	25°C 50% relative humidity
Elevated Conditions	85°C 85% relative humidity
Ramp Method	"Condensation Free" Profile (see Figure 4)
Bias Voltage	-50 volts DC
Measurement Voltage	+ 100 volts DC
Measurements	0, 24, 96, 168, 196 hours
Visual Examination	7-10X, with backlighting

Reference 4 is a NAWC AD Indianapolis report which better explains the SIR test and the preparations needed to do this test.

5.0 TEST RESULTS

5.1 Overview

The Phase 3 test was performed at the NAWC AD Indianapolis on November 8-9, 1991. On November 8, process sequences A1, A2, and D (rosin), were completed according to plan. On November 9, process sequences B1, B2, C, and D, were completed using water soluble fluxes. The test results are presented in the following order:

- Ionic Contamination by Omegameter 600SMD
- Ionic Contamination by Ion Chromatography
- Organic Residues by HPLC
- Surface Insulation Resistance Test
- Post-SIR Visual Examination

This Phase 3 test was intended to investigate water soluble flux technology. As such, no pass or fail criteria was established.

5.2 Total Ionic Contamination by Omegameter 600SMD

All results for this test are given in micrograms of sodium chloride equivalent per square inch ($\mu\text{g NaCl}/\text{in}^2$).

5.2.1 Summary Table - Phase 1 Benchmark vs. Phase 3 Results

Table 12

Phase 1 Benchmark Values			Phase 3 WSF Values		
Process	Mean	Std. Dev.	Process	Mean	Std. Dev.
A1	2.0	0.50	A1	1.04	0.90
A2*	—	—	A2	0.90	0.31
B1	10.8	1.48	B1	17.4	0.44
B2	47.4	2.95	B2	534	41
C	3.8	1.08	C	2.16	2.54
D	10.7	1.34	D	14.1	2.09

* = Process A2 was not performed in Phase 1.

5.2.2 Summary Chart

Chart values are expressed in units of micrograms of sodium chloride equivalent per square inch.

