23
2/9/78
to NTIS

BDX-613-1695 (Rev.)

MASTER

CONTAMINANT CLEANING FOR CRITICAL
ELECTRICAL ASSEMBLY AREAS

Final Report

L. C. Jackson, Project Leader

Project Team:

D. A. Cummings
R. L. Kirkpatrick
F. H. Lewis
M. L. Waddell
E. T. Walsh

Published February 1978

Prepared for the United States Department of Energy
Under Contract Number EY-76-C-04-0613.

**Kansas City
Division**

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Department of Energy, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

Printed in the United States of America

Available From the National Technical Information Service, U.S. Department of Commerce, 5285 Port Royal Road, Springfield, Virginia 22161.

Price:	Microfiche	\$3.00
	Paper Copy	\$5.25

CONTAMINANT CLEANING FOR CRITICAL
ELECTRICAL ASSEMBLY AREAS

Published February 1978

Project Leader:
L. C. Jackson
Department 814

Project Team:
D. A. Cummings
R. L. Kirkpatrick
F. H. Lewis
M. L. Waddell
E. T. Walsh

Final Report

Communications Services

**Kansas City
Division**

CONTAMINANT CLEANING FOR CRITICAL ELECTRICAL ASSEMBLY AREAS

BDX-613-1695 (Rev.), UNCLASSIFIED Final Report, Published
February 1978

Prepared by L. C. Jackson, D/814

The aspects of surface cleanliness have been studied and have involved contaminant detection, concentration measurements, contaminant characterization, contaminant removal by solvents and solvent blends, cleaning process effectiveness, surface characterization, and electrical properties of contaminated surfaces. Correlations were established between Meseran Surface Analyzer (ERA Systems Incorporated) radioactive surface energy probe measurements and solubility parameter values, surface tension values of known liquids and solids (plastics), and concentrations of polar and nonpolar contaminants. Principles of evaporative rate analysis and solubility parameter are described, which together provide the foundation for a new technology of understanding of surface chemistry.

WPC-bab

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Department of Energy, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

The Bendix Corporation
Kansas City Division
P. O. Box 1159
Kansas City, Missouri 64141

A prime contractor with the United
States Department of Energy under
Contract Number EY-76-C-04-0613

CONTENTS

Section	Page
SUMMARY	8
DISCUSSION	9
SCOPE AND PURPOSE.	9
ACTIVITY	9
<u>Contaminants</u>	9
<u>Solubility Parameter Technology</u>	10
<u>Evaporative Rate Analysis</u>	10
<u>Comparison Between Solubility Parameter and Radioactivity Counts</u>	10
<u>Interrelationship Between Solubility Parameter, Radioactivity Counts, and Surface Tension</u>	14
<u>Contaminant Removal by Solvent Selection</u>	16
<u>Solvents and Solvent Blends</u>	18
<u>Swell Index of Plastics</u>	26
<u>Characterization of Surfaces</u>	26
<u>Cleaning Process Efficiency</u>	36
<u>Contaminant Concentration</u>	49
<u>Surface Electrical Characteristics</u>	49
ACCOMPLISHMENTS.	52
REFERENCES	63
APPENDIX. PRODUCT IDENTIFICATION.	65
DISTRIBUTION	67

ILLUSTRATIONS

Figure		Page
1	Solubility Parameter Solubility-Incompatibility Concept.	11
2	Effectiveness of Alpha 611 Solder Flux Removal by Series of Solvents Characteristic of Solubility Parameter Range.	21
3	Effectiveness of OX-140 Machine Oil Removal by Series of Solvents Characteristic of Solubility Parameter Range	21
4	Effectiveness of AZ1350J Photo Resist Removal by Series of Solvents Characteristic of Solubility Parameter Range	22
5	Effectiveness of Krylon Spray Removal by Series of Solvents Characteristic of Solubility Parameter Range	22
6	Effectiveness of Fingerprint Removal by Series of Solvents Characteristic of Solubility Parameter Range.	23
7	Effectiveness of Sherwood Hospital Body Lotion Removal by Series of Solvents Characteristic of Solubility Parameter Range.	23
8	Polarity Indications According to Four-Quadrant Chart Analysis.	33
9	Classification of Known Chemical Films According to Polarity Characteristics.	35
10	Polarity Indications of Several Plastic Surfaces	37
11	Classification of Mold Releases According to Surface Polarity.	38
12	Classification of Contaminants on Aluminum Foil According to Polarity	39
13	Characterization of Several Fingerprints on Aluminum Foil in Terms of Polarity	40

14	Cleaning Method Comparison for Vacuum Oil Removal With Trichloroethylene After Vacuum Dry	45
15	Cleaning Method Comparison for Vacuum Oil Removal With Methylchloroform After Vacuum Dry	45
16	Cleaning Method Comparison for Vacuum Oil Removal With Solvent Blend C After Vacuum Dry	46
17	Cleaning Method Comparison for Kester 197 Solder Flux Removal With Trichloroethylene After Vacuum Dry	46
18	Cleaning Method Comparison for Kester 197 Solder Flux Removal With Methylchloroform After Vacuum Dry	47
19	Cleaning Method Comparison for Kester 197 Solder Flux Removal With Blend C After Vacuum Dry	47
20	Comparison of Oven Dry and Vacuum Dry Effectiveness in Removing Residual Solvent Blend C After Vapor Degreasing Kester 197 Solder Flux.	48
21	Effect of Various Solvents on Epoxy Surface of Printed Circuit Board Laminate.	48
22	Relationship of Meseran Data Versus Concentration of Vacuum Oil.	50
23	Relationship of Meseran Data Versus Concentration of Kester 197 Solder Flux. . .	50
24	Effect of Cure of AZ1350J Photo Resist on Meseran Data	51
25	Aging Effects of Kester 197 Solder Flux and Duo Seal Vacuum Oil on Meseran Data.	51
26	Relationship of Surface Electrical Leakage of Known Organic Residues at Various Applied Voltages	53

TABLES

Number		Page
1	Evaporative Rate Analysis of Known Chemicals Using Radioactive Solvents	12
2	Correlation Coefficients Relating Solubility Parameter to Meseran Numbers of Radioactive Solvents	13
3	Comparison of Solubility Parameters Derived From Evaporative Rate Analysis With Known Values	15
4	Comparison of Surface Tension Obtained by a Surface Tensiometer With Calculated Data From Meseran Analysis.	17
5	Meseran Values of Various Contaminants Prior to Solvent Cleaning.	18
6	Solubility Parameters of Solvents Used to Clean Contaminants	19
7	Effectiveness of Various Solvents on Removal of Contaminants From Aluminum Foil Substrate.	20
8	Effectiveness of Solvents for Contaminant Removal.	24
9	Effects of Solvents on Contaminants, Relative Ease of Removal of Contaminants by Solvent Series	25
10	Solvent Blend Formulations	27
11	Effects of Solvent Blends on Contaminants, Relative Ease of Removal of Contaminants by Solvent Blends.	28
12	Effects of Solvents on Plastics, Showing Relative Solvency by Solvent Series.	29
13	Effects of Solvent Blends on Plastics, Showing Relative Solvency by Solvent	30
14	Comparison of Effectiveness of Three Cleaning Processes	43

15	Process Effects on Printed Circuit Board Absorption of Solvents	44
16	Classification of Organic Residue Chemical Type With Surface Leakage.	54
17	Surface Leakage of Organic Contaminants on Printed Circuit Board.	55
18	Relative Electrical Surface Leakage of Contaminants	58
19	Classification of Organic Residue Chemical Type With Arc Over Limits.	59
20	Arc Over Voltage Limits of Contaminants. . . .	60
21	Relative Arc Over Characteristics of Contaminants	62

SUMMARY

Surface cleanliness, in the past, has generally been evaluated indirectly by adhesion or electrical tests. As parts become more complex, contamination detection and removal become more critical. Using the relatively new technologies of evaporative rate analysis and solubility parameter, a new approach to surface cleanliness has been achieved. Based on the principles of solubility parameter, compatibility of contaminants with solvents is described in detail. Greater accuracy in solvent selection can be achieved when solvents are classed according to their hydrogen bonding potential. Surface measurements by the Meseran Surface Analyzer (ERA Systems Incorporated) permit contaminant detection as low as 0.1 micrograms for each 1.0 square centimeter of surface area. Using surface energy probes of various polarity levels, surface characterization can be achieved. Meseran radioactivity counts can be related to the solubility parameter and surface tension of a material. Blending solvents according to solubility parameter principles permits specific solubility characteristics to be obtained for specific contaminant removal. The swell index of plastics also follows solubility parameter principles of compatibility. Evaporative rate analysis can be used to characterize surface properties according to the degree of absorption of the functional group of the radiochemical surface energy probe. Application of four quadrant chart analyses thereby serves as a means of surface characterization. The cleaning methods of spray application, ultrasonic cleaning, and vapor degreasing also influence contaminant removal efficiency. The surface electrical properties of contaminants (surface leakage and arc over) can be shown to relate to the various levels of polarity-nonpolarity of the molecules. This work now permits actual measurement of surface cleanliness.

DISCUSSION

SCOPE AND PURPOSE

The purpose of this work has been to identify contaminant residues, characterize, and effect their removal so that optimum cleaning procedures can be established for use in controlled critical electrical assembly areas.

ACTIVITY

Previously, the criteria for acceptable surface cleanliness had been determined by the satisfactory performance of electrical components or by adhesion tests. Now, electrical failures on more complex, densely packed components require that a more fundamental approach to contaminant removal be initiated.

Contaminants

A contaminant (organic residue) is an unwanted material which usually occurs on electrical components as a very thin film or monomolecular layer. Contaminants are usually unknown materials described generally as oil, grease, fingerprints, or solder flux. Dust particles are also contaminants, but they are not included as part of this study. In the past, identification of an unknown contaminant has largely been speculative.

Airborne organic residues can be defined as being condensable on, or attracted to, a substrate. Low boiling point molecules are not readily condensable and high molecular weight molecules do not remain gaseous without difficulty. Between the two extremes is the likely domain of airborne contaminants.

Contaminants carried to a substrate by a cleaning operation will reflect previous process conditions that may have involved machine oils, fingerprint residues, plasticizers from a plastic or a wiping cloth, and solder fluxes. Generally, however, these contaminants will not be highly volatile, will include airborne vapor materials, will not include soluble materials, but may include moderately high molecular weight polymers. In the majority of cases, it can be postulated that organic residue contaminants will have a boiling point range between the highly volatile liquids and the nonvolatile polymers.

Contaminants have a molecular structure; therefore, they have properties that are combinations of polarity, nonpolarity, and hydrogen bonding. These characteristics are reflected in their solubility parameter value which is based on the cohesive energy of a molecule. This, in effect, is a measure of the properties of that material.

Solubility Parameter Technology

Solubility parameter technology involves the study of how compatible materials are with each other. Similar molecules will dissolve more easily in each other than will dissimilar molecules. When the solubility parameter of a material to be dissolved is known, it becomes the "target area" shown in Figure 1. The selection of a solvent reasonably close to that of the target solubility parameter will provide for increased solubility. However, if a solvent is chosen that has a solubility parameter too far away from the target area, the molecules will not match or fit together, and there will be little diffusion, molecular attraction, or solubility.

The accuracy in selecting solvents for contaminant removal can be improved by utilizing the knowledge that molecules have different levels of activity which greatly influence compatibility. Classification of solvents into the three groups of weak, moderate, and strong hydrogen bonding potential is very useful. It tends to group solvents according to their electron charge capability. The strong hydrogen bonders are the alcohols; these have high solubility parameter values. The weak hydrogen bonding solvents are the chlorinated compounds and hydrocarbons such as heptane and toluene; they have low solubility parameter values. In between are the moderate hydrogen bonders such as esters and ketones.

Evaporative Rate Analysis

Evaporative rate analysis is a relatively new technique for the examination of surfaces. It permits determination of surface changes and is based on the physical or chemical adsorption, as well as attractive forces that exist between molecules. It involves measuring the rate of evaporation of a carbon-14 tagged radioactive solvent from a surface by a Geiger counter. The degree of retention of the radioactive solvent is a measure of that surface or contamination. The Meseran Surface Analyzer employs this principle and was used as a surface energy probe for this investigation. For purposes of this study, surface measurements by radioactivity counts were for a period of 112 seconds.

Comparison Between Solubility Parameter and Radioactivity Counts

Establishing a relationship between the solubility parameter values of known organic chemicals and Meseran numbers (radioactive solvent counts) was considered essential prior to unknown contaminant detection.

Figure 1. Solubility Parameter Solubility-Incompatibility Concept

A series of pure chemical liquids was selected (Table 1) which was considered to represent the intermediate boiling point range of contaminants (125° to 290°C) (Table 1). In addition, these chemicals represented the major portion of the solubility parameter range which provided molecules having no polarity or hydrogen bonding, polarity but no hydrogen bonding, moderate polarity and moderate hydrogen bonding, and strong hydrogen bonding.

Nine radioactive chemicals were evaluated in developing data on the known chemical residues on aluminum foil using the Meseran Surface Analyzer. Solubility parameter data was either calculated or obtained from Hoy tables.¹ The data was statistically analyzed to determine the significance of the information developed. Linear relations were considered to establish the correlation between the solubility parameters and the radioactivity values of the known chemicals. Correlation coefficients were determined and are shown in Table 2. Three aliphatic and one aromatic radioactive chemical yielded high correlation coefficients (near 0.8), far enough away from zero to be considered good--1.0 is a perfect fit. Greater correlation was obtained when nonpolar, nonhydrogen-bonded liquids were omitted.

Table 1. Evaporative Rate Analysis of Known Chemicals Using Radioactive Solvents
(The analysis was performed with the Meseran Surface Analyzer)

Chemicals	Solubility Parameter (Hoy Data)	Evaporative Rate Analysis Numbers**			
		Tridecane***	Tetrabromoethane***	Diethylsuccinate***	Average
Nonane	7.63	709	648	657	671
Dodecane	7.91	969	938	877	928
1-Chlorododecane	8.20*	922	906	872	900
p-Cymene	8.35*	888	905	982	925
1,2,4,-Trimethylbenzene	8.94	860	870	759	830
1-Methylnaphthalene	9.90	804	801	710	772
2-Ethylhexylchloride	8.13	894	1018	869	927
Dibutylamine	8.15	865	954	853	891
Cellosolve Acetate	9.35	802	1042	933	926
Isophorone	9.36	782	993	839	872
Dibutylphthalate	9.85	641	757	660	686
Diethylsuccinate	9.63	827	927	794	849
Ethylcinnamate	9.80*	769	846	728	781
Cyclohexanone	10.42	573	826	760	720
2-Ethylhexanoic acid	11.00	821	793	780	798
Octyl alcohol	10.30	840	855	784	826
Cyclohexanemethanol	10.65*	639	596	663	633
Diethylenetriamine	11.54	54	181	368	201
Methylcellosolve	11.68	346	485	792	441
Triethyleneglycol	12.81	-52	241	103	97
*Calculated **Meseran numbers are an average of three tests. ***Radioactive solvent in cyclopentane.					

Table 2. Correlation Coefficients Relating Solubility Parameter to Meseran Numbers of Radioactive Solvents

Radioactive Solvent	Correlation Coefficients for all Materials Tested	Correlation Coefficients Excluding Nonpolar and Nonhydrogen Bonded Chemicals
Tridecane	0.79	0.82
Tetrabromoethane	0.73	0.80
Diethylsuccinate	0.76	0.84
Naphthalene	0.78	0.82
Nitrobenzene	0.52	0.66
Cyclohexylethanol	0.45	0.65
Dimethylphthalate	0.58	0.76
Diphenylmethane	0.31	0.49
Dibromononane	0.63	0.59

Although a correlation coefficient is a measure of the association between Meseran numbers and solubility parameters, the straight line relationship

$$M = a + bT \quad (1)$$

can be used to describe the relation between the variables

where

a = intercept,

b = slope,

M = radioactive counts (Meseran Number), and

T = solubility parameter.

A comparison of the slopes of the curves of the three aliphatic radioactive chemicals revealed they were similar. Differences in the curves were insignificant at the 5 percent level. Therefore, a common slope was established in which values for a and b were substituted in Equation 1.

Solubility parameter values of the organic liquids were calculated from the equation having the best correlation with nonpolar and nonhydrogen bonding molecules omitted.

$$T = 14.34 - 0.00627M, \quad (2)$$

where

T = solubility parameter, and

M = radioactive counts.

There are very few nonpolar and nonhydrogen bonded molecules. As a result, Equation 2 is justified for use in contaminant characterization.

Comparison of the calculated data with solubility parameters of the known organic liquids is given in Table 3. The variation about the fitted line is denoted by s (one standard deviation) which can serve to forecast limits on T (solubility parameter) for a given M (Meseran Number). The standard deviation of the difference from the known values was found to be

$$s = \pm 0.50.$$

In either case, the accuracy of prediction is good and use of the technique for detecting unknown contaminants is warranted.

Interrelationship Between Solubility Parameter, Radioactive Counts, and Surface Tension

Ideally, a fundamental that has been proven should be substantiated by an independent and alternate means of analysis. In this regard, confirmation was obtained through the use of surface tension measurements of the known organic liquids and correlated with the radioactive counts using previously derived relationships.

The best correlation between radioactivity counts and solubility parameter was obtained by omitting liquids which were completely nonpolar in character. Correlation between surface tension and solubility parameter was also found to be best when strong hydrogen bonding liquids were not included.² The remaining liquids were used to establish the relationship between Meseran data and surface tension data, the latter of which was obtained by surface tension measurements in triplicate.

Curves fitted to the plot of solubility parameter data versus surface tension data revealed the following relationship.

Table 3. Comparison of Solubility Parameters Derived From Evaporative Rate Analysis With Known Values

Chemicals	Solubility Parameters		
	Known	Calculated From Meseran Data	Difference
p-Cymene	8.35	8.54	0.19
1,2,4-Trimethylbenzene	8.94	9.14	0.20
Diphenylmethane	9.55	10.03	0.48
Methylnaphthalene	9.90	9.50	-0.40
1-Chlorododecane	8.20	8.70	0.50
Ethylhexylchloride	8.13	8.53	0.40
Dibutylamine	8.15	8.75	0.60
Cellosolve Acetate	9.35	8.54	-0.81
Isophorone	9.36	8.88	-0.48
Dibutylphthalate	9.85	10.04	0.19
Diethylsuccinate	9.63	9.02	-0.61
Ethylcinnamate	9.80	9.46	-0.34
Cyclohexanone	10.42	9.83	-0.59
Hexanoic Acid	11.00	9.34	-1.66
Octyl Alcohol	10.30	9.16	-1.14
Cyclhexylmethanol	10.65	10.37	-0.28
Diethylenetriamine	11.54	13.07	1.53
Methylcellosolve	11.68	11.58	-0.10
Triethyleneglycol	12.81	13.73	0.92

$$S = 0.387T^2, \quad (3)$$

where

S = surface tension,

T = solubility parameter, and

T^2 = cohesive energy.

Introducing a constant into the formula based on the fact that solubility parameters much below 7.0 do not exist, yielded an alternate formula which allowed surface tension to be calculated with slightly greater accuracy where one standard deviation is equal to ± 0.00576 N/m (2.9 dynes/cm) or,

$$S = -23.12 + 6.17T.$$

(4)

The calculated surface tension derived from evaporative rate analysis using Equation 4 is given in Table 4 and is compared with actual surface tension measurements.

Thus the radioactivity count, as a tool of evaporative rate analysis, can be related to the surface tension of many chemicals through cohesive energy or solubility parameter.

Contaminant Removal by Solvent Selection

It is possible to characterize contaminants so that it can be known exactly which solvent or solvents will do an effective job of cleaning. Six contaminants were selected for this study (Table 5). They were considered as having the greatest potential of being present in or around electrical component manufacture. The selection was also based on obtaining a wide range of non-polar and polar characteristics. Purposely contaminated surfaces of aluminum foil were prepared and allowed to air-dry. The Meseran Surface Analyzer was used to record the radioactive counts of the contaminated surfaces before cleaning. The counts are also given in Table 5. A radioactive chemical (diethylsuccinate) in cyclopentane was used as the surface characterization probe.

A series of solvents (Table 6) was chosen which represented a major portion of the solubility parameter range 7 to 12. Selection was also based on obtaining solvents which represented the weak, moderate, and strong categories of hydrogen bonding. The solubility parameters and polarity values of each solvent were obtained from Hoy tables¹ and are also listed in Table 6.

Each of the contaminated foils was individually rinsed by a stream of the respective solvent under investigation. A volume of 100 ml of solvent was used for 60 seconds for each application.

After each contaminant was rinsed by the respective solvent, the level of radioactivity counts was determined by the Meseran Surface Analyzer for 112 seconds at room conditions of 24°C and 30 percent relative humidity. These data are given in Table 7. The data provide an indication of the effectiveness of contaminant removal by a specific solvent. A family of bar charts was developed for the six contaminants (Figures 2 through 7). The most effective contaminant removal is indicated by the lowest Meseran values obtained. In some cases, complete removal of a contaminant by a solvent is not quite achieved. However, the very low values obtained by the most effective solvents are significant when compared to values resulting from the use of fair to poor solvents. According to this analysis, selection of the best solvents can be made for most effective contaminant

Table 4. Comparison of Surface Tension Obtained by a Surface Tensiometer With Calculated Data From Meseran Analysis

Chemicals	Surface Tension in Dynes/cm (N/m)		
	Surface Tensiometer	Calculated From Meseran Data	Difference
1-Chlorododecane	30.6 (0.061)	30.56 (0.061)	-0.04 (0.00008)
p-Cymene	29.4 (0.059)	29.57 (0.059)	0.17 (0.00034)
1,2,4-trimethylbenzene	30.6 (0.061)	33.27 (0.067)	2.67 (0.00534)
Diphenylmethane	40.1 (0.080)	38.76 (0.078)	-1.33 (0.00266)
Methylnaphthalene	41.1 (0.082)	35.56 (0.071)	-5.54 (0.01108)
Ethylhexylchloride	28.7 (0.057)	29.41 (0.059)	0.71 (0.00142)
Dibutylamine	25.4 (0.051)	30.87 (0.062)	5.47 (0.01094)
Cellosolve Acetate	30.4 (0.061)	29.51 (0.059)	-0.89 (0.00178)
Isophorone	32.8 (0.066)	31.67 (0.063)	-1.13 (0.00226)
Dibutylphthalate	35.4 (0.071)	38.77 (0.078)	3.37 (0.00674)
Diethylsuccinate	33.9 (0.068)	32.47 (0.065)	-1.43 (0.00286)
Ethylcinnamate	38.6 (0.077)	35.24 (0.070)	-3.35 (0.00670)
Cyclohexanone	36.0 (0.072)	37.53 (0.075)	1.53 (0.00306)

Table 5. Meseran Values of Various Contaminants
Prior to Solvent Cleaning

Contaminant	Meseran Value Using Diethylsuccinate Radioactive Chemical
Alpha 611 Solder Flux	1145
OX-140 Micro Oil	1003
AZ1350J Photo Resist	606
Spray Coating 1303	1145
Fingerprint (Oil From Forehead)	739
Hospital Body Lotion	558

removal (Table 8). Trichloroethylene dissolves more contaminants than the other solvents. Methylchloroform and 2-ethylhexylacetate are secondary choices based on the number of contaminants removed. However, the latter two have the potential of greater contaminant removal if longer rinse times are utilized. Trichloroethylene is not exempt from federal regulations since it is a photochemically reactive solvent and, therefore, an air pollutant. Methylchloroform has a higher minimum threshold limit value of toxicity (350 ppm) as compared to trichloroethylene (100 ppm). Less is known about the toxicity characteristics of 2-ethylhexylacetate.

Solvents and Solvent Blends

As a further extension of solubility parameter principles for greater accuracy in solvent selection for contaminant removal, classification of solvents into three groups of weak, moderate, and strong hydrogen bonding potential was used. It tends to group solvents into their electron charge capability. The strong hydrogen bonders are the alcohols. These have high solubility parameter values. The weak hydrogen bonding solvents are the chlorinated solvents and solvents such as heptane and toluene. These have low solubility parameter values. In between are the moderate hydrogen bonders such as esters and ketones.

The effects of solvents on contaminants by this classification technique are shown in Table 9. Cleaning efficiency is based on how close the solubility parameter value and its hydrogen bonding class matches that of the contaminant.

Table 6 Solubility Parameters* of Solvents Used to Clean Contaminants

Solvents	Solubility Parameter	Polarity
Heptane	7.50	0
2-Ethylhexylchloride	8.13	2.65
2-Ethylhexylacetate	8.29	3.10
1,1,1,-Trichloroethane (Methylchloroform)	8.44	5.98
n-Butylacetate	8.69	3.79
Toluene	8.93	3.90
1,1,2-Trichloroethylene	9.16	6.85
Ethyleneglycolmonoethyl ether acetate (Cellosolve acetate)	9.35	4.41
Acetone	9.62	4.79
1,1,2-Trichloroethane (Vinyltrichloride)	9.88	6.30
Cyclohexanone	10.42	4.58
Isopropyl Alcohol	11.45	4.23
*Hoy Tables		

Since there is no solvent that will remove all contaminants, the practice has been to use two or three solvents, one after the other. It would be more desirable to have a formulation blend that had the potential of dissolving more contaminants than the individual solvents do. A blended solvent acquires the percentage average of the solubility parameter and polarity of the individual components, and, therefore, a new entity. However, once the solubility parameter and polarity of a solvent have been varied because of a blending operation, there is no guarantee that the original contaminant removal capability of the individual solvents will be retained.

Text continued on page 26.

Table 7. Effectiveness of Various Solvents on Removal of Contaminants From Aluminum Foil Substrate

Solvents	Meseran Values Obtained From Contaminant Cleaned Surfaces Using Diethylsuccinate Radioactive Chemical						
	Alpha 611 Solder Flux	Machine Oil	AZ1350J Photoresist	Krylon Spray	Finger-print	Sherwood Hospital Lotion	Stearic Acid (Flux)
Heptane	1142	497	288	810	73	25	132
2-Ethylhexylchloride	291	105	191	947	0	0	8
2-Ethylhexylacetate	0	12	574	800	60	0	12
1,1,1-Trichloroethane (Methylchloroform)	1	21	431	6	3	69	0
n-Butylacetate	86	406	0	32	0	0	30
Toluene	225	25	557	0	27	0	0
1,1,2-Trichloroethylene	4	0	409	0	6	0	0
Ethyleneglycolmonoethyl ether acetate (Cellosolve acetate)	74	490	55	29	33	120	62
Acetone	36	540	20	0	11	304	16
1,1,2-Trichloroethane (Vinyltrichloride)	87	446	1012	191	50	109	671
Cyclohexane	97	273	0	96	49	214	119
Isopropyl alcohol	40	629	144	968	0	151	16

Figure 2. Effectiveness of Alpha 611 Solder Flux Removal by Series of Solvents Characteristic of Solubility Parameter Range

Figure 3. Effectiveness of OX-140 Machine Oil Removal by Series of Solvents Characteristic of Solubility Parameter Range

Figure 4. Effectiveness of AZ1350J Photo Resist Removal by Series of Solvents Characteristic of Solubility Parameter Range

Figure 5. Effectiveness of Krylon Spray Removal by Series of Solvents Characteristic of Solubility Parameter Range

Figure 6. Effectiveness of Fingerprint Removal by Series of Solvents Characteristic of Solubility Parameter Range

Figure 7. Effectiveness of Sherwood Hospital Body Lotion Removal by Series of Solvents Characteristic of Solubility Parameter Range

Table 8. Effectiveness of Solvents for Contaminant Removal

Solvent	Contaminant Effectively Removed
Trichloroethylene	Alpha 611 Solder Flux Machine Oil Krylon Spray Fingerprint Hospital Lotion Stearic Acid Flux
Methylchloroform	Alpha 611 Solder Flux Krylon Spray Residue Fingerprint Stearic Acid Flux
2-Ethylhexylacetate	Alpha 611 Solder Flux Machine Oil Hospital Lotion Stearic Acid Flux
2-Ethylhexylchloride	Fingerprint Hospital Lotion Stearic Acid Flux
n-Butylacetate	Photoresist Fingerprint Hospital Lotion
Toluene	Krylon Spray Hospital Lotion Stearic Acid Flux
Acetone	Krylon Spray Fingerprint
Cyclohexanone	Photoresist
Isopropyl Alcohol	Fingerprint
Heptane	None
Cellosolve Acetate	None
Vinyltrichloride	None

Table 9. Effects of Solvents on Contaminants, Relative Ease of Removal of Contaminants by Solvent Series

Contaminants	Hydrogen Bonding Class														
	Weak									Moderate					Strong
	Hep- tane	2-Ethyl- hexyl Chloride	Trichloro- trifluoro- ethane	Methyl Chloro- form	Tol- uene	Tri- chloro- ethylene	Perchloro- ethylene	Methylene Chloride	Vinyl Tri- chloride	2-Ethyl- hexyl Acetate	n-Butyl Acetate	Cello- Solve Acetate	Ace- tone	Cyclo- hexanone	Isopropyl Alcohol
Solder Flux Types															
• Abietic Acid	C	C	C	A	C	A	C	A	B	A	B	B	B	B	B
• Stearic Acid	C	A	C	A	A	A	A	A	C	A	B	B	B	C	A
Machine Oil	C	C	A	B	B	A	A	A	C	B	C	C	C	C	C
Photo Resist	C	C	C	C	C	C	C	C	C	C	A	B	B	A	C
Spray Coating	C	C	C	A	A	A	B	A	C	C	B	B	A	B	C
Fingerprint	B	A	A	A	B	A	A	B	B	B	A	B	A	B	A
Hand Lotion	B	A	A	B	A	A	A	A	C	A	A	C	C	C	C
Detergent	C	C	C	C	C	C	A	C	B	B	C	B	C	C	A
Mold Release (Carnauba Wax)	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
Grease	B	C	C	C	C	C	C	A	B	B	C	C	B	C	C
Silicone Grease	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
Levels of contaminants solubility based on Meserian (ERA Systems, Inc., Chattanooga, Tennessee) values after solvent rinsing.															
A = Contaminant effectively removed (16 or less Meserian units)															
B = Partly soluble. Longer rinse times should improve contaminant removal (17 to 99 Meserian units)															
C = Limited contaminant solubility in solvent (greater than 100 Meserian units)															

A series of solvent blends was formulated to provide polarity and solubility parameter composites which represented areas not covered by the individual weak, moderate, and strong hydrogen bonding solvents. The formulations are given in Table 10. Their contaminant removal capability is shown in Table 11. The effect on plastics is given in Table 12. Selection of solvents can be made depending upon the type of contaminant that must be removed. Solvent blends designated C, I, and J, show more potential in multicontaminant removal than individual solvents do.

Swell Index of Plastics

Some plastics are not affected by solvents; other plastics are affected in varying degrees. If a polymer is crosslinked, as are plastics derived from thermosetting resins, or is highly crystalline, solvency will be less likely to occur. An amorphous or loosely structured plastic would probably be soluble in several solvents.

Where plastics are used as substrates, solvents selected to remove contaminants must not dissolve the plastic or cause crazing of the surface. Swell index is a measure of the effects of solvents on plastics. A small, weighed amount (1 to 2 grams) of plastic is placed in a vial with the solvent being investigated. In 24 hours, the plastic sample, if it hasn't dissolved, is reweighed to determine the extent of solvent absorption. The percentage increase in weight is defined as the swell index.

Swell index data on a variety of thermoplastic and thermosetting plastics, including a glass-filled printed circuit board laminate (Tables 12 and 13), when used with contaminant solvency (Tables 9 and 11), provide for solvent selection best suited for a particular application. For example, if the plastic being used is sensitive to moderate hydrogen bonding solvents, then it may be necessary to use a weak hydrogen bonding solvent to remove contaminants.

Trichloroethylene is a good solvent for removing contaminants, but it may also be a good solvent for several plastics as well. In contrast, isopropyl alcohol is quite often recommended for cleaning solvent sensitive plastics, since it doesn't attack the plastic. By the same token, its contaminant removal capability is limited.

Characterization of Surfaces

There has always been a need for more specific information concerning the nature of surface contamination. The chemical properties of a surface control the adhesion potential and the surface electrical properties depending upon the reactivity of the surface

Text continued on page 31.

Table 10. Solvent Blend Formulations

Solvent Blend Designation	Composition	Percent by Volume
A	Methylchloroform	50
	Vinyltrichloride	50
B	n-Butyl acetate	50
	Isopropyl alcohol	50
C	Methylchloroform	17
	n-Butyl acetate	33
	Trichloroethylene	33
	Isopropyl alcohol	17
D	n-Butyl acetate	25
	Acetone	25
	2-Ethylhexylchloride	25
	Vinyltrichloride	25
E	Acetone	20
	Vinyltrichloride	20
	Methylchloroform	20
	Cyclohexane	20
	Isopropyl alcohol	20
F	Methylchloroform	33
	n-Butyl acetate	33
	2-Ethylhexylacetate	33
G	Methylchloroform	33
	n-Butylacetate	33
	Trichloroethylene	33
H	Perchloroethylene	50
	Methylenechloride	20
	Methylchloroform	30
I	Methylchloroform	60
	Methylenechloride	40
J	Methylchloroform	38
	Methylenechloride	48
	n-Butylacetate	14

Table 11. Effects of Solvent Blends on Contaminants,*
Relative Ease of Removal of Contaminants by
Solvent Blends

Contaminants	Solvent Blend Designation**									
	A	B	C	D	E	F	G	H	I	J
Solder Flux Types										
Abietic Acid	B	B	B	C	A	C	A	C	A	B
Stearic Acid	B	A	A	C	B	A	C	A	B	A
Machine Oil	A	C	B	C	C	C	A	A	A	B
Photo Resist	C	B	A	B	B	C	C	C	C	C
Spray Coating	C	B	A	B	C	C	A	B	B	B
Fingerprint	B	C	B	C	B	B	B	A	B	A
Hand Lotion	A	C	B	A	C	B	B	A	A	B
Detergent	B	C	B	C	C	B	A	C	B	B
Mold Release (Carnauba Wax)	C	C	C	C	C	C	C	C	C	C
Grease	C	B	C	C	C	C	C	C	A	A
Silicone Grease	C	C	C	C	C	C	C	C	C	C
<p>*Levels of contaminant solubility based on Meseran (ERA Systems Inc., Chattanooga, Tennessee) values after solvent rinsing.</p> <p>**Refers to Table 10</p> <p>A = Contaminant effectively removed (16 or less Meseran units)</p> <p>B = Partly soluble. Longer rinse times should improve contaminant removal (17 to 99 Meseran units)</p> <p>C = Limited contaminant solubility in solvent (greater than 100 Meseran units)</p>										

Table 12. Effects of Solvents on Plastics,* Showing Relative Solvency by Solvent Series

Plastics	Hydrogen Bonding Class														
	Weak									Moderate					Strong
	Hep- tane	2-Ethyl hexyl Chloride	Trichloro- trifluoro- ethane	Methyl- Chloro- form	Tol- uene	Tri- chloro- ethylene	Perchloro- ethylene	Methylene Chloride	Vinyl Tri chloride	2-Ethyl hexyl Acetate	n-Butyl Acetate	Cello- solve Acetate	Acetone	Cyclo- hexanone	Isopropyl Alcohol
Teflon (1)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Polyethylene	1	1	1	1	2	2	2	2	2	1	1	1	1	1	1
Polyvinyl- chloride	1	1	1	1	2	3	1	5	4	2	4	2	4	5	1
Nylon	1	1	1	1	1	1	1	2	1	1	1	1	1	1	1
Acrylic	1	1	1	1	1	5	1	5	5	1	1	5	5	1	1
Polystyrene	1	5	1	5	5	5	5	5	5	5	5	5	5	5	1
Cellulose Acetate	1	1	1	2	2	3	1	5	5	1	3	5	5	5	2
Mylar (1)	1	1	2	1	1	2	1	2	2	1	1	1	2	1	1
Polyphenyl- sulfide	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Polycarbonate	1	1	1	3	3	5	2	5	5	1	3	3	3	5	1
Phenoxy (2)	1	1	2	1	2	4	1	5	5	1	3	5	5	5	1
Diallyl- phthalate	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Phenolic	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Polyphenylene Oxide	1	2	1	5	5	5	5	5	5	2	3	3	3	4	1
ABS	3	1	1	4	4	5	3	5	5	1	5	5	5	5	1
Urethane	2	3	2	3	3	4	3	4	4	2	3	3	3	3	2
Microballoon- filled Epoxy	1	1	1	1	1	2	1	5	3	2	1	2	2	2	1
Polyester	1	1	1	1	1	1	1	2	1	1	1	1	1	1	1
Kapton (1)	1	1	1	1	1	2	1	3	3	1	1	1	2	1	1
Polysulfide	1	1	1	3	4	4	3	4	4	1	3	3	3	4	1
Printed Circuit Board, Laminate	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

Levels of plastic solubility are based on percent swell in 24 hours.

*1. Little or no solvent absorption (swell equals less than 1 percent)
 2. Slight absorption of solvent (swell equals 1 to 10 percent)
 3. Moderate absorption of solvent (swell equals 11 to 49 percent)
 4. Excessive solvent absorption (swell equals greater than 50 percent)
 5. Plastic dissolved partially or completely in solvent

(1) Trade name of product of E. I. du Pont de Nemours
 (2) Trade name of product of Union Carbide

Table 13. Effects of Solvent Blends on Plastics,*
Showing Relative Solvency by Solvent

Plastics	Solvent Blend Designation**									
	A	B	C	D	E	F	G	H	I	J
Teflon (1)	1	1	1	1	1	1	1	1	1	1
Polyethylene	2	1	2	1	1	1	2	2	2	2
Polyvinylchloride	3	2	2	3	3	2	2	3	4	4
Nylon	1	1	1	1	1	1	1	1	1	1
Acrylic	5	1	5	5	5	1	5	5	5	5
Polystyrene	5	5	5	5	5	5	5	5	5	5
Cellulose Acetate	4	3	3	3	4	1	3	3	3	3
Mylar (1)	1	1	1	1	1	1	1	1	2	2
Polyphenylene sulfide	1	1	1	1	1	1	1	1	1	1
Polycarbonate	5	1	3	3	3	2	3	5	5	5
Phenoxy (2)	5	5	5	5	5	2	5	3	5	5
Diallylphthalate	1	1	1	1	1	1	1	1	1	1
Phenolic	1	1	1	1	1	1	1	1	1	1
Polyphenylene Oxide	5	1	4	3	3	2	4	5	5	5
ABS	5	2	4	5	5	3	4	5	5	5
Urethane	4	3	4	3	4	3	4	4	4	4
Microballoon Filled Epoxy	1	1	1	1	2	1	1	1	2	2
Polyester	1	1	1	1	1	1	1	1	1	1
Kapton (1)	1	1	1	2	1	1	1	2	2	2
Polysulfide	4	2	3	3	3	2	4	3	4	4
Printed Circuit Board Laminate	1	1	1	1	1	1	1	1	2	1

Levels of plastic solubility are based on percent swell in 24 hours.

- *1. Little or no solvent absorption (swell equals less than 1 percent)
2. Slight absorption of solvent (swell equals 1 to 10 percent)
3. Moderate absorption of solvent (swell equals 11 to 49 percent)
4. Excessive solvent absorption (swell equals greater than 50 percent)
5. Plastic dissolved partially or completely in solvent.

(1) Trade name of product of E. I. du Pont de Nemours.
(2) Trade name of product of Union Carbide.

**Refer to Table 10.

molecules. Contaminants can drastically change the functionality of these surfaces. Solubility parameter technology and the evaporative rate analysis technique have been used to characterize surface contaminants indirectly through solvency technology.³ This technology can be expanded to include direct characterization of surfaces in terms of their balance of forces based on their polarity and nonpolarity attributes.

The Meseran Surface Analyzer utilizes an evaporative rate analysis technique to detect surface conditions. The Analyzer is based on the use of radioactive carbon-14 tagged chemicals as surface energy probes. The degree of retention of the radiochemical on a surface is measured by a Geiger counter and is an indication of the interaction of the functional group of the radiochemical and of the surface.⁴ Evaporative rate analysis has been used to characterize surface properties according to the degree of absorption of the functional group of the radiochemical surface energy probe.⁵

Solubility parameter technology is the study of how well materials are compatible with each other. Similar molecules will dissolve more easily in each other than will dissimilar molecules. Applying the same principle to surface characterization, it follows that polar solvents emphasize polar characteristics of surfaces and nonpolar solvents emphasize nonpolar characteristics. Spreading characteristics (contact angle) of a variety of solvents on several surfaces have been used to show the significance of polarity, nonpolarity, and hydrogen bonding in the use of solubility parameter technology in surface characterization.⁶

The relative level of polarity of molecules can be estimated from the electronegativity differences in the functional groups. As the electronegativity differences in the elements of a chemical bond increase, the bond becomes more polar.⁷

Three radioactive chemicals were selected for use with the Meseran Surface Analyzer according to their level of polarity. The radiochemical diethylsuccinate with its C-O and C=O bonds, will have a moderately large electronegativity difference of 1.0. Tetrabromoethane, on the other hand, with its C-Br bonds, will have a small electronegativity difference of 0.3. In these two cases, the electronegativities of the terminal atoms (oxygen and bromine) are more negative than the carbon atom and are considered as being of negative polarity. Diethylsuccinate has a greater charge potential than tetrabromoethane and therefore is more polar. Tridecane, however, with its C-H bonds can be considered as being nonpolar since the terminal hydrogen atom is less electronegative than the carbon atom.

If the bulk vapor pressure of the radiochemicals is substantially equivalent, the observed amount of measured retained radioactivity results primarily from the ability of the surface to interact with the functional group of the radioactive chemical.⁸ In this regard, the three radiochemicals (tridecane, tetrabromoethane, and diethylsuccinate) have similar vapor pressure properties.

The three radioactive chemicals can be used as surface energy probes to determine which one reflects the polarity or nonpolarity condition of a surface. In this manner, the level of polarity or balance of forces that exist on a surface can be ascertained. The largest Meseran number obtained by one of the three radioactive chemicals will reflect the strongest character of the surface. Thus, if the tetrabromoethane number is largest, the predominant characteristic of the surface will be of weak polarity. If diethylsuccinate provides the largest number, the surface has a moderate to strong polarity. If the surface is nonpolar, the tridecane number will be the largest. Therefore, if A stands for tetrabromoethane, C stands for diethylsuccinate, and B stands for tridecane then;

A > C > B equals a weak polar surface,

C > A > B equals a moderate to strong polar surface, and

B > A or C equals a nonpolar surface.

Investigators have used 2- or 3-dimensional graphs to identify compatibility of solvents, resins, and polymers based on units of solubility parameter, polarity, nonpolarity, and hydrogen bonding. This technique characterizes materials according to their regions of solubility with a greater degree of definition. In this work, however, the degree of affinity for the surface by each radioactive chemical is expressed by radioactive counts which is the extent of compatibility based on solubility parameter principles. The radioactivity counts are a measure of the surface and since there is a degree of nonpolarity in every molecule, the nonpolar tridecane data can be subtracted from the Meseran numbers obtained with the polar radiochemicals to reveal the relative polarity level present on a surface. Thus, A minus B (Formula 1) equals weak polar data and C minus B (Formula 2) equals moderate to strong polar data.

This principle was applied to known pure organic chemical films on aluminum foil surfaces, to plastic surfaces, and to various contaminants on aluminum foil surfaces. The maximum benefit was obtained by locating the specific data combination of Meseran numbers (tridecane, tetrabromoethane, and diethylsuccinate) according to Formulas 1 and 2, on a four-quadrant chart (Figure 8). In this manner, surfaces of materials can be viewed in terms of relative level of polarity or nonpolarity.

Figure 8. Polarity Indications According to Four-
Quadrant Chart Analysis

The Y-axis is a measure of Meseran data obtained by subtracting tridecane from diethylsuccinate (C-B) radioactivity counts. In this work, data was collected for 112 seconds for each test made. The X-axis is a measure of tetrabromoethane minus tridecane data (A-B). This negative data (larger tridecane Meseran numbers) will reflect the nonpolar characteristics of a surface. Polar surfaces, on the other hand, will be shown in the greater diethylsuccinate data (strong to moderate polarity) and the tetrabromoethane data (weak polarity). The intercept of the two lines is the zero origin from which plus or minus data is plotted. This type of surface characterization by four-quadrant chart analysis is a logical extension of solubility parameter concepts. It provides an insight into actual surface chemistry heretofore not available by other analytical techniques.

Since organic residue contaminants and plastics do not have the freedom of molecular orientation at the surface as do liquids, the location on the four-quadrant chart is a measure of the balance of forces (polarity and nonpolarity) that are exposed at the surface. In addition, the structure of polymers, (linearity, degree of crystallinity, molecular size) will influence the availability of reactive sites at a surface.

Known Chemical Films

The four-quadrant chart analysis was applied to known pure organic chemical liquid films spread on aluminum foil. These chemicals represented the major portion of the solubility parameter range and provided molecules having no polarity, moderate and weak polarities, and strong hydrogen bonding potential.⁹

Analysis of the location of the chemicals plotted on the chart (Figure 9) shows that the chemicals which are composed only of carbon and hydrogen (nonpolar) are located in the lower left quadrant. The esters and ketones are located in the weak polar area, while the hydroxyl and amine molecules tend towards the more strongly polar area.

The clear separation of nonpolar molecules from polar molecules is considered significant.

Plastics

The surfaces of polymers provide fewer active sites to react with the radioactive chemicals than would be expected with liquids which, in contrast, are very small molecules. However, greater retention of the radiochemical may occur due to absorption into the plastic. This is exemplified by swell index analysis.^{3,10} By the same token, it is also an indication of compatibility according to solubility parameter principles.

Figure 9. Classification of Known Chemical Films According to Polarity Characteristics

The classification of the surfaces of several plastics is shown in Figure 10 based on Mescran analysis performed at 30 percent relative humidity. The plastics, which are composed only of carbon and hydrogen (polyethylene and polystyrene), are located in the lower left quadrant like the nonpolar known liquids (Figure 9). All the other plastics, which are composed of carbon, hydrogen, halogen, and oxygen or nitrogen, are in the polar quadrant.

The differentiation of plastic surfaces into polar and nonpolar areas is evident.

Organic Residue Contaminants

Contaminants carried to a substrate by a cleaning operation will reflect previous processing conditions which may involve machine oils, fingerprint residues, solder fluxes, and mold releases. Contaminants have a molecular structure; therefore, they have properties that are combinations of polarity and nonpolarity.

Many mold releases are composed of nonpolar materials. Since most plastics are polar, the lower surface energy (surface tension) mold release prevents adhesion of the plastics to the mold. If the mold release transfers to the plastic surface, it becomes a contaminant and can prevent adhesion. A four-quadrant chart analysis of several mold releases, identified in the Appendix, is given in Figure 11. Most of the mold releases are shown to be located well within the nonpolar area. The polarity of these materials is not evident by these analyses.

Other types of contaminants, however, are shown to reflect conditions ranging from nonpolarity to strong polarity (Figure 12). The contaminant obtained with the paper towels and a bristle brush was with the aid of isopropyl alcohol.

Fingerprint contaminants are variable. An analysis of the fingerprint characteristics of several people is given in Figure 13. Various levels of polarity and nonpolarity are evident.

Cleaning Process Efficiency

The current selection of solvents that effectively remove contaminants without damaging plastics and the efficiency of the cleaning processes used will control process costs in terms of time and material. Limitations of some application methods are encountered when parts to be cleaned have complex configurations or have surface areas of limited accessibility. The cleaning processes can be selected according to the critical degree of cleaning required, the complexity of the part, and the costs of each method. The efficiency of ultrasonic cleaning, spray application, and vapor degreasing with several solvents can be demonstrated in the removal of organic residue contaminants.¹¹

Figure 10. Polarity Indications of Several Plastic Surfaces

Figure 11. Classification of Mold Releases According to Surface Polarity

Figure 12. Classification of Contaminants on Aluminum Foil According to Polarity

Figure 13. Characterization of Several Fingerprints on Aluminum Foil in Terms of Polarity

In the electronics industry, removal of contaminants is critical because foreign material on surfaces has the potential of causing electrical leakage or failures in potting, coating, or adhesion applications. Joining and assembly operations can introduce contaminants from a previous process. Equipment, such as vacuum pumps, may be a source of airborne oil contamination. Soldering operations subsequently require that the flux material be removed. Other examples could be given but for purposes of this evaluation, vacuum oil (Duo Seal Pump Oil, Sargent Welch Scientific Company) and solder flux (Kester 197, Kester Solder Company) were used to study ultrasonic, vapor degreasing, and spray application solvent cleaning processes. The substrate used was the epoxy side of a glass-fiber-filled, epoxy-laminated, printed circuit board.

The surface contamination of the printed circuit board coated with solder flux or vacuum oil was measured using the Meseran Surface Analyzer before and after each cleaning process step using a diethylsuccinate radioactive chemical.^{12,13} Meseran data was obtained after 30 seconds and 1, 2, and 3 minute intervals during the vapor degreasing process. Ultrasonic and spray application processes were tested at 1 and 3 minute intervals. The spray was applied with a portable Jet-Pak Sprayer (Spray-On Products, Incorporated) at a distance of 25.4 to 76.2 mm from the board.

Vacuum Oil Removal

Vacuum oil was applied to the epoxy side of the printed circuit board. The contaminated boards were subsequently cleaned by the ultrasonic and vapor degreasing processes using trichloroethylene, methylchloroform, and a solvent blend C.

Since there is no solvent that will remove all contaminants, a series of solvents are often used in cleaning operations. Several solvent blends were evaluated, based on solubility parameter and polarity values, which were designed to remove a greater variety of contaminants.¹³ Solvent blend C showed more potential in multicontaminant removal and is given in the following tabulation.

<u>Solvent Blend C</u>	<u>Percent by Volume</u>
Methylchloroform	17
n-Butyl Acetate	33
Trichloroethylene	33
Isopropyl Alcohol	17

The processes of ultrasonic cleaning and vapor degreasing using laboratory equipment were compared for their effectiveness in removing the oil from the substrate. After the boards were cleaned, they were placed in a vacuum chamber at less than 133 Pa (1 torr) for 10 minutes prior to Meseran testing. The data obtained are given in Tables 14 and 15 and plotted in Figures 14, 15, and 16. With all three solvents, the vapor degreasing technique was found to be more effective in removing vacuum oil than the ultrasonic cleaning process. Thirty seconds to 1 minute was sufficient for maximum cleanliness as determined by the Meseran data.

Solder Flux Removal

The evaluation of solder flux removal from the printed circuit board was conducted in the same manner as described previously. However, an additional process, spray cleaning, was included. Vacuum drying was also performed before each Meseran analysis. The data on each solvent (trichloroethylene, methylchloroform, and solvent blend C) are given in Tables 14 and 15 and plotted in Figures 17, 18, and 19. Vapor degreasing is shown to be more effective than the alternate process. Only 30 seconds in the vapor degreaser were required.

Final Solvent Removal

Many of the studies made on contaminant removal by solvents (Figures 14 through 19) showed increased exposure of epoxy laminate to each of the solvents (trichloroethylene, methylchloroform, and solvent blend C) resulted in larger Meseran numbers. This was believed to have been caused by either incomplete contaminant removal and, therefore, solvent retention or by absorption of the solvent by the epoxy of the laminate substrate. The effect of each solvent on the uncontaminated substrate was determined by Meseran measurements using the vapor degreasing technique followed by vacuum drying. In all cases, little change was noted; the data was relatively consistent at about 200 Meseran units (Figure 21). The data indicated absorption of the solvent by the epoxy laminate was negligible. This analysis confirms earlier work where essentially no absorption occurred after 24 hours immersion of printed circuit boards in the solvents--trichloroethylene 0.10 percent, methylchloroform 0.02 percent, and blend C 0.01 percent.¹³

However, with one or two exceptions, this level of cleanliness (200 Meseran units) was not achieved after surfaces had been contaminated, subsequently solvent cleaned, and vacuum dried. A comparison of vacuum drying with oven drying at 82.2°C for 5 minutes was made using solder flux after vapor degreasing with trichloroethylene, methylchloroform, and solvent blend C (Table 14).

Text continued on page 49.

Table 14. Comparison of Effectiveness of Three Cleaning Processes

Contaminant	Cleaning Process	Solvent	Meseran Number*		
			Vacuum Dry	Oven Dry	Vacuum Bake
Vacuum Oil	3 Minute	Trichloroethylene	509		143
	Vapor	Methylchloroform	160		245
	Degrease	Blend C	332		240
Vacuum Oil	3 Minute	Trichloroethylene	698		386
	Ultrasonic	Methylchloroform	669		210
		Blend C	551		178
Solder Flux	3 Minute	Trichloroethylene	715	408	167
	Vapor	Methylchloroform	637	690	147
	Degrease	Blend C	370	509	321
		Isopropyl Alcohol		524	
Solder Flux	3 Minute	Trichloroethylene	548		208
	Ultrasonic	Methylchloroform	698		296
		Blend C	588		423
Solder Flux	3 Minute	Trichloroethylene	549		101
	Spray	Methylchloroform	496		111
		Blend C	600		181

*Radioactivity count for 112 seconds

Table 15. Process Effects on Printed Circuit Board Absorption of Solvents

Contaminant	Cleaning* Process	Solvent	Meseran Number**		
			After Initial Cleaning	After Three Minutes Cleaning Time	Difference
Vacuum Oil	Ultrasonic	Trichloroethylene	566	698	+132
	Vacuum Dry	Methylchloroform	586	668	+ 83
		Blend C	468	551	+ 83
Vacuum Oil	Vapor Degrease	Trichloroethylene	295	509	+214
	Vacuum Dry	Methylchloroform	229	160	- 69
		Blend C	384	332	- 52
Solder Flux	Ultrasonic	Trichloroethylene	559	548	- 11
	Vacuum Dry	Methylchloroform	632	678	+ 46
		Blend C	520	588	+ 68
Solder Flux	Vapor Degrease	Trichloroethylene	346	715	+369
	Vacuum Dry	Methylchloroform	361	637	+276
		Blend C	298	370	+ 72
Solder Flux	Spray	Trichloroethylene	463	549	+ 86
	Vacuum Dry	Methylchloroform	472	496	+ 24
		Blend C	690	600	- 90

*Ultrasonic and spray application initial cleaning time was one minute. Vapor degreasing cleaning time was 30 seconds.

**Radioactivity count for 112 seconds

Figure 14. Cleaning Method Comparison for Vacuum Oil Removal With Tri-chloroethylene After Vacuum Dry

Figure 15. Cleaning Method Comparison for Vacuum Oil Removal With Methyl-chloroform After Vacuum Dry

Figure 16. Cleaning Method Comparison for Vacuum Oil Removal With Solvent Blend C After Vacuum Dry

Figure 17. Cleaning Method Comparison for Kester 197 Solder Flux Removal With Trichloroethylene After Vacuum Dry

Figure 18. Cleaning Method Comparison for Kester 197 Solder Flux Removal With Methylchloroform After Vacuum Dry

Figure 19. Cleaning Method Comparison for Kester 197 Solder Flux Removal With Solvent Blend C After Vacuum Dry

Figure 20. Comparison of Oven Dry and Vacuum Dry Effectiveness in Removing Residual Solvent Blend C After Vapor Degreasing Kester 197 Solder Flux

Figure 21. Effect of Various Solvents on Epoxy Surface of Printed Circuit Board Laminate

In addition, isopropyl alcohol was included in this portion of the study. An example of the similarity of effectiveness of these two drying techniques is shown in Figure 20. A much more effective process of residual solvent removal was achieved by a vacuum bake procedure at 71.1°C for 30 minutes, regardless of the solvents used.

The data are given in Table 14. Vacuum drying and oven drying are not as effective as the vacuum bake procedure in preventing solvent absorption by the plastic after the contaminant has been removed.

Contaminant Concentration

The degree of cleanliness can be ascertained by measuring the extent of radioactivity of one of the Meseran surface energy probes.¹⁴ Known concentrations of solder flux, vacuum oil, and photo resist were established ranging from 0.1 gram to 0.1 microgram for each 1.0 square centimeter of surface area. The three radioactive chemicals used were tridecane (nonpolar), tetrabromothane (weakly polar), and diethylsuccinate (moderately polar). These surface energy probes were selected to reflect or measure the surface condition of the contaminants; the ones most compatible would provide greater sensitivity in Meseran measurements. A plot of the Meseran numbers versus contaminant concentration is given for Duo Seal vacuum oil (Figure 22) and Kester 197 solder flux (Figure 23). Photo resist concentration could not be determined since the surface changed within 48 hours (Figure 24). The semisolid solder flux and liquid vacuum oil surfaces remained unchanged after 7 days (Figure 25).

The Meseran data confirms the principles of solubility parameter; there is a preference of each contaminant for one or two of the three surface energy probes according to their level of polarity or nonpolarity. For convenience, the most responsive radioactive chemical is plotted in Figures 22 and 23.

The capability of contaminant detection for liquids and semisolids is as low as 0.1 to 1.0 part per million per 1.5 square centimeter surface area.

Surface Electrical Characteristics

Since contaminants are organic materials and can have varying degrees of polarity or nonpolarity, it can be expected that the electrical properties of these materials would respond to voltage in terms of surface leakage or voltage breakdown (arc over). Using a printed circuit board test pattern,¹⁵ electrical tests were made on a known series of chemicals and on contaminants.

Figure 22. Relationship of Meseran Data Versus Concentration of Vacuum Oil

Figure 23. Relationship of Meseran Data Versus Concentration of Kester 197 Solder Flux

Figure 24. Effect of Cure of AZ1350J Photo Resist on Meseran Data

Figure 25. Aging Effects on Kester 197 Solder Flux and Duo Seal Vacuum Oil on Meseran Data

Surface Leakage

A series of liquids were evaluated for surface leakage characteristics and represented the solubility parameter range which should cover most types of contaminants (Table 3). Surface leakage tests were made over a 10 to 500 applied voltage range. A definite pattern of electrical activity was found based on nonpolarity and polarity/hydrogen bonding characteristics in terms of solubility parameter values. The actual surface leakage data are plotted in Figure 26. A summary of the data is given in Table 16 which characterizes chemical type with surface leakage properties.

A large variety of contaminants were similarly measured for their surface leakage characteristics (Table 17). The principles developed with the known chemicals (Table 16) are also seen with the contaminants according to their level of polarity-nonpolarity. These contaminants have been grouped according to their relative surface leakage characteristics in Table 18.

Arc Over

Contaminant effects on static voltages and high voltage breakdown have been evaluated for their potential limit failures.^{16,17} Using the same type of test panels that were used for surface leakage, arc over tests were made on known chemicals. The first indication of voltage breakdown was recorded and the average of three tests was reported (Table 19).

Major arc over problem could occur with materials which are primary amines, alcohols (hydroxyls), and ketones. The more the hydrogen bonding characteristic there is of the chemical, the lower the breakdown voltage.

When contaminants are evaluated in a similar manner (Table 20), their characteristics may be summarized as given in Table 21.

ACCOMPLISHMENTS

A fundamental relationship has been established between the evaporative rate analysis measurement of a surface contaminated by a known organic molecule and the solubility parameter of that molecule. A verification of the relationship has been established independently by measuring surface tension. High confidence levels of correlation have been established through statistical analyses.

A technique based on solubility parameters and evaporative rate analyses has been established to specifically select the most effective solvents to remove contaminants. Through the use of solvents of known solubility parameter and polarity, as well as solvent classification into weak and moderate hydrogen bonding groups, characterization of contaminants is possible.

SURFACE LEAKAGE

Figure 26. Relationship of Surface Electrical Leakage of Known Organic Residues at Various Applied Voltages

Table 16. Classification of Organic Residue
Chemical Type With Surface Leakage

Types of Organic Residue	Leakage at 250 to 500 Volts (Amperes)
Alphatics, Aromatics	1 μ A to 1 pA
Chlorides, Secondary Amines	10 nA
Esters, Ethers, Ketones	0.1 mA to 1 μ A
Alcohols	0.1 A to 0.1 μ A
Primary Amines	>0.1 A

Selection of solvents or solvent blends can be made to remove specific contaminants (organic residues) without damaging plastics using compatibility charts. Selective solvent blending based on solubility parameter principles has been demonstrated to be more effective than individual solvents in variety type contaminant removal. A specific solvent blend (C) is best suited for various potential contaminants that might be encountered in electrical component manufacture.

A new method for the characterization of surfaces has been demonstrated. Organic residue contaminants can be evaluated in terms of their relative surface properties (polarity or nonpolarity), thereby providing an effective means or basis for identification and removal by solvents. A four-quadrant chart analyses technique has been established which can be applied to surface characterization of plastics as well as contaminants.

Vapor degreasing is shown to be a more efficient and effective process in removing organic residue contaminants than the ultrasonic or spray application procedures. Residual solvent removal after the cleaning process is best achieved by a vacuum bake procedure.

The capability of contaminant detection for liquids and semi-solids by Meseran surface analysis is as low as 0.1 to 1.0 microgram for each 1.5 square centimeter of surface area. A select surface energy probe, according to the level of polarity of a contaminant, controls the straight line relationship between contaminant concentration and radioactivity counts.

Table 17. Surface Leakage of Organic Contaminants on Printed Circuit Board

Contaminant Material	Leakage Current at Indicated Applied Voltage*					
	10 Volts Applied	25 Volts Applied	50 Volts Applied	100 Volts Applied	250 Volts Applied	500 Volts Applied
PAC Lotion Soap						
Wet	6.72 mA	7.12 mA	6.94 mA	7.05 mA	**	
Dried	0.751 mA	2.05 mA	2.57 mA	3.27 mA	5.63 mA	**
Vel Detergent						
Wet	8.20 mA	9.48 mA	10.28 mA	11.47 mA	**	
Dried	1.66 mA	5.00 mA	7.17 mA	8.16 mA	**	
Chap-Ans Cream						
Wet	3.54 mA	5.41 mA	5.52 mA	5.87 mA	7.95 mA	4.50 mA
Dried	97.7 μ A	0.261 mA	0.485 mA	0.809 mA	1.54 mA	3.65 mA
Hospital Body Lotion						
Wet	6.73 mA	5.41 mA	3.47 mA	2.45 mA	**	
Dried	49.3 μ A	160.6 μ A	0.310 mA	0.500 mA	0.921 mA	2.23 mA
Mold Release						
Frecote 11	0.1 pA	0.2 pA	0.4 pA	0.8 pA	2.1 pA	4.0 pA
Frecote 33	83.7 pA	0.21 nA	0.42 nA	0.82 nA	1.72 nA	3.7 nA
RAM 225	0.2 pA	0.5 pA	0.9 pA	1.6 pA	4.0 pA	7.9 pA
Mold Whiz P9	0.2 pA	0.3 pA	0.5 pA	1.0 pA	2.9 pA	5.6 pA
Mold Whiz 424R75	1.1 pA	3.0 pA	6.2 pA	12.8 pA	33.4 pA	68.8 pA
Rigidax	0.1 pA	0.1 pA	0.1 pA	0.2 pA	0.5 pA	1.2 pA

Table 17. Continued. Surface Leakage of Organic Contaminants on Printed Circuit Board

Contaminant Material	Leakage Current at Indicated Applied Voltage*					
	10 Volts Applied	25 Volts Applied	50 Volts Applied	100 Volts Applied	250 Volts Applied	500 Volts Applied
Carnauba Wax	20.8 nA	56.5 nA	116.1 nA	0.236 μ A	0.643 μ A	1.37 μ A
Silicone Oil	0.4 pA	0.7 pA	1.4 pA	2.8 pA	7.3 pA	16.7 pA
Silicone Grease (DC-7)	0.2 pA	0.2 pA	0.6 pA	1.2 pA	3.2 pA	6.3 pA
Fingerprints						
A	0.2 pA	0	0.4 pA	1.1 pA	3.4 pA	8.2 pA
B	0.4 pA	0.9 pA	1.8 pA	4.5 pA	28.1 pA	196.7 pA
C	0	0.3 μ A	0.7 pA	1.4 pA	3.9 pA	7.8 pA
D	0.6 pA	0.3 μ A	0	0.5 pA	1.8 pA	4.0 pA
Resins						
Versamid 140 (Amine)	8.74 μ A	24.9 μ A	55 μ A	127.3 μ A	0.466 mA	1.5 mA
Triethylenetetramine	94.3 μ A	328 μ A	844 μ A	925 μ A	6.75 mA	**
Diethanolamine	2.61 mA	7.12 mA	8.39 mA	9.24 mA	**	
Epon 828 Epoxy	1.8 nA	4.5 nA	8.8 nA	16.8 nA	39.2 nA	71.4 nA
Solder Fluxes						
Kester 197	0.6 pA	1.7 pA	3.3 pA	6.7 pA	16.6 pA	35 pA
Kester 1544	4.4 pA	10.9 pA	22.5 pA	46.7 pA	93.4 nA	0.487 μ A
Alpha 611	0.2 pA	0.5 pA	1.2 pA	2.7 pA	7.2 pA	14.7 pA
Alpha 346-35	0.01 nA	.39 nA	1.49 nA	42.9 nA	33.5 nA	117.9 μ A
Alpha 320-33	5.50 μ A	15.9 μ A	32.0 μ A	56.9 μ A	95.1 μ A	198 μ A

Table 17 Continued. Surface Leakage of Organic Contaminants on Printed Circuit Board

Contaminant Material	Leakage Current at Indicated Applied Voltage*					
	10 Volts Applied	25 Volts Applied	50 Volts Applied	100 Volts Applied	250 Volts Applied	500 Volts Applied
Isopropyl Alcohol and Kimwipes	0.8 pA	1.7 pA	2.9 pA	5.1 pA	12.1 pA	21.6 pA
Cel-Fibes	0.3 pA	0.6 pA	1.0 pA	1.9 pA	5.0 pA	9.8 pA
Urethane Sponge	2.3 pA	5.5 pA	10.8 pA	21.3 pA	53 pA	101.3 pA
Batiste Cloth	0.2 pA	0.3 pA	0.6 pA	1.3 pA	3.4 pA	6.4 pA
Acid Brush	0.8 pA	1.6 pA	2.8 pA	5.1 pA	12.4 pA	22.8 pA
Photoresist AZ1350J						
Wet	429 nA	1.228 μ A	2.65 μ A	5.20 μ A	12.88 μ A	31.3 μ A
24 Hour Cured	0.5 pA	0.7 pA	1.0 pA	1.7 pA	4.0 pA	8.3 pA
Polysulfide						
PR1201 Base Resin	4.36 nA	10.5 nA	1.97 nA	3.75 nA	8.96 nA	176.4 nA
PR1201 Cure Agent	4.24 nA	10.8 nA	2.13 nA	4.10 nA	8.89 nA	756 nA
Krylon Spray	0	0	0	0	0.1 pA	0.3 pA
Finger Cots	2.2 pA	1.8 pA	1.8 pA	2.4 pA	4.7 pA	8.3 pA
Gloves						
Plastic	2.3 pA	1.9 pA	1.8 pA	2.4 pA	4.8 pA	8.9 pA
White Rubber	2.8 pA	2.5 pA	3.0 pA	4.6 pA	10.5 pA	22.2 pA
Yellow Rubber	2.2 pA	2.2 pA	2.9 pA	4.8 pA	12.5 pA	27.6 pA
*Measured After 1 Minute of Applied Voltage						
**Voltage Breakdown						

Table 18. Relative Electrical Surface Leakage of Contaminants

Contaminant Material	Surface Leakage*	
	Range	Current
Detergents, Hand Lotion	High	1 ma
Amines (Epoxy Cure Agent)	High	1 ma
Active Solder Fluxes	High	1 ma
Wet Photo Resist	High	1 ma
Certain Mold Releases and Waxes	Moderate	0.1 to 10 μ A
Epoxy Resin	Moderate	0.1 to 10 μ A
Certain Solder Fluxes	Moderate	0.1 to 10 μ A
Uncured Polysulfide Components	Moderate	0.1 to 10 μ A
Most Mold Releases	Low	1 nA
Fingerprints	Low	1 nA
Certain Solder Fluxes	Low	1 nA
Sponges, Cloths, Paper Towels	Low	1 nA
Gloves	Low	1 nA

*Applied voltage of 250 to 500 volts

The various levels of polarity and hydrogen bonding class of known chemicals are related to surface electrical leakage in a predictable manner. Arc over limits are less sensitive to polarity differences. In both cases contaminants and known chemicals having high solubility parameter values, and therefore high polarity or hydrogen bonding, yield greater surface leakage (amperes) and least arc over (voltage) resistance.

Table 19. Classification of Organic Residue
Chemical Type With Arc Over Limits

Material		Arc Over (Volts)
Type	Chemical	
Primary Amine	Diethylenetriamine	92
Hydroxyls	Methylcellosolve	143
	Triethyleneglycol	208
	Cyclohexanemethanol	683
	Octyl Alcohol	1508
Ketones	Isophorone	783
	Cyclohexanone	1330
Secondary Amine	Dibutylamine	2483
Organic Acids Ester	Cellosolve Acetate	2567
	Diethylsuccinate	2614
	Dibutylphthalate	4033
	Ethylcinnamate	3700
Chloride	Ethylhexylchloride	2950
Organic Acid	Ethylhexanoic Acid	2800
Aliphatics and Aromatics	Nonane	2633
	Trimethylbenzene	3237
	Methylnaphthalene	3200
	Dodecane	3183
	Diphenylmethane	3900

*Uncontaminated printed circuit boards arc over at
2033 volts

Table 20. Arc Over Voltage Limits
of Contaminants

Contaminant Material	Arc Over* (Volts)
Vel Detergent, Dry	67
Chap-Ans Cream, Dry	367
Mold Releases	
Frekote 11	1967
Frekote 33	1967
RAM 225	2000
Mold Whiz P9	1833
Mold Whiz 424R75	1933
Rigidax	2300
Carnauba Wax	1467
Silicone Grease DC-7	3875
Silicone Oil	3250
Gloves	
White Rubber	2183
Yellow Rubber	1883
PVC Coated White Glove	2017
Fingercot	2125
Krylon Spray	2133
Polysulfide, PR1201	
Base Resin	>5300
Cure Agent	367
AZ1350J Photo Resist	
Wet	950
24 Hour Dry	2317
Isopropyl Alcohol and	
Kimwipes	2100
Cel-Fibes	2008
Urethane Sponge	1783
Batiste Cloth	1950
Acid Brush	2041
Fingerprints	
A	1716
B	2083
C	2033
D	1917
Resins	
Versamid 140	1000
Triethylenetetramine	50
Diethanolamine	83
Epon 828	1150

Table 20 Continued. Arc Over
Voltage Limits
of Contaminants

Contaminant Material	Arc Over* (Volts)
Solder Fluxes	
Kester 197	2017
Kester 1544	1633
Alpha 611	1925
Alpha 346-35	3333
Alpha 320-33	2050

*Average of three tests

Table 21. Relative Arc Over Characteristics
of Contaminants

Contaminant Materials	Arc Over (Volts)
Detergents, Hand Lotions	Less than 1000
Amines (Epoxy Cure Agents)	Less than 1000
Polysulfide Cure Agent	Less than 1000
Photo Resist, Wet	Less than 1000
Certain Waxes	1000 to 1800
Certain Fingerprints	1000 to 1800
Certain Solder Fluxes	1000 to 1800
Urethane Sponge	1000 to 1800
Epoxy Resin	1000 to 1800
Certain Mold Releases	More than 2000
Oil, Grease	More than 2000
Wiping Cloths, Paper Towels	More than 2000
Polysulfide Base Resin	More than 2000
Fingercots, Gloves	More than 2000
Cured Photo Resist	More than 2000
Certain Fingerprints	More than 2000
Epoxy Resin	More than 2000
Certain Solder Fluxes	More than 2000

REFERENCES

¹K. L. Hoy, "New Values of the Solubility Parameters from Vapor Pressure Data," *Journal of Paint Technology*, Volume 42, Number 9, February, 1970, pp 118-160.

²David H. Kaelble, *Physical Chemistry of Adhesion*. New York: Wiley, Interscience, 1971, pp 121-126.

³L. C. Jackson, "How to Select a Substrate Cleaning Solvent," *Adhesives Age*, December, 1974, pp 23-31.

⁴J. L. Anderson and others, "Measurement and Evaluation of Surfaces and Surface Phenomena by Evaporative Rate Analyses," *Journal of Paint Technology*, Volume 40, Number 523, August, 1968, pp 320-327.

⁵J. L. Anderson, "Adsorptive/Desorptive Behavior of ERA Radiochemicals," *ACS Symposium*, Chicago, Illinois, September, 1970.

⁶C. M. Hansen, "Characterization of Surfaces by Spreading Liquids," *Journal of Paint Technology*, Volume 42, Number 550, November, 1970, pp 660-664.

⁷Linus Pauling, *The Nature of the Chemical Bond*. Cornell University Press, 1960.

⁸J. L. Anderson and others, "Application of Evaporative Rate Analyses to the Surface Properties of Metals," *Journal of Colloid and Interface Science*, Volume 31, Number 3, November, 1969, pp 371-381.

⁹L. C. Jackson, *Solubility Parameters and Evaporative Rate Analyses in Organic Residue Characterization*, (Topical Report). UNCLASSIFIED. Bendix Kansas City: BDX-613-1099, March 1974, Available from NTIS.

¹⁰A. Beerbower and J. R. Dickey, "Advanced Methods for Predicting Elastomer/Fluids Interactions," *ASME/ASLE Lubrication Conference*, Atlantic City, October 8-10, 1968.

¹¹L. C. Jackson, "Solvent Cleaning Process Efficiency," *Adhesives Age*, July 1976.

¹²L. C. Jackson, *Contaminant Removal Based on Solubility Parameter and Evaporative Rate Analysis Technologies* (Topical Report). UNCLASSIFIED. Bendix Kansas City: BDX-613-1128, August 1974. Available from NTIS.

¹³L. C. Jackson, *Compatibility of Contaminants and Plastics with Solvents* (Topical Report). UNCLASSIFIED. Bendix Kansas City: BDX-613-1240, March 1975. Available from NTIS.

¹⁴C. B. Hamilton, "Evaluation of Electrolytic Alkaline Cleaners by Evaporative-Rate Analysis," *Plating and Surface Finishing*, June 1975.

¹⁵M. L. Waddell, *Static Charge and Current Leakage Effects Relating to Manufacture of JFET Assemblies* (Topical Report). UNCLASSIFIED. Bendix Kansas City: BDX-613-994, December 1973. Available from NTIS.

¹⁶W. J. Kirk, Jr., L. S. Carter, and M. L. Waddell, *Control of Electrostatic Damage to Solid State Devices* (Topical Report). UNCLASSIFIED. Bendix Kansas City: BDX-613-1080, March 1974. Available from NTIS.

¹⁷E. R. Brown, *Effects of Coating and Cleaning on Corona and High-Voltage Breakdown in Firing Sets* (Topical Report). UNCLASSIFIED. Bendix Kansas City: BDX-613-1181, August 1974. Available from NTIS.

APPENDIX

Product Identification

<u>Product</u>	<u>Supplier</u>
Cel-Fibe	Cel-Fibe Incorporated
Kaydry	Kimberly-Clark Corporation
Kimwipes	Kimberly-Clark Corporation
Mold Wiz	Axel Plastic Research Laboratories
Frekote Mold Release	Frekote Incorporated
Ram Mold Release	Ram Chemicals
MR6021 Mold Release	Green Chemical Products Incorporated
OSR-P2 Mold Release	Chem-Trend Incorporated
Permamold 920-01 Mold Release	Brulin and Company
1 Yellow Carnauba Wax	Ceara Products Incorporated
Rigidax	M. Argueso and Company Incorporated
DC-7 Silicone Grease	Dow Chemical Company
High Vacuum Silicone Grease	Dow Chemical Company
Due Seal Vacuum Pump Oil	Sargent Welch Scientific Company
Kester Solder Flux	Kester Solder Company
Alpha Solder Flux	Alpha Metals Incorporated
AZ1350J Photo Resist	Shipley Company Incorporated
OX-140 Micro Oil	Webber Gage Division, L. S. Starret Company
Krylon 1303	Krylon Incorporated
Hospital Body Lotion	Sherwood Medical Industries

Pac Lotion Soap

Vel Liquid Detergent

Chap-Ans

Versamide 140

Epon 828

PR1201 Polysulfide

Calgon Corporation

Colgate-Palmolive Company

Miller-Morton Company

General Mills Incorporated

Shell Chemical Company

Products Research and Chemical
Corporation

DISTRIBUTION

	Copy
R. Bulcock, ERDA-KCAO	1
V. C. Vespe, ERDA-ALO	2
K. C. Creed, G. E.	3
F. B. Baker, LASL	4
E. Casados, LASL	5
J. A. Freed, LASL	6
W. A. May, LASL	7
G. W. Taylor, LASL	8
M. P. Bonicelli, LLL	9
S. J. Buginas, LLL	10
W. E. Cady, LLL	11
H. M. Brinkmeier, Monsanto	12
L. E. Hartzell, Monsanto	13
H. W. Lichte, Pantex	14
H. M. Barnett, SLA	15
C. B. McCampbell, SLA	16
J. G. Curro, SLA	17
R. E. Cuthrell, SLA	18
N. J. DeLollis, SLA	19
K. Gillespie, SLA	20
R. E. Grover, SLA	21
K. D. Hardin, SLA	22
C. W. Jennings, SLA	23
L. K. Jones, SLA	24
E. P. Royer, SLA	25
R. K. Traeger, SLA	26
R. E. Gott, SLL	27
R. H. Meinken, SLL	28
H. R. Sheppard, SLL	29
D. N. Tanner, SLL	30
W. E. Tewes, Y-12	31
F. DuBois, LASL	32
R. L. Kirkpatrick, D/141, 2B30	33
H. F. Volk, D/141, 2B30	34
W. A. Johaningsmeir, D/231, 1D40	35
J. D. Corey, D/554, BD50	36-37
L. Stratton, D/554, 2C44	38-40
R. F. Pippert, D/700, 1A42	41
R. P. Frohberg, D/800, 2A39	42
D. H. Hax, D/800, 1A39	43
J. A. Morrison, D/800, 2A40	44
F. A. Spies, D/800, 2A39	45
W. J. Harte, D/812, 2A27	46
W. H. Deterding, D/814, 2C43	47

L. C. Jackson, D/814, 2C43	48
R. L. Sadler, D/814, 2C43	49
C. H. Smith, D/814, XD43	50
D. L. Stoltz, D/814, 2C43	51
G. L. MacCurdy, D/816, SC3	52
J. L. Couchman, D/821, 2A36	53
B. W. Landes, D/821, 2A36	54
D. D. Oswald, D/822, 2A36	55
D. P. Roberts, D/823, 1A27	56
A. O. Bendure, D/842, MD40	57
J. S. Bosnak, D/842, MD40	58
J. A. Peters, D/842, MD40	59
D. D. Peterson, D/842, MD40	60
T. A. Wiley, D/842, MD40	61
L. W. Smith, D/844, BW31	62
D. A. Cummins, D/845, MF39	63
R. C. Douglas, D/845, MF39	64
W. J. Kirk, D/845, MF39	65
F. H. Lewis, D/845, MF39	66
R. L. Morgan, D/845, MF39	67
R. J. Powell, D/845, MF39	68
W. R. Sprague, D/845, MF39	69
M. L. Waddell, D/845, MF39	70
V. E. Alley, D/861, 2A31	71
H. F. Darbyshire, D/862, MA40	72
M. Gray, D/862, MA40	73
B. T. Gregg, D/862, MA40	74
J. C. McCoy, D/862, MA40	75
G. A. Yocum, D/862, MA40	76
J. H. Swafford, D/863, FB39	77
R. E. Kessler, D/865, 2C40	78

BDX-613-1695 (Rev.)

CONTAMINANT CLEANING FOR CRITICAL ELECTRICAL ASSEMBLY AREAS, L. C. Jackson, D/814, UNCLAS Final, February 1978.

The aspects of surface cleanliness have been studied and have involved contaminant detection, concentration measurements, contaminant characterization, contaminant removal by solvents and solvent blends, cleaning process effectiveness, surface characterization, and electrical properties of contaminated surfaces. Correlations were established between Meseran Surface Analyzer (ERA Systems Incorporated) radioactive surface energy probe measurements and solubility

ELECTRICAL: Cleaning Contaminants

CONTAMINANT CLEANING FOR CRITICAL ELECTRICAL ASSEMBLY AREAS, L. C. Jackson, D/814, UNCLAS Final, BDX-613-1695 (Rev.), February 1978.

The aspects of surface cleanliness have been studied and have involved contaminant detection, concentration measurements, contaminant characterization, contaminant removal by solvents and solvent blends, cleaning process effectiveness, surface characterization, and electrical properties of contaminated surfaces. Correlations were established between Meseran Surface Analyzer (ERA Systems Incorporated) radioactive surface energy probe measurements and solubility

CONTAMINANT CLEANING FOR CRITICAL ELECTRICAL ASSEMBLY AREAS, L. C. Jackson, D/814, UNCLAS Final, BDX-613-1695 (Rev.), February 1978.

The aspects of surface cleanliness have been studied and have involved contaminant detection, concentration measurements, contaminant characterization, contaminant removal by solvents and solvent blends, cleaning process effectiveness, surface characterization, and electrical properties of contaminated surfaces. Correlations were established between Meseran Surface Analyzer (ERA Systems Incorporated) radioactive surface energy probe measurements and solubility

parameter values, surface tension values of known liquids and solids (plastics), and concentrations of polar and nonpolar contaminants. Principles of evaporative rate analysis and solubility parameter are described, which together provide the foundation for a new technology of understanding of surface chemistry.

parameter values, surface tension values of known liquids and solids (plastics), and concentrations of polar and nonpolar contaminants. Principles of evaporative rate analysis and solubility parameter are described, which together provide the foundation for a new technology of understanding of surface chemistry.

parameter values, surface tension values of known liquids and solids (plastics), and concentrations of polar and nonpolar contaminants. Principles of evaporative rate analysis and solubility parameter are described, which together provide the foundation for a new technology of understanding of surface chemistry.