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Cleaning Up Our Act

Alternatives for Hazardous Solvents Used in Cleaning

January, 1994

J.D. Shoemaker

**Michael Meltzer
David Miscovich
Dustin Montoya
Peg Goodrich
Gerald Blycker**

Lawrence Livermore National Laboratory

University of California Livermore, California 94551

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TABLE OF CONTENTS

EXECUTIVE SUMMARY.....	v
1.0 INTRODUCTION.....	1
1.1 Background.....	1
1.2 Justification.....	2
1.3 Scope.....	2
1.4 Types of Alternative Cleaners.....	3
2.0 HAZARDOUS CHARACTERISTICS OF ALTERNATIVES TESTED.....	5
2.1 Flammability.....	5
2.2 Toxicity.....	5
2.3 Carcinogenicity, Mutagenicity, and Reproductive Hazards.....	8
2.4 Air Emission Issues.....	8
3.0 INITIAL SCREENING TESTS.....	11
3.1 Substrates Cleaned.....	11
3.2 Contaminants.....	11
3.3 Dilution.....	11
3.4 Application Methods.....	11
3.5 Qualitative Cleanliness Test.....	12
3.6 Overall Performance.....	12
4.0 APPLICATION-SPECIFIC TESTS.....	19
4.1 Cleaning Solder Flux from Printed Wiring Board.....	19
4.2 Removing Cutting Fluid from Metal Turnings.....	23
4.3 Removing Tapping Compounds.....	23
4.4 Cleaning Glass Slides.....	25
4.5 Cleaning Graphite Lapping Compound from Machine Tools.....	26
4.6 Cleaning Oil from Graphite Parts.....	27
4.7 Cleaning Copper.....	27
4.8 Cleaning Aluminum.....	28
4.9 Cleaning Silk Screen.....	29
4.10 Removing Vacuum Grease.....	31
4.11 Removing Dykem.....	32
4.12 Cleaning Photographic Prints and Films.....	33
5.0 QUANTITATIVE HIGH PERFORMANCE ANALYSIS.....	35
5.1 Optical Scanning.....	36
5.2 X-Ray Fluorescence.....	38
5.3 Fourier Transform Infrared Spectrometry.....	39
5.4 Gas Chromatography/Mass Spectrometry.....	40
5.5 Electron Spectroscopy Chemical Analysis.....	40
5.6 Ionography.....	44
5.7 Ellipsometry.....	44
5.8 MESERAN Surface Analysis.....	45
5.9 Measurement with Stable Isotopes.....	46
5.10 Materials Compatibility and Environmental Testing.....	46
6.0 CONCLUSIONS.....	49
7.0 RECOMMENDATIONS.....	53
8.0 ABBREVIATIONS AND ACRONYMS.....	55
9.0 REFERENCES.....	57
APPENDIX A PROPERTIES OF ALTERNATIVE CLEANERS.....	A-1
APPENDIX B CONTACTS FOR ALTERNATIVE CLEANERS.....	B-1

EXECUTIVE SUMMARY

Lawrence Livermore National Laboratory (LLNL) has studied more than 70 alternative cleaners as potential replacements for chlorofluorocarbons (CFCs), halogenated hydrocarbons (e.g., trichloroethylene and trichloroethane), hydrocarbons (e.g., toluene and Stoddard Solvent), and volatile organic compounds (e.g., acetone, alcohols). This report summarizes LLNL's findings after testing more than 45 proprietary formulations on bench-scale testing equipment and in more than 60 actual shops and laboratories. Cleaning applications included electronics fabrication, machine shops, optical lenses and hardware, and general cleaning. Most of the alternative cleaners are safer than the solvents previously used and many are nonhazardous, according to regulatory criteria.

Reasons to convert cleaning operations to less hazardous solvents include the following: (1) CFCs and trichloroethane are stratospheric ozone-depleting substances (ODSs), whose availability will be drastically limited by the Montreal Protocol, the Clean Air Act (CAA) of 1990, Executive Order 12843, and Department of Energy (DOE) directives; (2) all DOE facilities must reduce the use of priority chemicals listed by the U.S. Environmental Protection Agency EPA 33/50 program; (3) air permits to use precursor organic compounds (POCs) and volatile organic compounds (VOCs) are expensive and require extensive record keeping; (4) the cost to dispose of spent hazardous solvents often far exceeds the initial cost of fresh solvent; (5) less hazardous alternatives usually present far less risk to worker safety; and (6) these alternatives present less risk of environmental harm and future liability.

Alternative cleaners have been identified that can replace CFCs; 1,1,1-trichloroethane (TCA); or other hazardous solvents in most of the applications tested. It is not possible to select one or two alternatives as the cleaners of choice for *all* LLNL applications. Different situations require different products. Vacuum applications, for instance, often require non-aqueous products because any residual moisture will freeze at low pressures. The alternatives that gave the best cleaning performance in different tests are listed below. The user may also need to consider changing the cleaning procedure as well as the cleaning solvent to employ the alternatives most effectively. For example, test data indicate that ultrasonic cleaners frequently clean better than traditional vapor degreasers. Except for a perfluorocarbon solvent, none of the cleaners that LLNL tested are suitable as drop-in replacements for vapor degreasers. EPA questions the use of perfluorocarbon solvent because of concern about its global warming potential.

Manufacturers of most of the alternative cleaners recommend rinsing parts with deionized water. Special drying techniques may enable use of water in applications that previously required nonaqueous cleaners. If the use of water cannot be tolerated for a particular application, then a hazardous material such as acetone or a volatile alcohol may have to be used for rinsing.

Over the last two years, LLNL has tested quantitative performance measures that can be used to compare traditional and alternative solvents in a variety of precision cleaning applications. Two fundamentally different analytical approaches have been examined: destructive and nondestructive tests. *Destructive* tests require removing residue from the sample after cleaning in order to perform an analysis. Complete removal is often very difficult to achieve. *Nondestructive* tests can measure residue in situ. Another advantage of nondestructive testing is that the sample can be subjected to subsequent testing.

LLNL performed quantitative cleanliness tests for selected applications by using the following techniques to measure the amount of impurities remaining on the cleaned surface: (1) optical scanning, (2) ionography, (3) x-ray fluorescence, (4) Fourier transform infrared (FTIR)

spectrometry, and (5) gas chromatography/mass spectrometry (GC/MS). Other techniques have been used elsewhere to determine surface cleanliness. For example, Los Alamos National Laboratory has used ellipsometry, Oak Ridge National Laboratory used electron spectroscopy chemical analysis (ESCA), and Allied-Signal Kansas City Division used measurement and evaluation of surfaces by evaporative rate analysis (MESERAN). Battelle developed measurement with stable (nonradioactive) isotopes for the Aerospace Guidance and Metrology Center. Section 5.0 discusses these methods in detail and presents the advantages and disadvantages of the various quantitative analytical methods that have been identified.

This report also contains a brief discussion of some techniques that have been used to examine the materials compatibility and long-term effects of using alternative cleaners.

Application	Best Performers	Cleaner Type	Potential Hazards
Removing solder flux from printed wiring board	Church & Dwight Co.- Armakleen E-2000	Unidentified	None identified ¹
Removing Molecular Fluid Tapping Compound	Brulin-MP1793 Inland Tech.-EP921 Brulin-1990GD Inland Tech-X-Caliber	Hydrocarbon Terpene Detergent Terpene and NMP	Toxicity untested None identified None identified None identified
Removing copper oxide from copper at room temperature	Inland Tech-Citra Safe	Terpene	Toxicity and flammability
Cleaning copper oxide from copper at 60°C	OCS Manufacturing -OCS H2002E	Glycol ether	Toxicity
Cleaning aluminum	Brulin-815GD	Detergent	None identified
Removing Dow Corning vacuum grease from glass	Goode Chemical Co.-E.C.G. Marine	Unidentified	Toxicity untested
Removing Apiezon vacuum grease from glass	Kyzen Corp.-Metalnox PC1	Unidentified	None identified
Removing Dow Corning vacuum grease from stainless steel	Kyzen Corp.-Metalnox PC1 Brulin-MP1793 U.S. Polychem-J.A.L.S.A.C.	Unidentified Hydrocarbon Borate and silicate	None identified Toxicity untested None
Removing Apiezon vacuum grease from stainless steel	Brulin-MP1793 U.S. Polychem-J.A.L.S.A.C. Brulin-815GD Brulin-1990GD	Hydrocarbon Borate and silicate Detergent Detergent	Toxicity untested None identified None identified None identified

(Continued on the next Page)

¹Armakleen E-2000 failed the aquatic toxicity test as a concentrate, but passed when diluted to recommended working strength.

(Cont'd)

Application	Best Performers	Cleaner Type	Potential Hazards
General Purpose Cleaning (aqueous)	Brulin-815GD	Detergent	None identified
General Machine Shop Cleaning (aqueous)	Brulin-815GD	Detergent	None identified
General Machine Shop Cleaning (nonaqueous)	Brulin-MP1793	Hydrocarbon	Toxicity untested
Removing Dykem from metals	Inland Tech-EP921	Terpene	None identified
	QO Chemicals Inc.- Furfuryl alcohol	Alcohol	Toxicity untested
	PURAC- Purasolv ELS	Lactate ester	Toxicity untested
	Ramco Specialty Products-SSD92	Terpene and glycol ether	Toxicity untested
	QO Chemicals Inc.- THFA	Alcohol	Toxicity untested
Cleaning Epoxy Paint from Silk Screen	Inland Tech.- X-Caliber	Terpene and NMP	None identified
	Brulin-815GD	Detergent	None identified
	U.S. Polychemical- J.A.L., S.A.C.	Borate and silicate	None identified
Cleaning graphite lapping compound from steel tools	Ramco Specialty Products-NC-300	Silicate	None identified
	Inland Tech.-EP921	Terpene	None identified
	Brulin-1990GD	Detergent	None identified
	Inland Tech.- X-Caliber	Terpene and NMP	None identified

1.0 INTRODUCTION

1.1 Background

Alternative cleaners are being studied as potential replacements for chlorofluorocarbons (CFCs), halogenated hydrocarbons (e.g., methylene chloride, trichloroethylene and trichloroethane²), hydrocarbons (e.g., toluene and Stoddard Solvent), and volatile organic compounds (e.g., acetone, alcohols). Table 1.1 lists some of the hazardous solvents that are used at LLNL. In the table, precursor organic compounds are indicated as "POC" and volatile organic compounds are "VOC." Those indicated as "priority chemicals" in the hazard column of the table are targeted for reduction in use under the EPA 33/50 program. The EPA 33/50 program calls for reducing the use of 17 priority chemicals by 50 percent in 1995 (based on 1988 usage) and 33 percent in 1997 (based on 1993 usage). Priority chemicals that are often used in solvent cleaning are benzene, carbon tetrachloride, methyl ethyl ketone, methylene chloride, methyl isobutyl ketone, tetrachloroethylene, TCA, trichloroethylene and xylenes. LLNL has previously eliminated the use of benzene and carbon tetrachloride as solvent cleaners. Although the EPA 33/50 program is voluntary, former Secretary of Energy James D. Watkins directed all DOE facilities to participate in the program (Watkins 1992). It is important to note that this is not an exhaustive list of all hazardous solvents that have been used at LLNL, but it does identify many that have been commonly used.

Table 1.1 Hazardous Solvents That Have Been Used at LLNL

Solvent	Hazard	Remarks
Acetone	Flammability, POC, VOC	
Chloroform	Priority chemical	
Flux-Off TM	Ozone depleter	Contains CFC and methylene chloride
Freon TE TM	Ozone depleter	Contains CFC-113 and ethanol
Freon TF TM	Ozone depleter	CFC-113
Isopropanol	Flammability, POC, VOC	
Methanol	Flammability, POC, VOC	
Methylene chloride	Priority chemical	
Safety-Kleen 105 TM	Flammability, ozone depleter	Hydrocarbon blend; also contains TCE and PCE
Safety-Kleen 699 TM	Flammability	Hydrocarbon blend
Stoddard Solvent	Flammability, POC, VOC	Hydrocarbon blend
Toluene	Flammability, POC, VOC, priority chemical	
1,1,1 Trichloroethane (1,1,1 TCA)	Ozone depleter, possible carcinogen, priority chemical	
Trichloroethylene (TCE)	Carcinogen, priority chemical	

Most of these alternative cleaners can be classified as safer than presently used products and many are nonhazardous according to regulatory criteria. Potential users should be aware that normal safety precautions shown on the Material Safety Data Sheet (MSDS) such as personal

²1,1,1 trichloroethane (TCA) is also referred to in regulations as methyl chloroform.

protective gear must be employed when using these materials. They should also remember that contaminants removed from the substrate will end up in the spent cleaner, potentially making the spent solution a hazardous waste.

1.2 Justification

There are several reasons to convert cleaning operations to less hazardous solvents. First, CFCs, carbon tetrachloride, and 1,1,1 TCA are stratospheric ozone-depleting substances (ODSs). The Montreal Protocol, the Clean Air Act (CAA) of 1990, Executive Order 12843,³ and DOE directives have mandated that these be discontinued. Second, the Secretary of Energy has directed all DOE facilities to reduce the use of priority chemicals listed by the EPA 33/50 program. Third, the use of POCs and VOCs must be permitted, which is expensive and requires extensive subsequent record keeping. Fourth, the cost to dispose of spent hazardous solvents often far exceeds the initial cost of fresh solvent. Fifth, less hazardous alternatives usually present far less risk to worker safety. Sixth, these alternatives present less risk of environmental harm and future liability. Finally, the CAA requires that products made with or containing Class I or Class II ozone-depleting chemicals carry a warning label (Koelsch 1993).

1.3 Scope

The scope of the LLNL study was to test alternative cleaners for suitability in various applications found at the Laboratory. As part of this work, LLNL also tested several quantitative methods for measuring the cleanliness of surfaces.

The selection of cleaners for testing in specific applications was influenced by literature information, vendor data, and user knowledge. Some substitutes for ozone-depleting solvents were not tested extensively because they present unacceptable safety risks or require local air permits. The materials examined in the greatest detail were those that exhibited cleaning characteristics comparable with standard cleaners such as CFCs, while at the same time were the least injurious to human health and the environment.

Hydrochlorofluorocarbons (HCFCs) have been substituted for chlorinated and CFC solvents by some users. The LLNL project did not include testing HCFCs because they will be phased out by the year 2015. One such compound, HCFC-141b, has a relatively high ozone depletion potential, and may be phased out even sooner (Koelsch 1993). In fact, EPA has proposed a rule that would effectively ban use of HCFCs in solvent cleaning.⁴

Several factors should be considered before substituting one type of cleaner for another. These include technical performance, potential hazards, regulatory issues, and economics. Technical performance, for the purpose of this study, means answering the question, "Will the proposed substitute clean as well as or better than the current solvent in a specific application?" Potential hazards include flammability, toxicity, and other health and safety criteria. "Regulatory issues" refer to whether and what kind of permits are required in order to either use the proposed cleaner or to dispose of the effluent. Economics considers both the continuing operating cost (e.g., purchase of the cleaner and disposal of effluent) and investment if new cleaning equipment must be installed.

There are many factors besides the choice of cleaner that affect the results of the cleaning process. These include equipment selection, operating parameters (e.g., temperature and

³Signed by President Clinton on April 21, 1993.

⁴40 CFR 82 published May 12, 1993 in the *Federal Register* vol. 58, No. 90.

dilution), and operator skill. These factors were not examined in this study. The reader should consult other literature for further discussion of these factors.

1.4 Types of Alternative Cleaners

Several literature articles have described the different types of alternative cleaners. A common way of dividing them is into aqueous and organic categories.

Aqueous Cleaners

Aqueous cleaners include builders, silicates, phosphates, borates, surfactants (detergents) and other complexing agents (Kresse 1989). Characteristics of these materials are summarized as follows:

- Builders are alkaline compounds, usually composed of hydroxides and inorganic salts. They are typically used to remove thick oils and pigments. When combined with surfactants, they effectively remove soaps, mill scale, oils and fats, and have high soil-carrying capacity. Because of the high alkalinity, they will attack amphoteric metals such as aluminum, brass, copper, and zinc.
- Silicates have high dispersing and emulsifying effect and high soil-carrying capacity. They are usually used for heavy-duty cleaning.
- Phosphates are good cleaners that also soften water used in the cleaning process and partly remove metal oxides and hydroxides from the substrate. However, they have become unpopular in some geographic areas for ecological reasons.
- Borates and carbonates are mildly alkaline builders because of their buffering effects. They are used for cleaning aluminum and zinc.
- Surfactant or detergent compounds may be either ionic or nonionic. They are also categorized as follows: (1) anionic, (2) cationic, and (3) nonionic. Anionics are the most effective wetting agents and the highest foamers, but are deficient in suspending soils. Cationics can coat a metal with a film that inhibits pitting. Nonionics have a cloud point, a combination of temperature and concentration at which the detergent changes from a clear solution in water to a cloudy, oil-like substance that floats on top of water (Scislowski 1990a).

Most aqueous cleaners are alkaline. Alkaline cleaners are either the precipitating type or the sequestering type. Precipitating types soften water by precipitation of the hard water minerals, and contain one or more of the following components: caustic soda, soda ash, trisodium phosphate, sodium metasilicate, and sodium orthosilicate. These have pH values ranging from 11.5 to 14. Sequestering types include sodium tripolyphosphate, tetra sodium pyrophosphate, and sodium hexametaphosphate. These combine with the hard water minerals and suspend them in solution. Their pH values range from 8.0 to 10.5 (Scislowski 1990b).

One aqueous cleaner (Bio-Z) that has been considered by LLNL is mildly acidic. This product employs enzymes as the active cleaning ingredient.

Organic Cleaners

A wide variety of organic chemicals can be used as cleaning agents, either alone or in combinations. The organic cleaners are often used where water is not acceptable, although some organics are water soluble. This classification includes oxygenated compounds, halogenated compounds, and hydrocarbons. Examples include:

- Oxygenated — Alcohols, ketones, and glycol ethers.
- Halogenated — CFCs, TCA, trichloroethylene, perchloroethylene, methylene chloride and carbon tetrachloride.
- Hydrocarbons — Hexane, toluene, xylene, Stoddard Solvent, and kerosene.
- Amines — Diethanolamine (DEA) and triethanolamine (TEA).
- Terpenes — d-limonene and pinenes.
- Other — N-methyl pyrrolidone (NMP), dimethyl sulfoxide (DMSO)

Some of these compounds are traditional hazardous solvents, while others are less hazardous materials that have been developed more recently. The disadvantage of this class of cleaners are (1) they are usually 100 percent VOC, (2) many have low flash points, (3) they may leave objectionable residues unless extremely pure, and (4) are not effective on all soils (Lucas 1993). CFCs are exceptions because they have none of these characteristics but they are objectionable because of their ozone depletion potential.

Many new cleaning compounds contain blends of organic and aqueous cleaners.

Hybrid Cleaners

Hybrid cleaners contain multiple chemicals and are typically formulated for specific applications. At least one supplier (Lucas 1993) claims hybrids have the following advantages because they can be designed to:

- Be nearly nonvolatile (i.e., have very low vapor pressure).
- Exhibit strong polarity, strong dispersion forces, and strong hydrogen bonding so that one cleaner is effective on a wide variety of contaminants.
- Have high capacity for contaminant loading.
- Have very high flash points.

2.0 HAZARDOUS CHARACTERISTICS OF ALTERNATIVES TESTED

Table A-1 presents a summary of properties for the alternative cleaners LLNL tested or considered for testing. The table includes the chemical constituents listed on manufacturers' material safety data sheets (MSDSs),⁵ compositions (when listed on the MSDS), vapor pressures, percent volatiles, solubility in water, boiling point, flash point, flammable limits (LFL = lower flammable limit and UFL = upper flammable limit), permissible exposure limit (PEL), threshold limit value (TLV), toxicity values, and manufacturer's recommendations for application of the cleaner. Cleaners identified with an asterisk (*) in Table A-1 have not yet been tested by LLNL. Table B-1 gives information for contacting suppliers of the alternative cleaners.

2.1 Flammability

Vendor data on flash point (an indicator of flammability) and upper and lower flammability limits in air were used whenever furnished. Different methods may give different flash points. The following symbols indicate the method used:

CC Closed Cup
COC Cleveland Open Cup
PM Penske-Martin
TCC Tag Closed Cup

The State of California classifies a material as flammable if its flash point is less than 140°F (60°C), but does not specify which test method must be used. The concentrates listed in Table 2.1 are hazardous according to this criterion:

Table 2.1 Concentrates with Flash Point Less Than 140°F (60°C)

Actrel 3338L Cleaner	Histo-Clear
Aero-Strip	Natra Sol D. C. D.
Bioact EC-7M	Opticlear
Bioact EC-7R	Perfect Way 147
Bioact EC-7	Surfynol 61 Surfactant
Citra Safe	Teksol EP
Citra Zapp	Tropiclean
Citri Solve	

2.2 Toxicity

Most of the cleaners tested are claimed to be nonhazardous by the vendors, and in all likelihood are when diluted according to the manufacturer's recommendations. However, some of the cleaners that are supplied in a concentrated form (i.e., *concentrates*) failed certain tests specified by the State of California. Vendor data on acute oral toxicity, acute dermal toxicity, and acute inhalation toxicity were used to determine this whenever furnished by the manufacturers. If the MSDS did not state toxicity for the solution, but supplied sufficient data on the composition of the solution, then LLNL calculated a value based on the compositions given by the MSDS using the method shown in *California Code of Regulations* Title 22, Article 11, §66696(4)(c).

⁵Usually the MSDS identifies only chemicals considered reportable under Title III of the Superfund Amendments and Reauthorization Act (SARA), which is also known as the Emergency Planning and Community Right-to-Know Act (EPCRA).

Toxicities for specific compounds may be found in standard references such as *Dangerous Properties of Industrial Materials* (Sax 1984).

Acute Oral, Dermal, and Inhalation Toxicity

Oral, dermal, and inhalation toxicities are usually reported in terms of lethal dose (LD) or lethal concentration (LC). Dosage is expressed as milligrams of substance per kilogram of body weight (mg/kg), while concentration is expressed as either milligrams per cubic meter of air (mg/m³) or parts per million (ppm). However, data may be reported for several types of small animals (e.g. guinea pigs, mice, rabbits, rats), and different values of LC₅₀ pertain to each type. LD₅₀ is the dose that caused 50 percent of the test animals to die, and LC₅₀ is the concentration that caused 50 percent of the test animals to die. California regulations define a substance as hazardous if it exceeds one or more of the following values:

Acute Oral	LD ₅₀ < 5,000 mg/kg
Acute Dermal	LD ₅₀ < 4,300 mg/kg
Acute Inhalation	LD ₅₀ < 10,000 ppm

The regulations do not specify which type of animal must be used for this determination. For consistency, LLNL has shown data for rats in Table A-1.

Many vendors have not supplied sufficient data to determine whether their products pass these toxicity tests. These products are listed in Table 2.2.

Table 2.2 Insufficient Data to Determine Toxicity

Actrel 3338L	Actrel 4493L
Aero-Strip	Alconox
All-Safe	Aquanox 101
Aquatene GM330	ART-210
ASP #1M	ASP #13L
Bioact EC-Ultra Semi-Aqueous Defluxer	Bioact EC-7M Manual Terpene Defluxer
Bioact EC-7R Semi-Aqueous Terpene Defluxer	Bioact EC-7R Semi-Aqueous Terpene Defluxer
Brulin 815GD	Brulin 1990GD
Brulin MP1793	Castrol Kleen 3652
Citranox	Citra Safe
Citra-Zapp	Citrikleen
Citri Solve	E. C. G. Marine
EP-921	Furfuryl Alcohol
GM581	J.A.L.S.A.C.
Liquinox	LPS Precision Cleaner
Metalnox PC1	Natra Sol D. C. D.
Natrasolve	NC-300
Nova Clean	PF-5060
Polyspray Jet 790	Primaclean 1000
Purasolv ELS	RB Degreaser
Re-entry KNI Solvent-2000	Re-entry RFS Solvent-2000
Rinsing Agent 6000	Samson
Simple Green	Skysol 500
SSD-92 Synthetic Solvent Degreaser	Teksol EP
Tetrahydrofurfuryl Alcohol	Tinuvin 622 LD
Tropiclean	Uniclean VII
X-Caliber	XUS 11269.01 Developmental Alkaline Cleaner
XUS 11288.00 Developmental Alkaline Cleaner	

The following concentrates failed one or more of the following toxicity criteria:

Brulin 815PCX	Failed oral and dermal
Brulin Rosin-X	Failed oral and dermal
DBE	Failed dermal and inhalation
OCS Immersion Cleaner H2002	Failed oral and inhalation
OCS Electronics Cleaner H2002E	Failed oral and inhalation
Purasolv BL	Failed oral
Super Wash	Failed oral

Aquatic Toxicity

According to California Code of Regulations Title 22, Article 11, §66696(a)(4), a waste is hazardous and toxic if it has an acute aquatic 96-hour LC₅₀ less than 500 mg/L when tested with fathead minnows.

No vendor supplied aquatic toxicity data. For some of the promising solvents that LLNL examined, aquatic toxicity was obtained experimentally by an outside laboratory.⁶ The results to date are given below:

Nontoxic Cleaners (Concentrates Passed Test)

Brulin 815GD	J.A.L.S.A.C.
Brulin 1990GD	OCS H2002E
Brulin SD1291	PF-5060
EP 921	

Toxic Cleaners (Concentrates Failed Test)

Axarel 32	Natra Sol
Brulin 815PCX	Perfect Way 147
Citra Safe	Rosin-X
Citrikleen	Super Wash
DBE	Uniclean VII
NC300	

A test is inconclusive if more than 50 percent of the specimens died within 96 hours at a concentration of 750 mg/L, and less than 50 percent died at 250 mg/L. Aquatic tests on Armakleen E2000 and Purasolv ELS were inconclusive so further testing of these must be done.

Even though a concentrate fails the aquatic toxicity test, the cleaner may be nonhazardous at its working strength. LLNL personnel diluted the following cleaners as shown below in Table 2.3 and submitted these samples for toxicity testing. Dilution represents the volumetric ratio of water to concentrate. A 10:1 dilution means that 10 volumes of water were added to 1 volume of concentrate.

⁶BC Analytical Laboratory. Emeryville, CA. This laboratory ceased operations during 1993.

Table 2.3 Aquatic Toxicity Results for Dilute Cleaners

Cleaner	Dilution	Result
Citrikleen ⁶	10:1	Passed
Perfect Way 147	4:1	Inconclusive ⁷
Rosin-X ⁶	20:1	Passed
Superwash ⁶	4:1	Failed
Uniclean VII ⁷	3:1	Inconclusive ⁸

2.3 Carcinogenicity, Mutagenicity, and Reproductive Hazards

Studies have shown evidence that the terpene compound d-limonene is a carcinogen in male rats, but not in female rats or mice (O'Connor 1991, p. 125).

Researchers at Johns Hopkins University have indicated that diethylene glycol dimethyl ether and ethylene glycol monomethyl ether acetate cause adverse reproductive effects in animals and possibly in humans (C&EN 1992, p. 8).

EPA has summarized the potential hazards of eight terpene compounds: d-limonene, anethole, alpha pinene, beta pinene, alpha terpinene, beta terpinene, and dipentene (dilimonene) and has stated that there is a basis of concern about the potential reproductive toxicity of these compounds (EPA 1990). However, the EPA document presents no hard evidence to substantiate this statement.

2.4 Air Emission Issues

Many of the aqueous cleaners tested do not require an air emissions permit since they contain no volatile organic compounds. This eliminates permit fees and the expense of preparing an application as well as the associated record-keeping requirements for the permit and, thus, should result in significant cost savings.

Some non-aqueous alternative cleaners contain organic chemical constituents and may require permitting if they are removed from the work piece by evaporation rather than by rinsing or wiping. However, this depends on the amount of cleaner used in a year, which is likely to be much smaller than the more volatile solvents now in widespread use. This must be evaluated on a case-by-case basis. Normal boiling point, vapor pressure, and percent volatiles data are employed to estimate the amount of volatile materials that may be generated by using the cleaner.

Perfluorocarbons (e.g., PF-5060) contain no hydrogen atoms and thus are not regulated as hydrocarbons. They have zero ozone depletion potential, and are relatively non-volatile. A two-step alternative vapor degreasing process that uses a perfluorocarbon rinsing agent is commercially available (Marino, 1993). However, one author states that these compounds have very long lifetimes in the atmosphere and contribute to global warming. Hence, according to this source, they may be regulated eventually (Wolf 1992, p. 145). In fact, EPA proposed a rule in May 1993 that would make the use of perfluorocarbons unacceptable if an alternative cleaning process exists (*Federal Register* May 12, 1993).

⁷Concentrate failed aquatic toxicity test.

⁸Passed at 250 mg/L but failed at 750 mg/L.

The following cleaners are some of those that do not require air permits from Bay Area Air Quality Management District (BAAQMD) at their recommended working strength:

Armakleen E-2001
Brulin 815GD
Brulin 1990GD
Castrol Kleen 3652
J.A.L.S.A.C.
NC-300
LPS Precision Clean
OCS Immersion Cleaner
RB Degreaser

See Table A for more information on these and other cleaners.

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3.0 INITIAL SCREENING TESTS

More than 70 "qualitative" screening tests of alternative cleaners were conducted in order to select the most promising performers. Visual examinations, waterbreak, white glove, and other tests were done. Test results are summarized in Tables 3.1 and 3.2.

3.1 Substrates Cleaned

Various objects and types of surfaces required different cleaning methods. Bare aluminum and stainless steel with smooth surfaces are normally easy to clean. Stainless steel machining scraps are somewhat more difficult because of their rough surfaces. A loaded (fully assembled with a variety of components) printed wiring board (PWB) is considered a challenge because of the number of crevices and variations in surface textures. The PWB surfaces tested typically consisted of tin/lead over copper that is laminated onto an epoxy-glass substrate, on which microchips and other electronic components have been soldered.

3.2 Contaminants

Oil, grease, and dirt are the contaminants most often removed by cleaning operations. Unless otherwise stated, the oil is a light-weight machine oil that would be used as coolant or lubricant in machining operations. Granule-containing oil was used in tests for LLNL's Lasers Directorate to examine the ability to clean scratched and abraded surfaces. Solder flux removal is a common problem in the electronics industry and was the focus for the PWB tests. One test was run on an alodined metal surface that had carbon deposits.

The second series of screening tests (Table 3.2) used TrimSol⁹ as the test contaminant. TrimSol is a water-soluble hydrocarbon-based material that is used as a machine tool coolant.

3.3 Dilution

Dilution ratios used in the tests are shown as volumes of water per volume of solvent. Usually, the ratios were recommended by the manufacturers. Some solvents were tested at several dilution ratios during preliminary screening, but there was no visible effect on cleanliness.

3.4 Application Methods

None of the alternative cleaners tested by LLNL have high enough vapor pressures to be used as "drop-in" replacements for CFCs or TCA in vapor degreasers. Most were applied by immersing the part in an ultrasonic bath. Immersion lasted 5 minutes, unless otherwise noted. Bath temperatures ranged from room temperature¹⁰ to 65°C, as recommended by the supplier of the cleaner. Brushing on was used for the PWB tests. One series of tests used wiping alone to apply the cleaner. Application methods are identified in Tables 3.1 and 3.2.

One series of nonaqueous tests employed wiping and air drying to remove solvent. All other tests used a deionized water rinse, followed by air drying. (A test for LLNL's Lasers Directorate used nitrogen instead of air for drying.)

The Waste Minimization Project originally obtained a 50 kilohertz (kHz) Branson ultrasonic

⁹ Trademark of Master Chemical Company.

¹⁰ Room temperature is typically 21 to 24°C.

cleaner. It was large enough to run as many as nine samples in 250 ml. beakers concurrently, but it was unheated and temperature control was poor. In late September 1992, the project obtained a new 50 kHz cleaner that is heated and allows better temperature control during the tests.¹¹ The new cleaner also has a timer, which improved control over cleaning time.

3.5 Qualitative Cleanliness Test

Visual Test

A 15-power loupe (magnifier) was used to inspect the test piece for visible particles.

White Glove Test

Residual particulates, oil, and grease were detected by wiping the test piece with a white glove.

Water Break Test

Residual oil and grease can be detected if water forms spots on the cleaned test piece that has been dipped in water. This water-break test is widely used in the metal finishing industry (Scislowski 1990c). One shortcoming is that false results may occur because of bridging of residues (ASM 1982). This test does not detect certain soils such as traces of soaps or surfactants (Cohen 1987).

Quantitative Tests

Quantitative cleanliness tests have been performed for selected applications by using ionography (conductivity measurements) and optical scanning (microscopic analyses). X-ray fluorescence (XRF) has been used to directly measure the amount of impurities remaining on the cleaned surface. Fourier transform infrared (FTIR) spectrometry and gas chromatography/mass spectrometry (GC/MS) were also used. Quantitative testing is discussed in Section 5.

3.6 Overall Performance

This is a subjective rating that is based on the tester's experience and observations. Generally, a rating of "Very Good" means that the alternative cleaned better than the usual solvent. "Good" indicates that the alternative cleaner performed as well as the solvent normally used. "Fair" means that the alternative is not quite as good as the normally used solvent. "Poor" means that either the alternative either did not remove the contaminant or that it damaged the substrate. These ratings are used in Tables 3.1 and 3.2.

¹¹A literature source indicates that a frequency of at least 18 kHz is needed to cavitate the liquid (Vaccari 1993).

Table 3.1 Initial Screening Test Data

Test #	Product Name	Product Type	Dilution	Replacing	Substrate Cleaned	Surface Texture	Contaminant	Application Method	Solvent Removal	Visual Test (with 15X Loupe)	White Glove Test	Water Break Test	Overall Performance	Remarks	Name of Tester
1	Brulin SD1291	Glycol ether	None	TCE	Aluminum	Smooth; bare	Light dirt & oil	Wipe with rag	Wipe & air dry	Clean	Clean	Good	Good		D. Miscovich
2	Brulin SD1291	Glycol ether	None	TCE	Stainless Steel	Smooth; bare	Dirt, machine oil, grease	Wipe with rag	Wipe & air dry	Clean	Clean	Good	Good		D. Miscovich
3a	Brulin 815GD	Sodium tri polyphosphate	5:1		Vacuum pump - Internal	Not visible	Oil & dirt	Recirculate		n.a.	n.a.	n.a.		Foaming problems	D. Miscovich
3b	Brulin 815GD	Sodium tri polyphosphate	10:1		Vacuum pump - external	Smooth; painted	Oil & dirt	Brush on	Wipe & air dry	Clean			Good		D. Miscovich
4	Brulin 815GD	Sodium tri polyphosphate	10:1		Alodined metal	Smooth to porous	Carbon deposits	Immersion	Blow dry, wipe, water rinse	Some residue			Fair	Did not remove alodine	L. Rocha
5	Brulin 815GD	Sodium tri polyphosphate	10:1	Freon TE Vapor Degreaser	Loaded PWB	Smooth; gold coated	Solder flux	Immersion; ultrasonic; 65C; brushing	Hot water rinse; Blow dry	Clean	Clean		Good	Some flux left; removable with light brushing	D. Miscovich
6	Brulin 815GD	Sodium tri polyphosphate	None 10:1 20:1		Stainless steel machining scraps	Smooth to rough	Machining oils	Immersion; ultrasonic; 65C for 5 min	Hot water rinse; air dry	Clean	Clean		Good	Dilutions had no significant effect	D. Miscovich
7	Brulin 815GD	Sodium tri polyphosphate	10:1	Freon or alcohol	Stainless Steel	Smooth	Oil, grease & dirt	Immersion; ultrasonic; 65C	Hot water rinse; air dry	Clean	Clean	Good	Very good		D. Miscovich
8	Brulin 815GD	Sodium tri polyphosphate	10:1	Freon or alcohol	Aluminum	Smooth	Oil & dirt	Immersion; ultrasonic; 65C	Hot water rinse; air dry	Clean	Clean		Very good		D. Miscovich
9	Citra Safe	Terpene-based	None	Freon TE Vapor Degreaser	Loaded PWB	Smooth; semi-porous	Solder flux	Acid brush	Air dry @ room temp.	Clean except where brush couldn't reach			Good for burnt-on flux	Some flux left; recommend spray wand; slow evaporation	Dave Hildebrand
10	Citra Safe	Terpene-based	None		Stainless steel machining scraps	Smooth to rough	Machining oils	Immersion; ultrasonic; 22C for 5 min	Hot water 70C rinse; air dry	Clean	Clean		Good		D. Miscovich
11	Citra Safe	Terpene-based	None	TCE	Aluminum	Smooth	Oil & dirt	Immersion, brushing @ room temp.	Hot water rinse; air dry	Clean	Clean		Good		D. Miscovich
12	Citra Safe	Terpene-based	None	Freon TE Vapor Degreaser	Loaded PWB	Smooth; semi-porous; gold plated	Solder flux	Immersion, brushing @ room temp.	Hot water rinse; Blow dry	Clean	Clean		Very good	Better than Freon	D. Miscovich
13	Citra Safe	Terpene-based	None	Freon or alcohol	Stainless Steel	Smooth	Oil, grease & dirt	Immersion, brushing @ room temp.	Hot water 70C rinse; air dry	Clean	Clean	Not as good as usual	Good		D. Miscovich
14	Rosin-X	Ethanolamine & glycol ether	10:1	Freon or alcohol	Aluminum	Smooth	Oil & dirt	Immersion; ultrasonic; 65C	Hot water rinse; air dry	Clean	Clean		Poor	Etched surface of aluminum	D. Miscovich
15	Rosin-X	Ethanolamine & glycol ether	10:1	Freon or alcohol	Stainless Steel	Smooth	Oil, grease & dirt	Immersion; ultrasonic; 65C	Hot water rinse; air dry	Clean	Some dirt & oil		Poor	Poor degreaser	D. Miscovich
16	Rosin-X	Ethanolamine & glycol ether	20:1	Freon TE Vapor Degreaser	Loaded PWB	Smooth; semi-porous; gold plated	Solder flux	Immersion; ultrasonic; 65C	Hot water rinse; air dry	Clean	Clean		Fair	Some flux left	D. Miscovich

Table 3.1 Initial Screening Test Data (Continued)

Test #	Product Name	Product Type	Dilution	Replacng	Substrate Cleaned	Surface Texture	Contaminant	Application Method	Solvent Removal	Visual Test (with 15X Loupe)	White Glove Test	Water Break Test	Overall Performance	Remarks	Name of Tester
17	OCS H2002E	Butoxyethanol	10:1	Freon TE Vapor Degreaser	Loaded PWB	Smooth; semi-porous; gold plated	Solder flux	Immersion; ultrasonic; 65C	Hot water rinse; air dry	Clean	Clean		Very good	As good as Freon; can be sprayed	D. Miscovich
18	OCS H2002E	Butoxyethanol	10:1	Freon or alcohol	Aluminum	Smooth	Oil & dirt	Immersion; ultrasonic; 65C	Hot water rinse; air dry	Clean	Clean		Good		D. Miscovich
19	OCS H2002E	Butoxyethanol	10:1	Freon or alcohol	Stainless Steel	Smooth	Oil, grease & dirt	Immersion; ultrasonic; 65C	Hot water rinse; air dry	Clean	Clean		Fair	Needed brushing	D. Miscovich
20	Perfectway 147	Terpene-based	4:1	Freon TE Vapor Degreaser	Loaded PWB	Smooth; semi-porous; gold plated	Solder flux	Immersion; ultrasonic; 49C	Hot water rinse; air dry	Clean	Clean		Fair	Needed brushing	D. Miscovich
21	Perfectway 147	Terpene-based	4:1 8:1 12:1		Stainless steel machining scraps	Smooth to rough	Machining oils	Immersion; ultrasonic; 65C	Hot water (75C) rinse; air dry	Clean	Clean		Good	Dilutions had no significant effect	D. Miscovich
22	Perfectway 147	Terpene-based	4:1	Freon or alcohol	Aluminum	Smooth	Oil & dirt	Immersion; ultrasonic; 65C	Hot water rinse; air dry	Clean	Clean		Good	Etched surface of aluminum	D. Miscovich
23	Perfectway 147	Terpene-based	4:1	Freon TE	Stainless Steel	Smooth	Oil, grease & dirt	Immersion; ultrasonic; 65C	Hot water rinse; air dry	Clean	Clean	Fair	Fair		D. Miscovich
24	NatraSol D. C. D.	Unidentified	5:1	Freon or alcohol	Aluminum	Smooth	Oil & dirt	Immersion; ultrasonic; 70C	Hot water rinse; air dry	Clean	Clean		Good	Good degreaser	D. Miscovich
25	NatraSol D. C. D.	Unidentified	5:1	Freon TE Vapor Degreaser	Loaded PWB	Smooth; semi-porous; gold plated	Solder flux	Immersion; ultrasonic; 55C	Hot water (70C) rinse; air dry	Clean	Clean		Fair	Some residue	D. Miscovich
26	NatraSol D. C. D.	Unidentified	5:1	Freon or alcohol	Stainless Steel	Smooth	Oil, grease & dirt	Immersion; ultrasonic; 70C	Hot water (70C) rinse; air dry	Clean	Clean		Good	Good degreaser	D. Miscovich
27	Uniclean VII	Glycol ethers	5:1	Freon TE	Stainless Steel	Smooth	Oil, grease & dirt	Immersion; ultrasonic; 49C	Hot water rinse; air dry	Clean	Clean		Good	Good degreaser	D. Miscovich
28	Uniclean VII	Glycol ethers	5:1	Freon or alcohol	Aluminum	Smooth	Oil & dirt	Immersion; ultrasonic; 49C	Hot water rinse; air dry	Clean	Clean		Good		D. Miscovich
29	Uniclean VII	Glycol ethers	3:1 10:1 50:1		Stainless steel machining scraps	Smooth to rough	Machining oils	Immersion; ultrasonic; 65C	Hot water (75C) rinse; air dry	Clean	Clean		Good	Dilutions had no significant effect	D. Miscovich
30	Uniclean VII	Glycol ethers	5:1	Freon TE Vapor Degreaser	Loaded PWB	Smooth; semi-porous; gold plated	Solder flux	Immersion; ultrasonic; 49C	Water rinse; air dry	Clean	Clean		Fair	Some residue	D. Miscovich
31	Bruin 815GD	Sodium tri-polyphosphate	10:1	Freon	Aluminum	Scratched & abraded	Granular oil	Immersion; ultrasonic; 42C	Water rinse; N2 dry	Clean		Clean	Very good		Sam Cowley & D. Miscovich
32	Freon	CFC	None		Aluminum	Scratched & abraded	Granular oil	Immersion; ultrasonic; 40C	Water rinse; N2 dry	Looked dirty		Poor	Poor	Solvent overloaded	Sam Cowley & D. Miscovich
33	NatraSol D. C. D.	Unidentified	10:1	Freon	Aluminum	Scratched & abraded	Granular oil	Immersion; ultrasonic; 42C	Water rinse; N2 dry	Clean		Poor (beaded)	Fair	Bubbles clung to sample	Sam Cowley & D. Miscovich
34	Uniclean VII	Glycol ethers	10:1	Freon	Aluminum	Scratched & abraded	Granular oil	Immersion; ultrasonic; 42C	Water rinse; N2 dry			Clean	Very good	Better than Freon	Sam Cowley & D. Miscovich

Table 3.1 Initial Screening Test Data (Continued)

Test #	Product Name	Product Type	Dilution	Replacing	Substrate Cleaned	Surface Texture	Contaminant	Application Method	Solvent Removal	Visual Test (with 15X Loupe)	White Glove Test	Water Break Test	Overall Performance	Remarks	Name of Tester
35	OCS H2002E	Butoxyethanol	10:1	Freon	Aluminum	Scratched & abraded	Granular oil	Immersion; ultrasonic; 50C	Water rinse; N2 dry	Looked bad		Clean	Fair	Pattern seen, may be aluminum defect	Sam Cowley & D. Miscovich
36	Citra Safe	Terpene-based	None	Freon	Aluminum	Scratched & abraded	Granular oil	Immersion; ultrasonic; 50C	Water rinse; N2 dry	Looked bad		Poor (beaded)	Poor		Sam Cowley & D. Miscovich
37	Perfectway 147	Terpene-based	4:1	Freon	Aluminum	Scratched & abraded	Granular oil	Immersion; ultrasonic; 50C	Water rinse; N2 dry	Clean		Good	Fair	Some streaks and dots	Sam Cowley & D. Miscovich
38	Rosin-X	Ethanolamine & glycol ether	20:1	Freon	Aluminum	Scratched & abraded	Granular oil	Immersion; ultrasonic; 58C	Water rinse; N2 dry	Clean		Good	Good		Sam Cowley & D. Miscovich
39	Bruin 1990GD	Unidentified	10:1	Freon	Aluminum	Scratched & abraded	Granular oil	Immersion; ultrasonic; 50C	Water rinse; N2 dry	Clean		Good	Good	Some spots	Sam Cowley & D. Miscovich
40	EP 921	Terpene-based	None	Freon	Aluminum	Scratched & abraded	Granular oil	Immersion; ultrasonic; 32C	Water rinse; N2 dry	Clean		Poor (beaded)	Fair		Sam Cowley & D. Miscovich

Table 3.2 Additional Screening Test Data (Continued)

Test #	Product Name	Product Type	Dilution	Replating	Substrate Cleaned	Contaminant	Application Method	Solvent Removal	Visual Test (with 15X Loupe)	Overall Performance	Remarks	Name of Tester
41	Skysol 500	Hydrocarbon & Terpene	None	Freon TE	Glass Slide	TrimSol Oil	Ultrasonic Immersion	Blown dry	Clean	Very good		G. Blyker
42	TEKSOL EP	Hydrocarbon & Terpene	None	Freon TE	Glass Slide	TrimSol Oil	Ultrasonic Immersion	Blown dry	Clean	Very good		G. Blyker
43	Safety Strip HT	Glycol Ether	None	Freon TE	Glass Slide	TrimSol Oil	Ultrasonic Immersion	Blown dry	Solvent left film after drying; rinsed with water	Fair	Obnoxious odor; attacked plastic pipette	G. Blyker
44	X-Caliber	Terpene & NMP	None	Freon TE	Glass Slide	TrimSol Oil	Ultrasonic Immersion	Blown dry	Residue left that lessened as it dried	Poor	Difficult to dry	G. Blyker
45	Brulin SD1291	Glycol Ether	None	Freon TE	Glass Slide	TrimSol Oil	Ultrasonic Immersion	Blown dry	Left some streaks	Good	Unpleasant odor	G. Blyker
46	Brulin SD1291	Glycol Ether	None		Aluminum plate	TrimSol Oil	Ultrasonic Immersion	Blown dry	Clean	Very good	Unpleasant odor	G. Blyker
47	PF-5060	Perfluoro carbon	None	Freon TE	Glass Slide	TrimSol Oil	Ultrasonic Immersion	Blown dry	Left oil film	Poor		G. Blyker
48	Freon TE	CFC	None		Glass Slide	TrimSol Oil	Ultrasonic Immersion	Blown dry	Left oil film	Poor		G. Blyker
49	Brulin 815GD	Phosphate Detergent	10:1	Freon TE	Glass Slide	TrimSol Oil	Ultrasonic Immersion	Blown dry	Some streaking by residue	Fair	Effective @ 60 to 82C	G. Blyker
50	Perfect Way 147	Terpene & Glycol Ether	4:1	Freon TE	Glass Slide	TrimSol Oil	Ultrasonic Immersion	Blown dry	Unacceptable residue	Poor	Mfr. recommends water rinse	G. Blyker
51	Skysol 500	Hydrocarbon & Terpene	None	Freon TE	Glass Slide	TrimSol Oil	Ultrasonic Immersion	Blown dry	Slight streaking	Good	Dries quickly and well	G. Blyker
52	Citra Safe	Terpene	None	Freon TE	Glass Slide	TrimSol Oil	Ultrasonic Immersion	Blown dry	Unacceptable residue	Poor	Brushing required	G. Blyker
53	TEKSOL EP	Hydrocarbon & Terpene	None	Freon TE	Glass Slide	TrimSol Oil	Ultrasonic Immersion	Blown dry	Some streaking by residue	Fair	Residue slid off in sheets during drying	G. Blyker
54	Natra Sol DCD	Unidentified	None	Freon TE	Glass Slide	TrimSol Oil	Ultrasonic Immersion	Blown dry	Very slight residue	Good		G. Blyker
55	EP921	Terpene & Propylene Carbonate	None	Freon TE	Glass Slide	TrimSol Oil	Ultrasonic Immersion	Blown dry	Some solvent left	Good	Difficult to dry	G. Blyker
56	Brulin 1990GD	Unidentified	None	Freon TE	Glass Slide	TrimSol Oil	Ultrasonic Immersion	Blown dry	Oil & solvent left	Poor		G. Blyker
57	X-Caliber	Terpene & NMP	None	Freon TE	Glass Slide	TrimSol Oil	Ultrasonic Immersion	Blown dry	Residue left that lessened as it dried	Very good	Dried quickly; strong odor	G. Blyker
58	Brulin SD1291	Glycol Ether	None	Freon TE	Glass Slide	TrimSol Oil	Wipe on/off	Blown dry	Very clean; no streaks	Very good	Unpleasant odor	G. Blyker

Table 3.2 Additional Screening Test Data (Continued)

Test #	Product Name	Product Type	Dilution	Replacing	Substrate Cleaned	Contaminant	Application Method	Solvent Removal	Visual Test (with 15X Loupe)	Overall Performance	Remarks	Name of Tester
59	PF-5060	Perfluoro carbon	None	Freon TE	Glass Slide	TrimSol Oil	Ultrasonic Immersion	Blown dry	Oil & solvent left	Very poor		G. Blyker
60	Isopropyl alcohol	Alcohol	None		Aluminum plate	TrimSol Oil	Ultrasonic Immersion	Blown dry	Clean	Very good		G. Blyker
61	Freon TE	CFC	None		Aluminum plate	TrimSol Oil	Ultrasonic Immersion	Blown dry	Blotchy appearance	Good		G. Blyker
62	Brulin 815GD	Phosphate Detergent	10:1		Aluminum plate	TrimSol Oil	Ultrasonic Immersion	Blown dry	Some streaking by residue	Very good		G. Blyker
63	Brulin 1990GD	Unidentified	None		Aluminum plate	TrimSol Oil	Ultrasonic Immersion	Blown dry	Clean	Very good		G. Blyker
64	Uniclean VII	Glycol Ether	None		Aluminum plate	TrimSol Oil	Ultrasonic Immersion	Blown dry	Unacceptable film residue	Poor	Viscous cleaner; must be rinsed	G. Blyker
65	Natra Sol DCD	Unidentified	None		Aluminum plate	TrimSol Oil	Ultrasonic Immersion	Blown dry	Clean	Good	Not as good as alcohol; brushing required	G. Blyker
66	Citra Safe	Terpene	None		Aluminum plate	TrimSol Oil	Ultrasonic Immersion	Blown dry	Unacceptable film residue	Very poor	Brushing required	G. Blyker
67	SkySol 500	Hydrocarbon & Terpene	None		Aluminum plate	TrimSol Oil	Ultrasonic Immersion	Blown dry	Clean	Fair	Brushing required	G. Blyker
68	Perfect Way 147	Terpene & Glycol Ether	4:1		Aluminum plate	TrimSol Oil	Ultrasonic Immersion	Blown dry	Blotchy	Good		G. Blyker
69	PF-5060	Perfluoro carbon	None		Aluminum plate	TrimSol Oil	Ultrasonic Immersion	Blown dry	Heavy film of oil left	Very poor	Residual oil did not dry	G. Blyker
70	Super Wash	Alkaline	10:1		Aluminum plate	TrimSol Oil	Ultrasonic Immersion	Blown dry	Clean	Very good		G. Blyker

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4.0 APPLICATION-SPECIFIC TESTS

The alternatives that performed best in the screening tests were examined more extensively for specific applications. The application-specific tests include both laboratory simulations and field site testing. LLNL also tried a number of additional cleaners that had not been identified during the screening tests. Some of these had been tested by other organizations, such as those discussed in Section 5 of this report, while others appeared promising from the information in the manufacturer's literature.

4.1 Cleaning Solder Flux from Printed Wiring Board

A loaded PWB was cleaned of solder flux to test alternatives for Freon TE cleaning. The boards (2,950 square centimeters of surface) were dipped in the cleaner at room temperature and brushed with the cleaner for 5 minutes, then rinsed twice in deionized water. Product cleanliness was tested by comparing conductivity using an Alpha Metals, Inc. Model 500 Ionograph, as specified in MIL-P-28809. This specification requires that conductivities do not exceed 20 micrograms (μg) NaCl equivalents per square inch ($\mu\text{g}/\text{in}^2$). An uncleaned board measured 29.1 $\mu\text{g}/\text{in}^2$. Tables 4.1a and b show the ionograph measurements. All the alternative cleaners that were tested easily met the specification, and two (Brulin 815PCX and Brulin 815GD) gave significantly better results than Freon TE, which produced an ionograph measurement of 12.1 $\mu\text{g}/\text{in}^2$. The best performer, Brulin 815 PCX, measured 6.2 $\mu\text{g}/\text{in}^2$. Table 4.1 and Figure 4.1 show the ionograph results at room temperature.

Table 4.1 PWB Cleaning at Room Temperature

Cleaner	Dilution	Micrograms NaCl per square inch	Remarks
Brulin 815PCX	None	6.2	Very good
Brulin 815GD	10:1	9.6	Very good
Freon TE	None	12.1	Good
Uniclean VII	5:1	12.7	Good
Rosin-X	20:1	12.9	Good
OCS H2002E	10:1	13.4	Good
Citra Safe	None	15.0	Good

A second series of tests used elevated temperatures (45 to 55°C). Ionograph measurements, shown in Table 4.2 and Figure 4.2, were always much lower than for the runs performed at room temperature, indicating that more contamination had been removed. At elevated temperatures, all the alternative cleaners that were tested performed better than Freon TE. Citra Safe and Rosin-X were the best performers at the elevated temperature, although they were worse than Freon at room temperature.

Table 4.2 PWB Cleaning at Approximately 50°C

Cleaner	Dilution	Micrograms NaCl per square inch	Remarks
Rosin-X	20:1	1.7	Very good
Citra Safe	None	1.8	Very good
Brulin 815PCX	None	2.5	Very good
Brulin 815GD	10:1	3.8	Good
Uniclean VII	5:1	4.5	Good
Freon TE	None	4.9	Good

Figure 4.1 PWB CLEANING AT ROOM TEMPERATURE

Figure 4.2 PWB CLEANING AT ELEVATED TEMPERATURE

Another series of tests cleaned 30-square inch PWBs that were loaded with 5 integrated circuit chips and soldered with a rosin-based flux. The boards were cleaned with both long (normal) and short (stiff) bristle acid brushes for 7 minutes. This series included Flux-off, a blend of CFC and methylene chloride that is used currently to pre-clean PWBs before final cleaning with Freon TE. Temperatures were those recommended by the manufacturers of the cleaners. One run of samples was tested for cleanliness with the ionograph without rinsing, producing the results shown in Table 4.3. Only one non-CFC cleaner could meet the MIL spec conductivity level. The others actually increased conductivity compared to the uncleaned specimen. These results underscore the importance of good rinsing procedures after many alternative cleaners are used.

Table 4.3 Cleanliness of Unrinsed Printed Wiring Boards

Cleaner	Dilution	Temp., °C	Micrograms NaCl per square inch	Remarks
Uncleaned			24.9	
Freon TE	None	40	3.9	Passed MIL spec
Brulin 815PCX	25:1	66	64.4	
Rosin-X	20:1	63	93.3	
Citra Safe	None	23	47.8	
Teksol EP	None	23	16.7	Passed MIL spec
OCS H2002E	10:1	65	53.7	
Flux-off	None	23	9.7	Passed MIL spec

For four other runs, the boards were rinsed in deionized water at the same temperature that was used for cleaning, then tested for cleanliness with the ionograph. Test results are shown in Table 4.4, as well as in Figure 4.3, which gives the average conductivity for the four runs. Only OCS H2002E failed to meet the MIL spec, and this was in only one run. All other alternatives easily met the cleanliness specification.

Table 4.4 Cleanliness of Rinsed Printed Wiring Boards

			Micrograms NaCl per square inch				
Cleaner	Dilution	Temp., °C	Run 2	Run 3	Run 4	Run 5	Average
Uncleaned	NA	NA	35.3	30.3	26.7	30.8	30.8
Freon TE	None	40	14.4	10.0	9.0	3.9	9.3
Brulin 815PCX	25:1	66	4.4	10.4	11.1	4.9	7.7
Rosin-X	20:1	63	6.4	3.8	1.0	3.2	3.6
Citra Safe	None	23	7.5	3.5	1.6	8.6	5.3
Teksol EP	None	23	1.6	4.9	2.6	8.1	4.3
OCS H2002E	10:1	65	19.6	19.3	12.4	20.2	17.9
Flux-off	None	23	9.1	4.5	3.7	9.3	6.7
Armakleen E-2000	9:1	74	15.5	8.6	8.6	13.6	11.6

In Runs 2 and 3, the cleaner was taken off the hot plate while the board was being cleaned. The solution temperature dropped as much as 15°C during this process. During Runs 4 and 5, the solution was maintained at the initial temperature. Therefore, results from the four runs have been averaged to determine the relative effectiveness of the cleaners.

LLNL's Electronics Fabrication Division selected Armakleen E-2000 as its main replacement cleaner for future cleaning operations. This decision was made largely because the cleaner appears to have the fewest potential hazards.

4.2 Removing Cutting Fluid from Metal Turnings

Stainless steel turnings that had been soaked in TrimSol cutting fluid were cleaned with Brulin 815GD, Citra Safe, Perfect Way 147, and Uniclean VII. This is a new application, so there is no existing cleaner or solvent for comparison. The residues left by each cleaner were analyzed by gas chromatography/mass spectrometry (GC/MS) and Fourier transform infrared (FTIR) spectroscopy (Sanborn 1992). The least residue was left by 815GD, although Perfect Way 147 performed almost as well. Citra Safe and Uniclean VII left significantly more residue.

4.3 Removing Tapping Compounds

LLNL's Building 321 Machine Shop formerly used 1,1,1 TCA to remove tapping compounds from machined metal parts. The melting points for these materials are listed in Table 4.5:

Table 4.5 Melting Points of Tapping Compounds

Compound	Melting Point, °C
Molecular Edge II ¹²	110
Safe Tap ¹³	55
#140 Stik Wax ¹⁴	65

The shop previously tried RB Degreaser and Hurri-Safe OCS cleaners, but shop personnel reported that these did not remove the tapping compounds effectively.

At room temperature, these materials have consistencies that have been described as like either honey or mayonnaise. It is relatively easy to remove the tapping compounds when the cleaner operates near the melting point because the compound becomes fluid and dissolves fairly readily. However, Molecular Edge's melting point exceeds either the boiling point or the flash point of many alternative cleaners. Of the three compounds, Molecular Edge generally is the most difficult to remove. Table 4.6 shows the boiling points and flash points for the cleaners that were screened for this application.

¹²Molecular Edge II is a trade mark of Tapmatic Corporation.

¹³Safe Tap is a trade mark of ITW Devcon Corporation, Rustlick Products.

¹⁴#140 Stik Wax is a trade mark of Johnson Corporation.

Table 4.6 Boiling Points and Flash Points of Selected Cleaners

Cleaner	Type	Boiling Point, °C	Flash Point, °C
Brulin 815GD	Detergent (phosphate)	100	None
Brulin SD1291	Glycol ether	100	71.1
Brulin 1990GD	Aqueous detergent, phosphate & silicate	100	None
Brulin MP1793	Hydrocarbon	182.2–207.2	61.1
Citra Safe	Terpene	171.1	48.9
EP921	Terpene & Propylene Carbonate	171.1	63.3
Natra Sol D.C.D.	Unidentified	177.8	50.0
Perfect Way 147	Terpene, amine, alcohol & glycol ether	Undefined	50.0
Skysol 500	Terpene & Hydrocarbon	171.1	66.7
Teksol EP	Terpene & Hydrocarbon	154.4	44.4
Uniclean VII	Glycol ether	93.3	None
X-Caliber	Terpene & NMP	187.8	68.3

An aluminum test piece that has a 1/4-20 tapped hole was used to perform a screening test on the cleaners listed in Table 4.6. Freon TE was also tested for comparison purposes. The alternative cleaners were applied undiluted, except for one test of 815GD, which used 2 parts of water per part of concentrate. Because of the flash point limitations, temperatures ranged from 45 °C for Teksol EP to 70°C for EP921, Uniclean VII, and 815GD. Cleaning time was 5 minutes, except for diluted 815GD, which was used for 15 minutes. The ability of each cleaner to remove the compound was determined by driving a screw into the hole, then removing the screw for visual inspection. Residual tapping compound can be seen easily on the screw threads. The inside of the hole was examined with a 30-power microscope.

Freon TE, Citra Safe, EP921, Skysol 500, Teksol EP, and X-Caliber all removed the Molecular Edge tapping fluid. The other cleaners tested did not. Moreover, Perfect Way 147 attacked the aluminum.

The cleaners that were successful in the screening test, plus Natra Sol D.C.D., Brulin MP1793, and Brulin 1990GD, were tested again. All were used undiluted. The samples were immersed in an ultrasonic bath for 5 minutes, then removed. A screw was driven into the hole, then withdrawn, wiped, and blown dry. The results of this series are shown in Tables 4.7 for Molecular Edge tapping fluid, Table 4.8 for Safe Tap and Table 4.9 for Stik Wax. MP1793 was not tested with Stik Wax.

Brulin 1990GD, Citra Safe, EP921, Skysol 500, Teksol EP and X-Caliber removed all three tapping compounds. Brulin 1990GD, EP921, Skysol 500 and X-Caliber present the fewest identified hazards, but 1990GD contains water, making it unacceptable to the LLNL Main Machine Shop. Citra Safe and Teksol EP have flash points that are low enough to classify them as hazardous in California. Also, Teksol EP had to operate very close to its flash point, which is undesirable. Natra Sol D.C.D. removed only two of the three compounds.

Table 4.7 Removing Molecular Edge Tapping Compound

Cleaner	Temperature, °C	Time, Min.	Removed Compound
Brulin 1990GD	85-90	5	Yes
Brulin SD1291	60-70	5	Yes
Brulin MP1793	40	5	Yes
Citra Safe	40	5	Yes
EP921	40	5	Yes
Natra Sol D. C. D.	40	5	No
Skysol 500	50	5	Yes
Teksol EP	40	5	Yes
X-Caliber	40	5	Yes

Table 4.8 Removing Safe Tap Tapping Compound

Cleaner	Temperature, °C	Time, Min.	Removed Compound
Brulin 1990GD	60	5	Yes
Brulin SD1291	60	5	Yes
Brulin MP1793	40	5	Yes
Citra Safe	40	5	Yes
EP921	40	5	Yes
Natra Sol D. C. D.	40	5	Yes
Skysol 500	40	5	Yes
Teksol EP	40	5	Yes
X-Caliber	60	5	Yes

Table 4.9 Removing #140 Stik-Wax Tapping Compound

Cleaner	Temperature, °C	Time, Min.	Removed Compound
Brulin 1990GD	65	5	Yes
Brulin SD1291	58	5	Yes
Citra Safe	40	5	Yes
EP921	40	5	Yes
Natra Sol D. C. D.	40	5	Yes
Skysol	65	5	Yes
Teksol EP	40	5	Yes
X-Caliber	65	5	Yes

4.4 Cleaning Glass Slides

Oil-Coated

Glass slides (38 by 38 by 6 mm) were smeared with dirty machine oil that contained metal particles. The slides were cleaned with Brulin 815GD, Uniclean VII, OCS H2002E, and Freon. The cleaning time was 20 minutes, except for one run with 815GD at 60 minutes. The glass samples were very sensitive to thermal stresses and all but one cracked upon removal from the bath, despite special care taken by the tester. What is significant about this test is that all of the alternative cleaners removed the machine oil better than Freon. The sample cleaned with it beaded water significantly.

Sol-gel™ Coated

This test involved cleaning a glass slide that had been coated with Sol-gel™ and allowed to dry in the sun. Sol-gel™ is an anti-reflective coating composed of quartz micro-spheres in ethanol that is used in LLNL's Lasers Directorate. After the solvent evaporates, the quartz particles remain tightly bonded to the glass surface. This test is a measure of how well different cleaners remove particulates. The cleaning time for all samples was 20 minutes. Table 4.10 shows the comparative results for several cleaners, in descending order of overall ratings, and includes one run that employed deionized water alone.

Table 4.10 Removing Sol-gel™ Coating from Glass

Sample No.	Cleaner	Dilution	Temp. °C	Overall Performance
7s	OCS H2002E	10:1	70	Very good
6s	Perfect Way 147	4:1	65	Very good
2s	Brulin 815GD	10:1	58	Good
11s	Brulin 1990GD	10:1	53	Good
8s	Uniclean VII	10:1	70	Good
4s	EP921	None	47	Poor
5s	Rosin-X	20:1	45	Poor
9s	Natra Sol D. C. D.	10:1	50	Poor
10s	Citra Safe	None	57	Poor
3s	Deionized Water	None	62	Very Poor

In this test, the "Overall Performance" ratings were strictly relative comparisons of the different alternative cleaners. There is no base solvent for comparison, since Sol-gel™ is normally removed either by mechanical abrasion or by dissolution with hydrofluoric acid.

Samples that had been cleaned most effectively were subjected to a particle-count analysis, with the results shown in Table 4.11. Note that for this type of particulate removal, the best alternative cleaners far surpass Freon in performance.

Table 4.11 Particle Counts After Cleaning Sol-gel™

Cleaner	Particles per 2.8 mm ²
OCS H2002E	2
Brulin 815GD	5
Perfect Way 147	8
Freon	28

4.5 Cleaning Graphite Lapping Compound from Machine Tools

A cutting tool coated with a grease-like graphite lapping compound was cleaned with the following alternative cleaners: (1) X-Caliber, (2) Citra Safe, (3) EP921, (4) Brulin 1990GD, and (5) Brulin SD1291. Each cleaner was tested full strength at room temperature. The dirty tool was immersed in solvent for 2 minutes, removed, and brushed with solvent on all sides to remove the graphite. The tool was then wiped with a rag and allowed to air dry for about 10 minutes. All of the alternative cleaners appeared to work effectively, based on visual examinations. The machine shop formerly had tried both OCS H2002 and RB Degreaser

unsuccessfully as an alternative to TCE for this cleaning application. Neither were effective in removing the compound.

Subsequently, the main LLNL machine shop field tested a new Brulin material, MP1793. The machinists found that MP1793 performed well, and did not have an objectionable odor as do the other alternatives (such as some of the terpene compounds). In addition, it does not contain glycol ethers. The shop decided to convert to MP1793 for most of its cleaning applications.

4.6 Cleaning Oil from Graphite Parts

LLNL's Lasers Directorate uses CFC to clean light machine oil and dirt from new machined graphite parts before they are plasma coated. The Directorate has tested Citra Safe and Brulin 1990GD for this use. The cleaners were both applied at room temperature by wiping; then removed by baking in an oven at 275°C. Citra Safe removed about 70 percent of the oil, while 1990GD removed significantly less. Neither performed as well as CFC and will not be considered further for this application. Other alternative cleaners are being investigated.

4.7 Cleaning Copper

The purpose of this test was to determine whether alternative cleaners could remove oxide film from copper surfaces without damaging the substrate, a common requirement in the electronics industry. Copper samples (38 by 38 by 1.6 mm) that had a light covering of oxide and some paint overspray were cleaned at room temperature with Brulin 815GD, Citra Safe, OCS H2002E, Perfect Way 147, Skysol 500, and Uniclean VII. Table 4.12 summarizes test results in descending order of overall performance. Although Citra Safe gave the best overall performance, it does present a flammability hazard because of its low flash point. Brulin 815GD appears to have the fewest environmental, health, and safety risks in this group.

Table 4.12 Copper Cleaning at Room Temperature

Cleaner	White Glove Test	Water Break Test	Overall Performance	Remarks
Citra Safe	Clean	Good	Very good	Removed paint overspray
Brulin 815GD	Clean	Good	Good	
OCS H2002E	Clean	Good	Good	
Skysol 500	Clean	Good	Good	
Perfect Way 147	Clean	Fair	Fair	
Uniclean VII	Clean	Fair	Fair	

Additional samples were cleaned at 60°C using (1) Brulin 815PCX, (2) OCS H2002E, (3) Perfect Way 147, (4) Rosin-X, (5) Teksol EP, and (6) Uniclean VII. Brulin 815PCX was substituted for Brulin 815GD, because the former is specifically formulated for cleaning printed circuit (PC) boards. Table 4.13 summarizes test results in descending order of overall performance.

Table 4.13 Copper Cleaning at 60°C

Cleaner	White Glove Test	Water Break Test	Overall Performance	Remarks
OCS H2002E	Clean	Good	Very good	Removed paint overspray
Brulin 815PCX	Clean	Good	Good	Removed paint overspray
Rosin-X	Clean	Good	Good	Removed paint overspray
Perfect Way 147	Clean	Poor	Fair	Removed paint overspray
Uniclean VII	Clean	Poor	Fair	Removed paint overspray
Teksol EP	Poor	Poor	Poor	Spots remained on sample

The higher temperature did not substantially improve the relative performances of Perfect Way 147 or Uniclean VII in removing copper oxide, although it did remove the paint overspray. Rosin-X and OCS H2002E, which are designed for cleaning PC boards, also performed well in this application. However, all of the cleaners in this group present some potential hazard. OCS H2002E contains glycol ether and failed both the acute oral and acute inhalation toxicity criteria. Rosin-X also contains glycol ether and failed the acute oral, acute dermal, and aquatic toxicity criteria.¹⁵ 815PCX failed the acute oral, acute dermal, and aquatic toxicity criteria. Perfect Way 147 contains glycol ether, has a low flash point that defines it as flammable, and failed the aquatic toxicity criterion. Uniclean VII contains glycol ether and failed the aquatic toxicity criterion.¹⁶ Teksol EP has a low flash point that defines it as flammable. Suppliers of Teksol EP and Uniclean VII did not furnish quantitative oral, dermal and inhalation toxicity data.

4.8 Cleaning Aluminum

Aluminum samples that had been deliberately contaminated with TrimSol coolant were immersed in an ultrasonic bath at room temperature for 5 minutes. Then they were removed, rinsed in deionized water, and air dried. Results are shown in Table 4.14 in descending order of overall performance.

Table 4.14 Cleaning Aluminum

Cleaner	Visual Test	White Glove Test	Water Break Test	Overall Performance	Remarks
Brulin 815GD	Clean	Clean	Good	Good	
Natra Sol D. C. D.	Clean	Clean	Good	Good	
SD1291	Clean	Clean	Good	Good	
Uniclean VII	Clean	Clean	Good	Good	
Citra Safe	Clean	Clean	Poor	Fair	
Perfect Way 147	Clean	Clean	Poor	Poor	Etched sample

Another series of tests quantitatively compared performances of the above solvents as well as

¹⁵Although Rosin-X concentrate failed the aquatic toxicity test, this cleaner passed the test when diluted 20:1.

¹⁶Aquatic toxicity tests for Uniclean VII at 3:1 dilution were inconclusive.

many additional cleaners for the removal of TrimSol contamination from aluminum coupons. The alternative cleaners were used in an ultrasonic bath at room temperature. The residual thicknesses of hydrocarbon contamination in nanometers (nm) for the cleaners performing best are shown graphically in Figure 4.4. Brulin 815GD and Polychem J.A.L.S.A.C. appear to have the fewest environmental, health, and safety risks in this group. Traditional hazardous cleaners (Freon-TE, 1,1,1 TCA, isopropanol, and acetone) were used either in a vapor degreaser (V) or an ultrasonic bath (U). The application temperature for the hazardous cleaners is also shown (e.g., 39V indicates vapor degreasing at 39°C). Cleanliness was measured using Reflectance Fourier Transform Infrared Spectroscopy.

Note that the alternative cleaners performed very well against the traditional solvents, even though the traditional materials were applied at elevated temperatures.

4.9 Cleaning Silk Screen

Several shops at LLNL perform silk screen printing. Silk screens contaminated with dried epoxy paint residues are normally cleaned with acetone. Alternative cleaners were applied at room temperature by brushing for 5 minutes, then were wiped. Visual and white glove tests were employed to determine cleanliness of the test screen. Results are shown in Table 4.15 in descending order of performance.

Table 4.15 Silk Screen Cleaning (Brushing at Room Temperature)

Cleaner	Results
Aero-Strip	Removed all residue. Appeared to be the best performer of this group.
DBE	Removed almost all residue from screen and frame.
Purasolv ELS	Removed almost all residue from screen and frame.
Safety Strip	Removed paint from frame but only some from screen.
X-Caliber	Left light covering of residue.
SD1291	Left light covering of residue.
815GD (Full strength)	Left some residue on screen and frame.
J.A.L.S.A.C. (9:1 dilution)	Removed some paint from screen but not from frame.
NC-300 (15:1 dilution)	Removed most paint from screen but not from frame.
EP921	Removed most paint from screen but not from frame.
Citra Safe	Removed most paint from screen but only some from frame.
SSD-92	Removed some paint from screen and frame.
Uniclean VII	Removed some paint from screen and frame; dried very slowly.

Inland Technology's Aero-Strip performed best using this cleaning method, followed by Du Pont's DBE and Purac's Purasolv ELS. However, 815GD, J.A.L.S.A.C., and NC-300 present fewer environmental, health, and safety hazards.

Figure 4.4 HYDROCARBON CONTAMINATION ON CLEANED ALUMINUM

In addition, the test piece was cleaned with selected alternatives for 5 minutes in an ultrasonic bath at 40°C, then rinsed for 5 minutes in deionized water. These cleaners were selected because they have performed very well in other applications, are known to be nontoxic, and do not require air permits for use. Dilutions were made according to manufacturers' recommendations. Results are shown in Table 4.16.

Table 4.16 Silk Screen Cleaning (Ultrasonic at 40°C)

Cleaner	Results
815GD (Full strength)	Removed all residue.
815GD (10:1 dilution)	Removed all residue.
J.A.L.S.A.C. (9:1 dilution)	Removed all residue.
NC-300 (15:1 dilution)	Removed all residue.

The visual and white glove inspections indicated that ultrasonic cleaning at 40°C was more effective than brushing at room temperature, producing a cleaner test piece.

4.10 Removing Vacuum Grease

Vacuum grease is considered one of the most difficult contaminants to remove from parts. Bench-scale tests were performed on both glass and stainless steel samples that were contaminated with either Dow Corning High Vacuum Grease or Apiezon Vacuum Grease. For all of the alternative cleaners, the samples were cleaned by immersion in a heated (50°C) ultrasonic bath for 5 minutes, rinsed in another ultrasonic bath using deionized water for 5 more minutes, and then dried.

Glass Samples

Baseline glass samples were cleaned with 1,1,1 TCA and dried. Then they were washed with detergent, rinsed with deionized water, and oven-dried at 93°C for 4 to 5 hours. Finally, they were cooled in an argon chamber. The alternatives tested included: 815GD, 1990GD, SD1291, NC-300, J.A.L.S.A.C., Teksol EP, Metalnox PC1, Alconox, Citranox, Citra Zapp, Citra Safe, E.C.G. Marine, MP1793, Tropiclean, Perfectway 147, Armakleen E-2000, and OCS H2002. Qualitative cleanliness tests (visual inspection, white glove, and waterbreak) gave the results in Table 4.17. Subsequently, glass samples were examined with the Optical Image Analyzer, but results were incomplete at the time of this report (Goodrich 1993).

Table 4.17 Removing Vacuum Grease from Glass

Vacuum Grease	Most Successful	Partly Successful
Dow Corning	E.C.G. Marine OCS H2002	815GD Alconox
Apiezon	Metalnox PC1	E.C.G. Marine Alconox SD1291

Stainless Steel Samples

Baseline stainless steel samples were wiped with ethanol, wiped dry, bead blasted, and washed with hot deionized water. Then they were scrubbed with cleaning powder, dipped in ethanol,

rinsed with deionized water, blown dry with argon gas, washed in Freon, and dried in a vacuum chamber. The baseline data were compared with alternative cleaners. The alternatives tested included: 815GD, 1990GD, SD1291, NC-300, J.A.L.S.A.C., Teksol EP, Metalnox PC1, Alconox, Citranox, Citra Zapp, Citra Safe, E.C.G. Marine, and MP1793. Qualitative cleanliness tests (visual inspection, white glove, and waterbreak) performed as shown in Table 4.18. The stainless steel samples were submitted for FTIR analysis, but results were incomplete at the time of this report (Goodrich 1993).

Metalnox PC1, MP1793, and J.A.L.S.A.C. appear to have the fewest environmental safety and health hazards of the group that successfully removed Dow Corning grease. 815GD, 1990GD, MP1793, and J.A.L.S.A.C. appear to have the fewest environmental safety and health hazards of the group that successfully removed Apiezon grease. However, MP1793 has not been tested for aquatic toxicity.

Table 4.18 Removing Vacuum Grease from Stainless Steel

Vacuum Grease	Successful	Unsuccessful
Dow Corning	Citra Safe SD1291 Teksol EP Metalnox PC1 MP1793 J.A.L.S.A.C.	815GD Alconox Citranox E.C.G. Marine NC-300 1990GD
Apiezon	SD1291 815GD 1990GD MP1793 J.A.L.S.A.C.	Metalnox PC1 E.C.G. Marine Alconox Citranox Citra Safe Teksol EP NC-300

4.11 Removing Dykem

Dykem is a dye that is frequently used in laying out metal parts for machining. Two types are used at LLNL-spray-on (Steel Blue No. SP-1100) and brush-on (Red No. DX-296). Each type was applied to a clean 38 by 457 mm aluminum strip and allowed to dry for 48 hours. The test sample was then wiped with the cleaner at room temperature for 30 to 45 seconds. Only visual and white glove tests were used in determining the relative effectiveness of the cleaners. Table 4.19 shows the results. No environmental, health, or safety hazards have been identified for EP921 or X-Caliber. The toxicity data for the other successful cleaners are incomplete.

Table 4.19 Effect of Alternative Cleaners on Dykem

Removed Dykem	Did not Remove Dykem
Acetone	Alternative 2000
EP921	Citra Safe
Furfuryl alcohol	duPont 6100
Purasolv ELS	MP1793
Safety Strip	Metalnox PC1
SD1291	OCS H2002E
SSD92	Perfectway 147
Tetrahydrofurfuryl alcohol	Surfynol 61
X-Caliber	Surfynol TG
	Teksol EP
	Uniclean VII

4.12 Cleaning Photographic Prints and Films

LLNL's Technical Information Department (TID) in the Plant Operations Directorate prepares documents for publication. TID uses acetone and Bestine™ solvent and thinner to remove contaminants from photographic color prints and clear positive films. The contaminants include gums from tape, fingerprints, and ink from ball-point pens. Aqueous cleaners are unacceptable because water damages the film emulsion. Nonaqueous cleaners were wiped on for one minute, wiped off for one minute, and then wiped dry at room temperature. The results observed are shown in Table 4.20. None of the materials tested could remove ball-point pen ink, while all of the cleaners easily removed fingerprints. Only Safety-Strip and X-Caliber, as well as the hazardous solvents acetone and isopropanol, could remove both tape residue and paint. There are no quantitative tests for this application so only the visual and white glove tests were used to determine cleanliness.

Table 4.20 Cleaning Photographic Films and Prints

Cleaner	3M Tape Residue	Fingerprints	Ball-point pen ink	Paint
Acetone	Yes	Yes	No	Yes
Isopropanol	Yes	Yes	No	Yes
Citra-Safe	Yes	Yes	No	No
DBE	No	Yes	No	Yes
EP921	No	Yes	No	Yes
MP1793	No	Yes	No	No
Furfuryl alcohol	No	Yes	No	Yes
Purasolv ELS	No	Yes	No	Yes
Safety Strip	Yes	Yes	No	Yes
Skysol 500	No	Yes	No	No
Surfynol 61	No	Yes	No	Yes
Teksol EP	No	Yes	No	No
THFA	No	Yes	No	Yes
X-Caliber	Yes	Yes	No	Yes

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5.0 QUANTITATIVE HIGH PERFORMANCE ANALYSIS

Additional cleanliness tests have been performed for selected applications by using the following techniques to quantitatively measure the amount of impurities remaining on the cleaned surface: (1) optical scanning, (2) x-ray fluorescence (XRF), (3) Fourier transform infrared (FTIR) spectrometry, (4) gas chromatography/mass spectrometry (GC/MS), and (5) ionography. Other methods reported in the literature, but not used by LLNL are electron spectroscopy chemical analysis (ESCA), ellipsometry, MESERAN, and measurement with stable isotopes. Table 5.1 presents a summary of the advantages and disadvantages of these methods.

Table 5.1 Advantages and Disadvantages of Analytical Methods

Analytical Method	Advantages	Disadvantages
Optical Scanning	Nondestructive test. Very good for particulates.	Measures area only. Limited to transparent substrate. Operator dependent. Gives only relative thickness of residue.
X-ray Fluorescence (XRF)	Nondestructive test. High precision. High accuracy.	Limited to contaminants that fluoresce strongly enough for detection. Not sensitive enough to compare the best cleaners.
Fourier Transform Infrared (FTIR) Spectrometry	Reflectance FTIR is non-destructive test. Can analyze films 1-2 nanometers thick.	Calibration is difficult, and requires sophisticated equipment such as ESCA. Sample surface must be reflective.
Gas Chromatography/Mass Spectrometry (GC/MS)	Equipment is widely available.	Requires removal of residue from substrate. Difficult to achieve complete removal.
Electron Spectroscopy Chemical Analysis (ESCA)	Nondestructive test. Measures all elements in residue except H and He.	Time-consuming process. High vacuum operation (10^{-9} Torr).
Ellipsometry	Nondestructive test. Relatively quick analysis Measures film thickness. Usable on metal surfaces.	Surface to be analyzed must be smooth and free of gross contamination.
MESERAN	Nondestructive test. Direct measurement of residual surface contaminants.	Measures relative amount of organic films. Radioactive tracer required.
Measurement with Stable Isotopes	Nondestructive test. No radioactive tracer required. Works for irregular geometry.	Isotopes are very expensive. Complex method requires well-trained staff.
Ionography	Nondestructive test.. MIL-spec standard procedure. Measures performance by conductivity.	Limited to ionic contaminants of electronic components that are soluble in IPA solution. Requires removal of residue from substrate; difficult to achieve complete removal.

The purpose of this section is not to present an exhaustive survey of all quantitative cleaning performance work being done but simply to discuss some of the measurement techniques that have proved valuable in evaluating new cleaners. Some other techniques that have been described in the literature include surface carbon analysis, evaporative rate analysis, and

electrostatic charge decay (Cohen 1987); laser ionization mass spectroscopy, Auger electron spectroscopy and scanning electron microscopy (Gill 1986); and surface secondary ion mass spectroscopy (Greene et al. 1992). These methods are not discussed here.

5.1 Optical Scanning

Optical scanning measures relative amounts of contamination on smooth substrates. LLNL found this method to be most useful on transparent substrates such as glass. Thus, it is especially good for optics cleaning applications. It can be used on other smooth surfaces as well, as long as contamination can be differentiated (using only light in the visible spectrum) from surface imperfections such as scratches or craters.

The method illuminates a magnified section of the sample surface and passes the image through a surface scanner, similar to the scanners commonly used to digitize a printed page. The digitized pixels are measured for their level of "grayness." In this way, contamination is distinguished from clean sections of the surface. The output is a measurement of the percent of the surface containing a detectable level of contamination. Although this does not yield an absolute measurement of the amount of residue remaining on the surface, it does provide a very useful way of comparing the levels of cleanliness attained with different solvents.

Figure 5.1 shows the results of optical scanning tests on glass slides contaminated with TrimSol. In this test, glass slides 3.7 by 2.5 by 0.1 centimeters were coated on both sides with TrimSol, then placed in a beaker containing 20 ml of cleaning solution. The beaker was put in an ultrasonic bath for 5 minutes at 40°C. The slides were brushed with acid brushes for the last two minutes of this time. Rinsing was done by putting the slides in beakers of deionized water for 2 minutes at 40°C, with ultrasonic agitation, then brushed again.

For each contaminant, it is necessary to try several different magnifications to determine which will sufficiently detect the residue. Fewer measurements are needed at lower than at higher magnification to observe a representative fraction of the part surface (at least 10 percent of the surface should be measured). For instance, 50-power magnification appears sufficient to detect most of the TrimSol residue on the surface (at this magnification, areas of contamination as small as 8 microns are detectable). For parts originally contaminated with Apiezon vacuum grease and then cleaned with the various solvents, only a fraction of the residue was detected at 50-power magnification. At higher magnification a fine, peppery structure appeared that accounted for a large percentage of the total residue. For Apiezon grease, 200-power magnification was sufficient, but this required 16 times more measurements than at 50-power magnification to attain a total measurement of 10 percent of the part surface.

The optical scanning approach has been combined with computer-aided analysis of the data using Cue Series Image software. Approximately five measurements can be performed on a sample per minute.

Note that many of the alternative cleaners perform better than standard solvents such as Freon TE, Freon 113, methyl ethyl ketone and methylene chloride.

Figure 5.1 TYPICAL OPTICAL IMAGE ANALYSIS RESULTS

Contaminant: Trimisol Coolant

Substrate: Glass

For the best cleaners, only 1 to 2 percent of the surface typically contains measurable contamination after cleaning, while many other cleaners leave 3 to 4 percent of the surface with measurable residue. Alkaline detergents such as 815GD, 1990GD, and J.A.L.S.A.C. were consistently among the best of the cleaners. This is encouraging because these detergents are also nonhazardous. In the cleaning procedures used in this study, these aqueous-based solvents were followed by a heated deionized water wash to remove all traces of the detergent. Pure d-limonene was also among the many cleaning chemicals tested. This terpene generally did not perform as well as the best detergent-based cleaners.

5.2 X-Ray Fluorescence

Certain contaminants in common residues, such as chlorine and sulfur, can be detected quite well through their x-ray fluorescence spectra. Thus, their presence can serve as "signatures" of the compounds that contain them. Machining oil, for instance, frequently contains chlorine and sulfur. The relative amount of these elements remaining on a surface after cleaning is proportional to the number of counts per second detected when the surface is subjected to x-rays.

This is a "nondestructive" type of analysis in that the sample does not have to be destroyed through removal of the residue on the part surface. Nondestructive testing has certain advantages, one of which is that the sample can be subjected to subsequent testing.

In our tests, machined aluminum coupons were contaminated with a chlorine-bearing oil. The samples were cleaned using several of the most promising cleaners identified at that time, as well as common solvents known to clean well. These included Freon TE (a CFC-ethanol azeotrope) and isopropyl alcohol. These provided "baseline" measurements; it was important that an alternative cleaner being considered give a comparable cleaning performance. The results of the XRF analysis are listed in Table 5.2. Please note that "ND" indicates no detectable contamination.

Table 5.2 Results of X-Ray Fluorescence Test

Cleaner (Manufacturer)	X-Ray Counts/second
Uncleaned	301
Isopropyl alcohol	4
Freon TE	ND
815GD (Brulin)	ND
1990GD (Brulin)	23
Citra Safe (Inland Technology)	2
Natra Sol (Sunshine Chemical Specialties)	ND
Perfect Way 147 (Polychemical Corp)	4
Skysol 500 (Inland Technology)	ND
Super Wash (SWI International)	6
Uniclean VII (Uniclean Products)	7

Although this technique was able to clearly identify the most powerful cleaners (all the ones with no detectable contamination remaining), it does not appear sensitive enough to distinguish between the performances of the best cleaners. The cleaners that performed best in this test included Freon TE, 815GD, Natra-Sol (terpene-based), and Skysol 500 (a blend of d-limonene and C12-C13 hydrocarbons). Close in performance to these were isopropyl alcohol, Citra-

Safe (almost pure d-limonene), and Perfect Way 147 (terpenes, propanol, amine, and monomethyl ether) (Blycker 1992).

5.3 Fourier Transform Infrared Spectrometry

Fourier transform infrared (FTIR) spectrometry techniques are based on absorbance of infrared signals by the chemicals that are being analyzed. Molecular bonds and groups of bonds resonate and absorb infrared frequencies that match their vibrational modes. Thus, each organic compound exhibits a unique "fingerprint" of absorbed infrared frequencies. This method can be used to identify the types and/or amounts of contamination on a part. The amount of hydrocarbon residue remaining after cleaning is indicated by infrared absorption in the wave number range 2500 to 3000. The result is a plot of absorbance versus wave number. The areas of peaks indicate the degree of contamination. Residue thicknesses can be measured either by calculating the height of the hydrocarbon peak above background, or by measuring the area under the curve. Both approaches appear to produce very similar results, and both can be measured automatically on FTIR equipment.

LLNL initially tried transmission FTIR spectrometry, which requires a substrate that is transparent to infrared. In most cases, this necessitates removing the residual contaminant from the part before measurement. Metal turnings that had been soaked in TrimSol cutting fluid were cleaned with Brulin 815GD, Perfect Way 147, Citra-Safe, or Uniclean VII. One sample was left uncleaned as a reference. Then the samples were washed once with 30 ml. of methylene chloride, which was subsequently evaporated to a volume of 1 ml. The concentrate was then evaporated onto a potassium bromide (KBr) plate for analysis by FTIR spectrometry.¹⁷ Brulin 815GD showed the least hydrocarbon residue, with Perfect Way 147 performing almost as well. Citra-Safe and Uniclean VII showed heavy residues, according to this test (Sanborn 1992). This approach can give erroneous results if only a fraction of the residual contamination is removed. Removal depends on the strength of the solvent used for this purpose (methylene chloride is typically used). Methylene chloride is a good solvent for polymers and hydrocarbon greases, but is ineffective on inorganic contaminants. Since methylene chloride and other organic solvents have been shown in other tests to remove less contamination under many circumstances than the cleaner being examined, many of the results obtained using this method are questionable.

Reflectance FTIR spectrometry gives the precision of FTIR, without requiring removal of the contaminant from the substrate. Its use is limited to reflective substrates. This technique has been used, for example, to analyze thin coatings on lenses (Compton and Stout, 1993). LLNL used FTIR with a low angle specular reflection accessory to measure the effectiveness of alternatives in cleaning organic residues from aluminum samples. A gold-coated mirror was used as the reference spectrum. Absorbance correlates to contaminant layer thickness, as shown in Figure 5.2. This calibration graph was obtained at Oak Ridge National Laboratory from two measurements. The lower value was measured by ESCA (Electron Spectroscopy Chemical Analysis), and the higher value was obtained by weighing the thin metal foil substrate used in this test, before and after it was contaminated with the hydrocarbon. Using this calibration data, LLNL is measuring hydrocarbon residue layer thicknesses on metal substrates to accuracies of better than one nanometer. This allows comparison of the contamination residues remaining after cleaning with the strongest solvents. The residue layer thicknesses for these solvents are typically between one and three nanometers; the differences between the performances of different cleaners are frequently only several tenths of a nanometer. Figure 5.3 shows the spectrum around wave number 3000 for a sample cleaned with CFC solvent.

¹⁷KBr is transparent to infrared.

In the reflectance FTIR method, the entire sample surface is scanned, and an average thickness is determined. In measurements of over 40 different cleaners, three samples cleaned with each solvent were analyzed, and these results averaged. Figure 5.4 depicts the results of these tests. On the left of the histogram are the residues remaining after cleaning with "traditional" hazardous solvents such as 1,1,1 TCA and Freon TE. Further to the right are results using alternative, "environmentally friendly" cleaners.

5.4 Gas Chromatography/Mass Spectrometry

Although LLNL tried a gas chromatography/mass spectrometry (GC/MS) technique to measure the amount and type of contaminant remaining on the cleaned surface, the results were generally unsatisfactory. GC/MS cannot analyze a solid surface. Instead, residual contamination on the substrate surface must be removed with a suitable solvent, such as methylene chloride.¹⁸ The solvent, carrying the residual contaminants, is then analyzed by GC/MS. A similar methodology used for the transmission FTIR test described above was used for this test, except that a 2-microliter sample of methylene chloride concentrate was injected into the GC/MS (Sanborn 1992).

One reason the technique gave poor results is that many alternative cleaners performed at least as well as methylene chloride. Thus, the methylene chloride was unable to remove the residual contamination on the surface and the GC/MS showed no detectable contamination.

5.5 Electron Spectroscopy Chemical Analysis

Electron spectroscopy chemical analysis (ESCA) is also known as X-ray photoelectron spectroscopy (XPS) because it uses an x-ray beam to excite the contamination layer on a sample. This causes electrons to be emitted by the excited atoms. This technique analyzes areas greater than or equal to 150 micrometers in diameter, to depths up to 10 nanometers. ESCA is sensitive to all elements except hydrogen and helium, and allows recognition of different species of a particular compound. Quantitative data can be obtained from a survey scan, and high-resolution scans over narrow energy ranges define stoichiometric relationships (Gill 1986).

Hewlett-Packard used ESCA in comparing aqueous cleaners to 1,1,1 TCA. The measure of cleanliness was the lowest residual carbon level and the absence of other contaminants. Elements analyzed included sulfur, chlorine, oxygen, chromium, iron, sodium, phosphorous, nitrogen, manganese, zinc, silicon, and nickel (Alston 1993).

While ESCA generates quite precise measurements of contamination levels, it is time consuming to generate each measurement. The equipment needed is expensive and operates at a high vacuum (10^{-9} Torr), which may be difficult to maintain. LLNL found ESCA to be most beneficial for calibrating approaches such as FTIR that can generate useful and accurate data more quickly.

¹⁸A 1:1 mixture of methylene chloride and isopropanol is sometimes used for surface extraction and can be much more effective than methylene chloride alone.

Figure 5.2 REFLECTANCE INFRARED SPECTROSCOPY CALIBRATION

FIGURE 5.3 RFTIR SPECTRA FOR WAVE NUMBERS 2700 TO 3100

**Aluminum Samples Coated with Trimsol and
Cleaned with Freon TE**

Figure 5.4 ALTERNATIVE CLEANERS PERFORMING BETTER THAN "BASELINE" SOLVENTS

5.6 Ionography

This method uses electrical resistance to measure the amount of ionic contamination on a surface. It requires the removal of that contamination before the measurement is made. This method is used as a standard in the electronics industry to determine cleanliness of printed wiring assemblies,¹⁹ and satisfies the requirements of MIL-P-28809 and MIL-P-55110.

In tests performed at LLNL, printed wiring assemblies were cleaned of solder flux using alternatives to Freon TE cleaning. Residues remaining after cleaning were removed using isopropyl alcohol. Product cleanliness was tested by comparing conductivities of the residues, as specified in MIL-P-28809, which requires that a conductivity no greater than 20 $\mu\text{g NaCl}$ equivalents per square inch ($\mu\text{g/in}^2$) remain on the surface after cleaning. As a point of comparison, an uncleaned board measured 29.1 $\mu\text{g/in}^2$. Table 4.1a shows the ionograph results for the various cleaners. All the alternative cleaners tested easily met the specification, and two (Brulin 815PCX and Brulin 815GD) gave significantly better results than Freon TE, which produced an ionograph measurement of 12.1 $\mu\text{g/in}^2$. The best performer, Brulin 815 PCX, measured 6.2 $\mu\text{g/in}^2$. The instrument employed was an Alpha Metals, Inc. Model 500 Ionograph.

Ionography alone may not be a sufficient test of cleanliness. While testing the removal of solder flux from circuit boards, researchers at DOE's Allied-Signal Kansas City Division extracted residue from cleaned surfaces using a solution of 75 percent isopropyl alcohol (IPA) and 25 percent deionized water. They employed an Alpha Metals Model 200 Omega Meter to measure the amount of ionic contaminant extracted. These researchers also used the Alpha Metals Model 600 SMD Omega Meter, which heats the IPA solution to 48.9°C and uses submerged spray jets to improve dissolution of the contaminant. However in both measurements, some specimens that showed low ionograph readings (corresponding to low amounts of ionic contamination) actually showed significant contamination when measured with another approach, MESERAN analysis (Benkovich 1993).

5.7 Ellipsometry

Los Alamos National Laboratory (LANL) chose ellipsometry to evaluate surface cleanliness for diamond-machined optics because it is capable of submonolayer sensitivity and gives a quantitative value for film thickness on the surface of the sample. This technique measures the state of polarization of a light wave, which changes abruptly as it is reflected at the interface of two optically dissimilar media. Ellipsometry appears to be a viable analytical method for substrates that have very smooth surfaces. The lower the ellipsometry value, the cleaner the surface. LANL stated that a single point measurement could be made in about 5 minutes. It is far too sensitive to be used for measuring relatively contaminated surfaces

LANL tried many alternatives for degreasing, cleaning, plastics welding, and paint stripping. Based on ellipsometry measurements of the amount of residue left on the cleaned surfaces, LANL concluded that X-Caliber was the most effective cleaner. Its advantages were better performance than 1,1,1 TCA for cleaning diamond-turned optics and compatibility with high explosives HMX, TATB, and PETN. Its disadvantages were incompatibility with the high explosive RDX and long drying time. PF degreaser was another good cleaner and performed efficiently in cleaning high vacuum components. Blue-Gold cleaner performed well in ultrasonic cleaning for electroplating (Noskin 1992).

¹⁹ANSI/IPC-RB-276 "Qualification and Performance Specification for Rigid Printed Boards" and ANSI/J-STD-001 "Requirements for Soldered Electrical Electronic Assemblies".

LANL machined samples of oxygen-free high-conductivity copper, using mineral oil as the cutting lubricant. The cleaning procedure consisted of immersing the sample in an ultrasonic bath of the cleaning agent for five minutes. Then the sample was rinsed ultrasonically in ethanol for five more minutes and dried with compressed air.

Test results have been reported for 20 alternatives and 1,1,1 TCA. Table 5.3 lists the alternatives which gave the lowest ellipsometry values (Noskin, 1992). Although it is necessary to know the identities and physical properties of contaminants to get absolute values of film thickness, relative cleanliness can be determined even for unknown contaminants with this method (Noskin 1993b).

Table 5.3 Results of Ellipsometry Test at LANL

Cleaner	Ellipsometry Value	Remarks
X-Caliber	1.738	Excellent cleaner but dries very slowly.
Isopar M	5.719	Not suitable for dip tank.
FO425A	6.026	Does not work well.
PF5060	6.495	Not suitable for dip tank.
EPA 2000	6.516	Removes oil and evaporates slowly.
Exxate 1000	6.620	Has strong odor. Not an excellent cleaner.
De-Solv-It	7.048	Not suitable for dip tank.
PF solvent	7.546	Works very well.
Trichloroethane (1,1,1 TCA)	9.0	Baseline solvent.

5.8 MESERAN Surface Analysis

Allied-Signal Aerospace Company Kansas City Division (KCD) used Measurement and Evaluation of Surfaces by Evaporative Rate Analysis (MESERAN) to measure organic contamination of surfaces before and after cleaning. KCD used MESERAN both as a stand-alone technique (Meier 1993) and as a comparison test for ionograph measurement (Benkovich 1993). In this method, the surface is coated with a solvent that has been tagged with carbon-14. Organic contaminants absorb the solvent, reducing the evaporation rate and increasing the radiation count. A Geiger counter is used to measure the rate of radioactive emission. KCD reported results as a MESERAN number (number of counts per 112 seconds). The lower the count, the cleaner the surface. KCD ranked the numbers as shown in Table 5.4 (Meier 1993).

Table 5.4 Definition of MESERAN Numbers

MESERAN number	Surface Condition
< 50	Very clean (sufficient for final cleaning)
51-100	Sufficient for in-process applications
100-200	Moderately clean
> 200	Grossly contaminated

5.9 Measurement with Stable Isotopes

In 1992, Battelle developed a method for quantifying cleanliness of parts that have irregular geometric surfaces. The result of this work for the Aerospace Guidance and Metrology Center at Newark Air Force Base was a process that applied stable (nonradioactive) isotopes to the test piece, then used mass spectroscopy to measure the isotopes removed by the cleaning process being tested. Three synthetic organic contaminants, each made up in two isotopic forms, represented "typical" soils to be removed from the test pieces. These were octadecanoic acid (a polar compound), phenanthrene (nonpolar) and dimethylphthalate (intermediate polarity). Two inorganic contaminants (silicon and iron) were also evaluated but were rejected for operational reasons. The procedure was used to compare the cleaning efficiencies of 1,1,1 TCA and an aqueous detergent. While this procedure can quantify the effectiveness of a cleaning method, the isotopic stimulants are very expensive. The method is complex, requiring a staff well trained in the methodology (Chauhan et al. 1992)²⁰.

5.10 Materials Compatibility and Environmental Testing

Effects on Weight, Dimension, Texture, or Visual Appearance

Sandia National Laboratories (SNL) tested the effects of various alternative cleaners on more than 70 different substrates. Substrates were primarily organic chemical polymers. Cleaners included decyl acetate and a terpene-based cleaner (Bioact® EC7).²¹ The laboratory specifically looked for changes in weight, dimension, texture appearance and glass transition temperature.²² Dimensional changes were measured using an Ono Sokki Linear Digital Gauge (Model EG225), having an accuracy of ± 0.001 millimeter. Scanning electron microscopy was employed to determine texture and appearance, and differential scanning calorimetry was used to measure glass transition temperature where applicable (Hoier and Nigrey 1992).

The Sandia study concluded that changes in visual appearance and weight were the most useful indicators of cleaners attacking organic materials. Interestingly, d-limonene and TCE can extract low molecular weight oligomers from polymeric materials. Sandia also noted that TCE attacked polystyrene foam, polyurethane elastomers polycarbonate, and polysulfone.

Effect of 815GD on Selected Surfaces

Because the cleaner Brulin 815GD has performed well in a variety of tests and has been determined to be nonhazardous, various shops at LLNL are examining it further for possible use. LLNL's Lasers Directorate tested the effects of Brulin 815GD on various selected materials to determine whether the cleaner degraded the surfaces. Samples A through D are pieces of a diamond-turned disk with circular grooves on the surfaces. Samples E through H are ungrooved, diamond-turned disks. Samples I through L are scaly aluminum sheets that have been silver coated. Samples M through P are smooth, flat, silver-coated aluminum sheets.

Samples A, E, I, and M were soaked for two hours in the cleaning solution. The cleaner did not affect the surface. Samples B, F, J, and N were contaminated with oil, then soaked for

²⁰For more information, contact Don E. Hunt, Chief Scientist, Aerospace Guidance and Metrology Center at Newark Air Force Base, Newark, OH.

²¹Subsequently replaced by Bioact® EC7R.

²²Glass transition temperature is the temperature at which a polymeric material changes from glassy to rubbery, indicating a loss of mechanical strength.

two hours in the cleaner. The cleaner did not remove the oil, and there was no etching of the surface. Samples C, G, K, and O were soaked for seven hours. No etching occurred. Samples D, H, L, and P were contaminated with oil, then soaked for seven hours in the cleaner. Samples D and H emerged with a flaky appearance, and the solidified oil fell off when the sample was agitated in the rinse water. Samples L and P also had a flaky appearance, but no oil came off in the rinse. It is speculated that the diamond-turned surfaces allowed the cleaner to penetrate beneath the contaminant.

Another series tested the effects on glass to see whether the relatively high pH of Brulin 815GD at 10:1 dilution would attack glass. Four weighed samples were soaked in the solution for various lengths of time, then reweighed. No etching was observed. The results are shown in Table 5.5.

Table 5.5 Effect of Brulin 815GD on Glass

Sample ID	Time, hr	Initial Weight, g	Final Weight, g	Change g	Change %	%/hour
Chip	4	26.7414	26.7371	0.0043	0.0161	0.0040
Blue	1	28.9253	28.9223	0.0003	0.0137	0.0137
Norm	2	30.0373	30.0340	0.0033	0.0110	0.0055
Sam	8	30.8115	30.8042	0.0073	0.0204	0.0030

Environmental Stress Testing

Electronic assemblies such as printed circuit boards that are intended for aerospace and military applications may be subjected to extreme environmental changes. These conditions can be simulated in the laboratory to test whether high temperature or high humidity can reveal a flaw in the cleaning process. Growth of contaminants, deterioration of insulation, and alterations in the surface are examined after environmental stress testing. LLNL has employed an environmental stress chamber analysis to determine the long-term performance of various cleaners on precision electronics assemblies. One month of stress testing under "85/85" conditions (85°C and 85% relative humidity) simulates approximately 15 years of normal aging at low heat operation (Hersey 1993).

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6.0 CONCLUSIONS

There is generally at least one alternative cleaner that can satisfactorily replace CFCs; 1,1,1 TCA; or other hazardous solvents. In most of the applications tested, it is not feasible to select one or two alternatives as the cleaner of choice for all LLNL applications. Table 6.1 summarizes the alternatives that gave the best cleaning performance in several tests. For applications where multiple products worked well, the table lists only the least hazardous. In other applications, all of the products that worked well also have some hazardous characteristics, although they are usually safer than the traditional solvents. The user may need to consider changing the cleaning procedure to use the alternatives effectively. For example, test data indicate that ultrasonic cleaners frequently give better results than traditional vapor degreasers.

Some of the overall best cleaners tested are alkaline detergents such as Polychem J.A.L.S.A.C., Brulin 815GD, and Brulin 1990GD. Besides being strong cleaners, the purely detergent compounds also tend to have fewer environmental issues associated with them. Even in geographical areas with the strictest air emission restrictions (such as the San Francisco Bay Area), the detergent cleaners do not require air emissions permits and are not regulated by local air quality agencies. In addition, many of the detergent cleaners at their diluted working strengths passed California's strict aquatic toxicity test, which means that they can be considered nonhazardous when they enter the waste stream. Some, including Polychem J.A.L.S.A.C., Brulin 815GD, and Brulin 1990GD, passed the test in their concentrated form as well.

Manufacturers of most cleaners recommend rinsing with deionized water. Tests performed without rinsing showed that several cleaners degraded the sample, based on ionograph measurements. Special drying techniques may enable use of water in applications that previously required non-aqueous cleaners. If the use of water cannot be tolerated for a particular application, then a hazardous material such as acetone or a volatile alcohol may be needed for rinsing.

Brulin 815GD appears to be an effective general-purpose cleaner, where the presence of water can be tolerated. It did not degrade either highly-polished aluminum or glass surfaces, nor did it cause detectable weight loss. Since these substrates are believed to be the most susceptible to chemical attack of all those tested, it is unlikely to harm other common substrates. A small portion of 815GD concentrate was analyzed by FTIR, which showed the active ingredient to be primarily sodium tripolyphosphate ($\text{Na}_5\text{P}_3\text{O}_{10} \cdot x\text{H}_2\text{O}$).

Cleaners that adversely affected aluminum test surfaces were: Axarel 32, Aquanox 101, Brulin 815PCX, Metalnox PC1, Perfect Way 147, and SSD-92. Of the formulations tested, no satisfactory alternative has been found to replace methylene chloride for removing cured epoxy resin.

There is no single analytical method for quantifying cleanliness in all applications. Nondestructive analytical methods (e.g., optical scanning, reflectance FTIR, ESCA, and ellipsometry) are preferable to destructive methods because they are more likely to distinguish between the best cleaners. However, ionography (a destructive test) has already become a standard for measuring cleanliness of electronic components. Optical image analysis is good for transparent substrates, while reflectance FTIR works well for many other reflective substrates.

Table 6.1 Best Performing Cleaners for Specific Applications

Application	Best Performers	Cleaner Type	Potential Hazards
Removing solder flux from printed wiring board	Church & Dwight Co.- Armakleen E-2000	Unidentified	None identified ²³
Removing Molecular Fluid Tapping Compound	Bulin-MP1793 Inland Tech.-EP921 Bulin-1990GD Inland Tech-X-Caliber	Hydrocarbon Terpene Detergent Terpene and NMP	Toxicity untested None identified None identified None identified
Removing copper oxide from copper at room temperature	Inland Tech-Citra Safe	Terpene	Toxicity and flammability
Cleaning copper oxide from copper at 60°C	OCS Manufacturing -OCS H2002E	Glycol ether	Toxicity
Cleaning aluminum	Bulin-815GD	Detergent	None identified
Removing Dow Corning vacuum grease from glass	Goode Chemical Co.-E.C.G. Marine	Unidentified	Toxicity untested
Removing Apiezon vacuum grease from glass	Kyzen Corp.-Metalnox PC1	Unidentified	None identified
Removing Dow Corning vacuum grease from stainless steel	Kyzen Corp.-Metalnox PC1 Bulin-MP1793 U.S. Polychem-J.A.L.S.A.C.	Unidentified Hydrocarbon Borate and silicate	None identified Toxicity untested None
Removing Apiezon vacuum grease from stainless steel	Bulin-MP1793 U.S. Polychem-J.A.L.S.A.C. Bulin-815GD Bulin-1990GD	Hydrocarbon Borate and silicate Detergent Detergent	Toxicity untested None identified None identified None identified
General Purpose Cleaning (aqueous)	Bulin-815GD	Detergent	None identified
General Machine Shop Cleaning (aqueous)	Bulin-815GD	Detergent	None identified
General Machine Shop Cleaning (nonaqueous)	Bulin-MP1793	Hydrocarbon	Toxicity untested

(Cont'd on next page)

²³ Armakleen E-2000 failed the aquatic toxicity test as a concentrate, but passed when diluted to recommended working strength.

Table 6.1 (Cont'd)

Removing Dykem from metals	Inland Tech-EP921	Terpene	None identified
	QO Chemicals Inc.-	Alcohol	Toxicity untested
	Furfuryl alcohol		
	PURAC-	Lactate ester	Toxicity untested
	Purasolv ELS		
	Ramco Specialty	Terpene and	Toxicity untested
	Products-SSD92	glycol ether	
	QO Chemicals Inc.-	Alcohol	Toxicity untested
	THFA		
	Inland Tech.-	Terpene and	None identified
Cleaning Epoxy Paint from Silk Screen	X-Caliber	NMP	
	Brulin-815GD	Detergent	None identified
	U.S. Polychemical-	Borate and	None identified
	J.A.L.S.A.C.	silicate	
	Ramco Specialty	Silicate	None identified
Cleaning graphite lapping compound from steel tools	Products-NC-300		
	Inland Tech.-EP921	Terpene	None identified
	Brulin-1990GD	Detergent	None identified
	Inland Tech.-	Terpene and	None identified
	X-Caliber	NMP	

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7.0 RECOMMENDATIONS

It is recommended that potential users make specific tests of several alternatives. If more than one cleaner seems to work well, then select the one whose concentrate has the least hazardous characteristics. Alkaline detergent-based cleaners are among the most powerful cleaners for many of the applications tested. Alkaline detergents are also among the more "environmentally friendly" cleaning materials and are considered nonhazardous in many areas.

Two glycol ethers (diethylene glycol dimethyl ether and ethylene glycol monomethyl ether acetate) cause adverse reproductive effects in animals and possibly in humans. Therefore, cleaners containing either of these chemicals are not recommended. There is no information concerning reproductive effects of other glycol ethers. However, it is recommended that cleaners containing this category of chemicals be avoided if other alternatives can perform satisfactorily.

Generally, increasing temperature increases cleaning ability for all formulations tested. Vendors recommend that the operating temperature not exceed 10°C below the flash point.

Users should test several concentrations of aqueous-based cleaners and determine the most cost effective for their specific applications. Lowering the concentration reduces the cost of concentrate, but increases the quantity of total waste. Techniques for extending the useful service life of aqueous cleaners were not investigated as part of this project but some information has been previously reported in the literature (Schwering et al. 1993).

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8.0 ABBREVIATIONS AND ACRONYMS

ACGIH	American Conference of Government Industrial Hygienists
ANSI	American National Standards Institute
a. u.	Absorbance units
BAAQMD	Bay Area Air Quality Management District
C	Celsius (Centigrade)
CAA	Clean Air Act
CC	Closed Cup
CFC	Chlorofluorocarbon
COC	Cleveland Open Cup
DMSO	Dimethyl sulfoxide
DOE	Department of Energy
EPA	Environmental Protection Agency
ESCA	Electron Spectroscopy Chemical Analysis
EPCRA	Emergency Planning and Community Right-to-Know Act
F	Fahrenheit
FTIR	Fourier Transform Infrared
g	Grams
GC/MS	Gas chromatography/mass spectrometry
HCFC	Hydrochlorofluorocarbon
in	Inch
IPA	Isopropyl alcohol
IRS	Infrared spectroscopy
KCD	Kansas City Division (Allied Signal Aerospace Co.)
kHz	Kilohertz
LANL	Los Alamos National Laboratory
LC	Lethal concentration
LD	Lethal dose
LFL	Lower flammable limit
LLNL	Lawrence Livermore National Laboratory
MESERAN	Measurement and Evaluation of Surfaces by Evaporative Rate Analysis
mg/kg	Milligrams per kilogram
mg/l	Milligrams per liter
mg/m ³	Milligrams per cubic meter
ml	Milliliter
mm	Millimeter
MSDS	Manufacturer's Safety Data Sheet
ND	Not detectable
nm	Nanometers
NMP	N-methyl pyrrolidone
ORNL	Oak Ridge National Laboratory
OSHA	Occupational Safety and Health Agency
PCB	Printed circuit board
PEL	Permissible Exposure Limit
PF	Perfluorocarbon
PMCC	Penske-Martin Closed Cup
POC	Precursor organic compound
PWB	Printed wiring board
SARA	Superfund Amendments and Reauthorization Act
SNL	Sandia National Laboratories

TCA	1,1,1 trichloroethane (also known as methyl chloroform)
TCC	Tag Closed Cup
TLV	Threshold Limit Value
UFL	Upper Flammable Limit
VOC	Volatile organic compound
XPS	X-ray Photoelectron Spectroscopy
XRF	X-ray Fluorescence
µg	Micrograms

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TABLE A PROPERTIES OF ALTERNATIVE CLEANERS

Table A presents a summary of properties for the alternative cleaners LLNL tested or considered for testing. The table includes the chemical constituents listed on manufacturers' material safety data sheets (MSDSs),²⁴ compositions (when listed on the MSDS), vapor pressures, percent volatiles, solubility in water, boiling point, flash point, flammable limits (LFL = lower flammable limit and UFL = upper flammable limit), permissible exposure limit (PEL), threshold limit value (TLV), toxicity values, and manufacturer's recommendations for application of the cleaner. Cleaners identified with an asterisk (*) have not yet been tested by LLNL.

Vendor data on flash point (an indicator of flammability) and upper and lower flammability limits in air were used whenever furnished. Different methods may give different flash points. The State of California classifies a material as flammable if its flash point is less than 140°F (60°C), but does not specify which test method must be used. The following symbols indicate the method used:

CC	Closed Cup
COC	Cleveland Open Cup
PM	Penske-Martin
TCC	Tag Closed Cup

Oral, dermal, and inhalation toxicities are usually reported in terms of lethal dose (LD) or lethal concentration (LC). Dosage is expressed as milligrams of substance per kilogram of body weight (mg/kg), while concentration is expressed as either milligrams per cubic meter of air (mg/m³) or parts per million (ppm). However, data may be reported for several types of small animals (e.g. guinea pigs, mice, rabbits, rats), and different values of LC₅₀ pertain to each type. The regulations do not specify which type of animal must be used for this determination. For consistency, LLNL has shown data for rats in Table A. LD₅₀ is the dose that caused 50 percent of the test animals to die, and LC₅₀ is the concentration that caused 50 percent of the test animals to die. California regulations define a substance as hazardous if the toxicities exceed one or more of the following values:

Acute Oral	LD ₅₀ < 5,000 mg/kg
Acute Dermal	LD ₅₀ < 4,300 mg/kg
Acute Inhalation	LD ₅₀ < 10,000 ppm

Properties that would make a cleaner hazardous under California regulations are shaded in Table A for easy identification. Certain constituents found in other alternative cleaners may require reporting. Those that require reporting under our local (San Francisco) regulations are indicated by a heavy border around the component name in Table A.

²⁴Usually the MSDS identifies only chemicals considered reportable under Title III of the Superfund Amendments and Reauthorization Act (SARA), which is also known as the Emergency Planning and Community Right-to-Know Act (EPCRA).

Appendix A Properties of Cleaners

Supplier	Trade Name	Chemical Components	CAS No.	Composition %	Sp. Gr.	Vapor Pressure, mm HG	Volatiles kg/kg	pH	Solubility In Water	OSHA PEL, ppm	ACGM TLV, ppm	Boiling Point, F	Flash Point, F H<140F	LFL, %	UFL, %	Acute Oral LD50, mg/kg H<5,000
Metalube Corporation	* 4U Multi-Purpose Cleaner-Degreaser				1.20			11.8 @ 32:1								No Data
		None Identified														
Exxon Chemical Americas	* Actrel 1111L Cleaner				0.81	0.1			<.01%			480	221 (PMCC)	1.6	10.2	Proprietary Data
Exxon Chemical Americas	* Actrel 3338L Cleaner				0.75				Insoluble				100	1.2	9.6	Proprietary Data
		Aliphatic petroleum hydrocarbon	64742-48-9													
Exxon Chemical Americas	* Actrel 4493L Cleaner				0.76	1			Insoluble			430	203	1.4	8.9	Proprietary Data
		Aliphatic petroleum hydrocarbon	64771-72-8													
Inland Technology	Aero-Strip				0.93	4	1.00		Very slight				132 (PMCC)	0.6	13.0	No Data
		2-Propanol, 1-methoxy acetate	108-65-6													
		Limonene	5989-27-5		0.84											4,400
		Methylpyrrolidone	872-50-4		1.03							396	204 (OC)			4,200
Alconox, Inc.	Alconox				N. A.	N. A.	N. A.	N. A.	10%	No Data	No Data		None			No Data
		None Identified														
Spartan Chemical Co., Inc.	All-Safe				1.05	18		8.9 to 9.1	100%			212	None			No Data
		None Identified														

Appendix A Properties of Cleaners (Continued)

Supplier	Trade Name	Chemical Components	Acute Dermal LD50, mg/kg H<4,300	Acute Inhalation LC50, mg/m ³ H<10,000 ppm	Fish Toxicity 96 hr LC50, mg/L H<500 mg/L	Remarks	Hazards & Other Issues	Recommended Application	Recommended Application Methods	Alternate For	Cleaner Type
Metalube Corporation	* 4U Multi-Purpose Cleaner-De		No Data	No Data	Untested	Do not air agitate; do not exceed 165F (74C).		General cleaning; automotive engines; Remove oil, grease, cosmoline from metals	Immersion, ultrasonic, high-pressure spray, parts washer, steam cleaner		Unidentified
		None identified									
Exxon Chemical Americas	* Actrel 1111L Cleaner		Proprietary Data	Proprietary Data	Untested	Aromatics content <0.5%		Petroleum based oils, grimes, waxes from metal or plastic			Hydrocarbon
Exxon Chemical Americas	* Actrel 3338L Cleaner		Proprietary Data	Proprietary Data	Untested						Hydrocarbon
		Aliphatic petroleum hydrocarbon									
Exxon Chemical Americas	* Actrel 4483L Cleaner		Proprietary Data	Proprietary Data	Untested	Aromatics content <0.01%					Hydrocarbon
		Aliphatic petroleum hydrocarbon									
Inland Technology	Aero-Strip		No Data	No Data	Untested	Mild citrus odor	Flammability				Terpene & Methylpyrrolidone
		2-Propanol, 1-methoxy acetate									
		Limonene					Flammability				
		Methylpyrrolidone									
Alconox, Inc.	Alconox		No Data	No Data	Untested	Supplied as a powder			Manual or ultrasonic cleaning		Detergent
		None identified									
Spartan Chemical Co., Inc.	All-Safe		No Data	No Data	Untested	Soapy odor		Remove oil, grease, carbon, inks, lapping compounds	Immersion, wipe, brush, spray, ultrasonic	Chlorinated solvents, kerosene	Unidentified
		None identified									

Appendix A Properties of Cleaners (Continued)

Supplier	Trade Name	Chemical Components	CAS No.	Composition %	Sp. Gr.	Vapor Pressure, mm Hg	Volatiles kg/kg	pH	Solubility in Water	OSHA PEL, ppm	ACGIH TLV, ppm	Boiling Point, F	Flash Point, F H<140F	LFL, %	UFL, %	Acute Oral LD50, mg/kg H<5,000
Kyzen Corp.	Aquanox 101				1.07	5		10.5 @ 5%sln.	Complete			239	None			
		Proprietary alcohol														1600 to 5250
Graymills Corp.	Aquatene GM330				1.00	0.6			Complete			212	None			No Data
		Dipropylene Glycol Methyl Ether	34590-94-8							100	100					
		Sodium Metasilicate	6834-92-0													
Church & Dwight Co.	Armakleen E-2000				1.26	17	0.72	10.5 to 10.9	Complete			212 to 230	None	None	None	>5,000
		None identified														
Enviro Tech International	ART-210				2.04	31	1.00		Slight			210	None			No Data
U. S. Polychemical	ASP #1M				0.92		1.00					335 to 390	143			No Data
		4 Hydroxy 4 Methyl 2-Pentanol	123-42-2								50					
		2 Ethyl 1-Hexanol	104-76-7													
		Succinate derivative (proprietary)														
U. S. Polychemical	ASP #13L				0.89		1.00					250 to 340	141			No Data
		4 Hydroxy 4 Methyl 2-Pentanol	123-42-2	50							50					
		2 Ethyl 1-Hexanol	104-76-7	50												
Petrolfirm Inc.	AVD Solvating Agent 19				0.87	1	Not determined		Insoluble			350	218 PMCC			No Data
		Aliphatic esters		100												

Appendix A Properties of Cleaners (Continued)

Supplier	Trade Name	Chemical Components	Acute Dermal LD50, mg/kg H<4,300	Acute Inhalation LC50, mg/m ³ H<10,000 ppm	Fish Toxicity 96 hr LC50, mg/L H<500 mg/L	Remarks	Hazards & Other Issues	Recommended Application	Recommended Application Methods	Alternate For	Cleaner Type
Kyzen Corp.	Aquanox 101				Untested		All ingredients are TSCA listed;				Alkaline
		Proprietary alcohol	5,000	4700 ppm/4hrs							
Graymills Corp.	Aquatene GM330		No Data	No Data	Untested						Glycol ether
		Dipropylene Glycol									
		Methyl Ether									
		Sodium Metasilicate									
Church & Dwight Co.	Armakleen E-2000		No Data	No Data	Passed @ 10% Failed @ 100%			Remove fluxes, inorganics, soils			Unidentified
		None identified									
Enviro Tech International	ART-210		No Data	No Data	Untested	Nonaqueous; terpene odor		Vapor Degreasing	Vapor Degreasing	Freon, TCA	Terpene
U. S. Polychemical	ASP #1M		No Data	No Data	Untested			Remove fluxes, oils, greases, coolants	Dip; ultrasonic; wipe		Alcohol
		4 Hydroxy 4 Methyl 2-Pentanol									
		2 Ethyl 1-Hexanol									
		Succinate derivative (proprietary)									
U. S. Polychemical	ASP #13L		No Data	No Data	Untested			Remove fluxes, oils, greases, coolants	Dip; ultrasonic; wipe		Alcohol
		4 Hydroxy 4 Methyl 2-Pentanol									
		2 Ethyl 1-Hexanol									
Petroform Inc.	AVD Solvating Agent 19		No Data	No Data					Vapor Degreasing	Freon, TCA	Hydrocarbon
		Aliphatic esters									

Appendix A Properties of Cleaners (Continued)

Supplier	Trade Name	Chemical Components	CAS No.	Composition %	Sp. Gr.	Vapor Pressure, mm HG	Volatiles kg/kg	pH	Solubility in Water	OSHA PEL, ppm	ACGIH TLV, ppm	Boiling Point, F	Flash Point, F H<140F	LFL, %	UFL, %	Acute Oral LD50, mg/kg H<5,000
Du Pont	* Axarel 32				0.84	<0.1			<0.1 wt. %			430 to 563	200 to 210 PMCC			
		Mixed aliphatic hydrocarbons	64742-47-8	70 to 90						400	n.e.					40,000
		Diisobutyl DBE	See text	15 to 20						1.5	n.e.					8,200
		Alkylpolyoxyethylene oxyethanol	68131-40-8	4.5 to 9.5												32,000
Du Pont	* Axarel 38				0.85	0.2		6 to 8	2.0 wt. %			385 to 563	159 TCC			
		Mixed aliphatic hydrocarbons	64742-47-8	60 to 85						400	n.e.					40,000
		DBE	See text	10 to 20						1.5	n.e.					8,200
		Diisobutyl DBE	See text	2 to 10						1.5	n.e.					8,200
		Alkylpolyoxyethylene oxyethanol	68131-40-8	6.5 to 9.5												32,000
		n-Octanol	111-87-5	1 to 5						n.e.	n.e.					5,000
Du Pont	* Axarel 52				0.82	<0.1			<0.1 wt. %			430 to 565	200 to 210 PMCC	0.8	16.4	
		Mixed aliphatic hydrocarbons	64742-46-7	70 to 90												40,000
		Diisobutyl DBE	See text	4 to 9												8,200
		Alkylpolyoxyethylene oxyethanol	68131-40-8	4.5 to 9.5												32,000
Du Pont	* Axarel 6100				0.81	<0.1			<0.1 wt. %			360 to 563	142 TCC			
		Mixed aliphatic hydrocarbons	64742-47-8	85 to 95												40,000
		Diisobutyl DBE	See text	5 to 15												8,200
Alpha Metals Inc.	* Bioact EC-Ultra Semi-Aqueous Defluxer				0.87	0.003		4 to 7					285 PMCC			No Data
		None Listed														

Appendix A Properties of Cleaners (Continued)

Supplier	Trade Name	Chemical Components	Acute Dermal LD50, mg/kg H<4,300	Acute Inhalation LC50, mg/m ³ H<10,000 ppm	Fish Toxicity 96 hr LC50, mg/L H<500 mg/L	Remarks	Hazards & Other Issues	Recommended Application	Recommended Application Methods	Alternate For	Cleaner Type
Du Pont	* Axarel 32				Failed @ 100%	Semi-aqueous		Printed wiring board	Semi-aqueous; Immersion, spray, ultrasonic	CFC	Hydrocarbon & DBE
		Mixed aliphatic hydrocarbons	2,000 to 4,000	24 mg/L							
		Dilsobutyl DBE	2,250	11 mg/L	18 to 24						
		Alkyloxy polyethylene oxyethanol	5,660		1 to 10						
Du Pont	* Axarel 38				Untested	Semi-aqueous		Printed wiring board	Spray	CFC	Hydrocarbon & DBE
		Mixed aliphatic hydrocarbons	2,000 to 4,000	24 mg/L							
		DBE	2,250	11 mg/L			Flammability				
		Dilsobutyl DBE	2,250	11 mg/L	18 to 24		Flammability				
		Alkyloxy polyethylene oxyethanol	5,660		1 to 10						
		n-Octanol			13.5						
Du Pont	* Axarel 52				Untested	Semi-aqueous		Metal cleaner	Semi-aqueous; Immersion	CFC	Hydrocarbon & DBE
		Mixed aliphatic hydrocarbons	2,000 to 4,000	24 mg/L							
		Dilsobutyl DBE	2,250	11 mg/L	18 to 24		Flammability				
		Alkyloxy polyethylene oxyethanol	5,660		1 to 10						
Du Pont	* Axarel 6100				Untested			Metal cleaner		CFC	Hydrocarbon & DBE
		Mixed aliphatic hydrocarbons	2,000 to 4,000	24 mg/L							
		Dilsobutyl DBE	2,250	11 mg/L	18 to 24		Flammability				
Alpha Metals Inc.	* Bioact EC-Ultra Semi-Aqueous		No Data	No Data	Untested			Flux removal		CFC	Unidentified
		None Listed									

Appendix A Properties of Cleaners (Continued)

Supplier	Trade Name	Chemical Components	CAS No.	Composition %	Sp. Gr.	Vapor Pressure, mm HG	Volatiles kg/kg	pH	Solubility in Water	OSHA PEL, ppm	ACGIH TLV, ppm	Boiling Point, F	Flash Point, F H<140F	LFL, %	UFL, %	Acute Oral LD50, mg/kg H<5,000
Alpha Metals Inc.	* Bioact EC-7M Manual Terpene Defluxer				0.84	1.6		5 to 6					117 TCC			No Data
		Terpenes														
Alpha Metals	* Bioact EC-7R Semi-Aqueous Terpene Defluxer				0.84	1.6		5 to 7					117 TCC			No Data
		Terpenes														
Alpha Metals	* Bioact EC-7 Semi-Aqueous Terpene Defluxer				0.84	1.6		5 to 7					117 TCC			No Data
		Terpenes														
Bio Z	* Bio-Z				0.95			3	Complete				None	None	None	No Data
Brulin Corp.																No Data
	Brulin 815GD				1.08	17		12	Complete			212	None	None	None	
		Detergents														
Brulin Corp.																
	Brulin 815PCX				1.02							338-342	150 TCC	None	None	2,277
		Ethanolamine	141-43-5	70 to 90		0.2				3	3					2,050
		Morpholine	110-91-8	5 to 10		10				20	20	128.9	100			1,050
Brulin Corp.	*															No Data
	Brulin MP1793				0.76	1			Insoluble	n. e.	n. e.	360-405	142 TCC	1.3	8.6	
		Hydrotreated Light Petroleum Distillates	64742-47-8	10 to 30						n. e.	n. e.					
		Isoparaffinic Hydrocarbon	64742-48-9	70 to 90						n. e.	n. e.					
Brulin Corp.																
	Brulin Rosin-X				1.01				Complete			338-342	150 TCC	None	None	2,929
		Ethanolamine	141-43-5	50 to 70		0.2				3	3					2,050
		Morpholine	110-91-8	1 to 5		0.2				20	20	128.9	100			1,050
		Diethylene glycol monomethyl ether	111-77-3	20 to 40	1.04	0.2				n. e.	n. e.	194.2	200			9,210

Appendix A Properties of Cleaners (Continued)

Supplier	Trade Name	Chemical Components	Acute Dermal LD50, mg/kg H<4,300	Acute Inhalation LC50, mg/m ³ H<10,000 ppm	Fish Toxicity 96 hr LC50, mg/L H<500 mg/L	Remarks	Hazards & Other Issues	Recommended Application	Recommended Application Methods	Alternate For	Cleaner Type
Alpha Metals Inc.	* Bloact EC-7M Manual Terpene	Terpenes	No Data	No Data	Untested	No water rinse required		Flux removal		CFC	Terpene
		Terpenes					Flammability				
Alpha Metals	* Bloact EC-7R Semi-Aqueous	Terpenes	No Data	No Data	Untested			Flux removal			Terpene
		Terpenes					Flammability				
Alpha Metals	* Bloact EC-7 Semi-Aqueous T	Terpenes	No Data	No Data	Untested			Flux removal			Terpene
		Terpenes					Flammability				
Bio Z	* Bio-Z		No Data	No Data		Use 10:1 dilution	None known		Spray; brushing; wiping; dipping		Enzyme
Brulin Corp.	Brulin 815GD	Detergents	No Data	No Data	Passed @ 100%	Dilution 1:10 heavy soil or 1:20 light soil	Moderate to high foaming	General purpose	Hot tanks, steam cleaner, pressure spray, ultrasonic		Detergent
Brulin Corp.	Brulin 815PCX	Ethanolamine Morpholine	1,500 n.l.		Failed @ 100%	Dilution 20:1; mild ammonia odor	Toxicity	Remove rosin and water-soluble fluxes	Spray; brushing; ultrasonic		Ethanolamine
				8,000							
Brulin Corp.	* Brulin MP1793	Hydrotreated Light Petroleum Distillates Isoparaffinic Hydrocarbon	No Data	No Data	Untested	Mild odor; Product Initially called EXP1793			Wipe, soak tank, spray		Hydrocarbon
Brulin Corp.	Brulin Rosin-X	Ethanolamine Morpholine Diethylene glycol monomethyl ether	2,143 1,500 n.l.		Failed @ 100%	Dilution 20:1; mild ammonia odor; slow evaporation	Toxicity	Remove rosin and water-soluble fluxes	Spray; brush; ultrasonic		Ethanolamine & Glycol ether
				8,000							

Appendix A Properties of Cleaners (Continued)

Supplier	Trade Name	Chemical Components	CAS No.	Composition %	Sp. Gr.	Vapor Pressure, mm HG	Volatiles kg/kg	pH	Solubility in Water	OSHA PEL, ppm	ACGIH TLV, ppm	Boiling Point, F	Flash Point, F H<140F	LFL, %	UFL, %	Acute Oral LD50, mg/kg H<5,000
Brulin Corp.	Brulin Safety Strip HT															
		Diethylene glycol n-butyl ether	112-34-5	20 to 25	0.96	0.02				n. e.	n. e.	>400	220	Unk	Unk	6,560
Brulin Corp.	Brulin SD 1291				0.95	0.4			Complete	50	100	212-350	160 PM	Unk	Unk	
		Ethyl 3-Ethoxypropionate	763-69-9	10 to 30	0.95							170.1	180			5,000
		Dipropylene glycol methyl ether	34590-94-8	50 to 70	0.95					100	100	190	185			5,660
		Aromatic Chemicals & Essential Oils		0 to 1												
Brulin Corp.	Brulin 1990GD				1.07	17		12	Complete			212	None	None	None	No Data
		None Listed														
	Castrol Kleen 3652											212	NA			41,000
		Ethanolamine	141-43-5	1 to 5						3	3	338	185	5.5	17.0	2,050
Alconox, Inc.	Citranox				1.12			2.5	Complete	No data	No data	217	None	NA	NA	No Data
		None Identified														
Inland Technology	Citra Safe				0.84	<2	1.00					340	120 TCC	0.6	7.0	4,400
		Limonene	5989-27-5							N. L.	N. L.					
Ramco	Citra Super Parts Degreaser (CSPD)				0.84	<2	0.87		Insoluble			339	134 PMCC	0.7	6.1	No Data
		D-Limonene	68647-72-3							N. L.	N. L.					
		Petroleum hydrocarbon	8042-47-5							5	5					

Appendix A Properties of Cleaners (Continued)

Supplier	Trade Name	Chemical Components	Acute Dermal LD50, mg/kg H<4,300	Acute Inhalation LC50, mg/m ³ H<10,000 ppm	Fish Toxicity 96 hr LC50, mg/L H<500 mg/L	Remarks	Hazards & Other Issues	Recommended Application	Recommended Application Methods	Alternate For	Cleaner Type
Brulin Corp.	Brulin Safety Strip HT		No Data	No Data	Failed @ 100%	Mild odor	Toxicity			Methylene chloride	Glycol ether
		Diethylene glycol n-butyl ether									
Brulin Corp.	Brulin SD 1291			No Data	Failed @ 100%	Mild fruity odor; slow drying	PEL&TLV are supplier recommendations	Remove grease, caulk, inks, adhesives	Wipe		Glycol ether
		Ethyl 3-Ethoxypropionate									
		Dipropylene glycol methyl ether	9,500								
		Aromatic Chemicals & Essential Oils									
Brulin Corp.	Brulin 1990GD		No Data	No Data	Passed @ 100%	Dilution 19:1; has corrosion inhibitor; mild odor; low foam		Remove production soils and residues	Spray wash		Detergent, phosphate, silicate
		None Listed									
	Castrol Kleen 3652		30,000		Untested						Ethanolamine
		Ethanolamine	1,500	n.l.							
Alconox, Inc.	Citranox		No Data	No Data	Untested	Use as 2% sol'n. High foaming	None	Glass; metals; porcelain; ceramics; plastics; rubber; fiberglass	Manual or ultrasonic cleaning		Amines & surfactants
		None identified									
Inland Technology	Citra Safe				Failed @ 100%	Mild citrus odor	GRAS			TCA, TCE, CFC	Terpene
		Limonene					Flammability				
Ramco	Citra Super Parts Degreaser		No Data	No Data	Untested		Flammability			TCA	Terpene
		D-Limonene									
		Petroleum hydrocarbon									

Appendix A Properties of Cleaners (Continued)

Supplier	Trade Name	Chemical Components	CAS No.	Composition %	Sp. Gr.	Vapor Pressure, mm HG	Volatiles kg/kg	pH	Solubility in Water	OSHA PEL, ppm	ACGIH TLV, ppm	Boiling Point, F	Flash Point, F H<140F	LFL, %	UFL, %	Acute Oral LD50, mg/kg H<5,000
Ramco Specialty Products	Citra-Zapp				1.00	ND	340g VOC/liter		Emulsifies				124 CC			No Data
		Limonene	5989-27-5							N. L.	N. L.					4,400
		Alkanolamide														
		Nonionic surfactants														
Penetone Co.	Citrikleen				0.98	ND	0.70	10.4	Emulsifies			212	165 COC; 125 PMCC			No Data
		Ethanolamine	141-43-5							3	3	338	185	5.5	17.0	2,050
		Limonene	5989-27-5		0.84					N. L.	N. L.					4,400
		Alkyl aryl sulfonate														2,320
		Diethylene glycol monobutyl ether														
		Alkyl aryl polyether														
		EDTA chelate														
		Butylated hydroxytoluene	128-37-0		1.05							245	260			890
		Water														
Omega Labs	Citri Solve				0.90	NA			Emulsifies			325	130			No Data
		Limonenes	8008579	>85	0.84											4,400
		Poly(oxyethylene) lime oil	8008-26-2	<10												
		Oxypropylene glycol	9003116	<12												
		Nonylphenol ethoxylate	26027363	<12												
Brulin Corp.	Compliance				1.05	Unknown		13.1					None	NA	NA	No Data
		Dipropylene glycol methyl ether	34590-94-8	5						100	100					
		2 Propanol, 1-methoxy propylene glycol methyl ether	107-98-2	5						100	100					
Ultra-Chem, Inc.	Conquer				1.05	Not given			Complete			212	None			No Data
		Ethylene glycol monobutyl ether		10 to 15												
		Sodium silicate		5 to 10												

Appendix A Properties of Cleaners (Continued)

Supplier	Trade Name	Chemical Components	Acute Dermal LD50, mg/kg H<4,300	Acute Inhalation LC50, mg/m ³ H<10,000 ppm	Fish Toxicity 96 hr LC50, mg/L H<500 mg/L	Remarks	Hazards & Other Issues	Recommended Application	Recommended Application Methods	Alternate For	Cleaner Type
Ramco Specialty Products	Citra-Zapp		No Data	No Data	Untested				Pressure washer		Terpene
		Limonene					Flammability				
		Alkanolamide									
		Nonionic surfactants									
Penetone Co.	Citrikleen		No Data	No Data	Passed @ 10% Failed @ 100%	Dilution 2:1 to 20:1			Spray, brush, or cold tank dip		Terpene & glycol ether
		Ethanolamine	1,500	n.i.							
		Limonene					Flammability				
		Alkyl aryl sulfonate									
		Diethylene glycol monobutyl ether									
		Alkyl aryl polyether									
		EDTA chelate									
		Butylated hydroxytoluene									
		Water									
Omega Labs	Citri Solve		No Data	No Data	Untested		Flammability				Terpene
		Limonenes									
		Poly(oxyethylene)									
		lime oil									
		Oxypropylene glycol									
		Nonylphenol ethoxylate									
Brulln Corp.	Compliance		No Data	No Data	Untested	VOC<0.5 lbs/gal		Uncured plastics resins	Brush, dip, spray	Acetone, methylene chloride	Glycol ether
		Dipropylene glycol methyl ether									
		2 Propanol, 1-methoxy propylene glycol methyl ether									
Ultra-Chem, Inc.	Conquer		No Data	No Data	Untested		Toxicity		Spray, immersion, wipe	TCA	Glycol ether
		Ethylene glycol monobutyl ether									
		Sodium silicate									

Appendix A Properties of Cleaners (Continued)

Supplier	Trade Name	Chemical Components	CAS No.	Composition %	Sp. Gr.	Vapor Pressure, mm HG	Volatiles kg/kg	pH	Solubility in Water	OSHA PEL, ppm	ACGM TLV, ppm	Boiling Point, F	Flash Point, F H<140F	LFL, %	UFL, %	Acute Oral LD50, mg/kg H<5,000
Du Pont	DBE Solvent				1.09	0.2			5.3 wt. %	n.e.	n.e.	385-437	212	0.9	8.0	8,191
		Dimethyl Glutarate	1119-40-0	66												
		Dimethyl Adipate	627-93-0	17								239F @ 13mmHg	285			
		Dimethyl Succinate	106-65-0	16.5												
		Methanol	67-56-1	0.1						200	200	148.46	53.6			5,628
		Hydrogen Cyanide	74-90-8	<10ppm						10	10	78.3	0	6.0	41.0	10
Gaylord Chemical	DMSO				1.10	0.46	1.00			None	None	372	192	3.0	63.0	17,400
		Dimethyl Sulfoxide	67-68-5	100	1.10	0.46	1.00			None	None	372	192	3.0	63.0	17,400
Goode Chemical Co., Inc.	E. C. G. Marine				1.17	10			Complete			235	None			No Data
		n-Butanol	71-36-3	0.03												
Inland Technology	EP-921				0.98	0.2	0.17					>340	146	0.7	6.1	No Data
		Limonene	5989-27-5	?	0.84					NL	NL					4,400
		Propylene Carbonate	108-32-7	?						NL	NL					
QO Chemicals, Inc.	FA								Complete	10	10	338	170 TCC	1.8	16.3	No Data
		Furfuryl Alcohol	98-00-0	100	1.14	1.0 @ 89F										
Graymills Corp.	GM581									2 mg/m3			n.a.			No Data
		Sodium Hydroxide	1310-73-2	100												
National Diagnostics, Inc.	Histo-Clear				0.85	6	1.00		Insoluble			355	195 (TCC)			>5,000
		Food Oil distillates														
U. S. Polychemical	J.A.L.S.A.C.				1.06		0.83					300				No Data
		Sodium Metasilicate	10213-79-3								10					

Appendix A Properties of Cleaners (Continued)

Supplier	Trade Name	Chemical Components	Acute Dermal LD50, mg/kg H<4,300	Acute Inhalation LC50, mg/m ³ H<10,000 ppm	Fish Toxicity 96 hr LC50, mg/L H<500 mg/L	Remarks	Hazards & Other Issues	Recommended Application	Recommended Application Methods	Alternate For	Cleaner Type
Du Pont	DBE Solvent		2,250	11	Failed @ 100%	LC50 96H is 18-24 mg/L	Flammability, toxicity				DBE
		Dimethyl Glutarate									
		Dimethyl Adipate									
		Dimethyl Succinate									
		Methanol	n.l.	61,000		IDLH=25000 ppm	Flammability				
		Hydrogen Cyanide		484			Acute toxic				
Gaylord Chemical	DMSO		40,000	No Data	32,000	Strong odor					DMSO
		Dimethyl Sulfoxide	40,000		32,000						
Goode Chemical Co., Inc.	E. C. G. Marine		No Data	No Data	Untested	USDA app'd; mild odor	None Indicated	Machine shop; belts; degreasing; marine; burnishing	Soaking; steam cleaning	CHC Vapor degreasing	Alcohol
		n-Butanol									
Inland Technology	EP-921		No Data	No Data	Passed @ 100%			Paint cleanup		MEK	Terpene
		Limonene					Flammability				
		Propylene Carbonate									
QO Chemicals, Inc.	FA		No Data	No Data	Untested						FA
		Furfuryl Alcohol									
Graymills Corp.	GM581		No Data	No Data	Untested		Very reactive				Caustic
		Sodium Hydroxide									
National Diagnostics, Inc.	Histo-Clear		>5,000		Untested						Terpene
		Food Oil distillates									
U. S. Polychemical	J.A.L.S.A.C.		No Data	No Data	Passed @100%						Borate & Silicate
		Sodium Metasilicate									

Appendix A Properties of Cleaners (Continued)

Supplier	Trade Name	Chemical Components	CAS No.	Composition %	Sp. Gr.	Vapor Pressure, mm HG	Volatiles kg/kg	pH	Solubility in Water	OSHA PEL, ppm	ACGIH TLV, ppm	Boiling Point, F	Flash Point, F H<140F	LFL, %	UFL, %	Acute Oral LD50, mg/kg H<5,000
Alconox, Inc.										No Data	No Data					No Data
	Liqui-nox				1.07	10.5		8.5	Complete			214	None			
		Sodium linear alkylaryl sulfonate														
		Sodium xylene sulfonate														
		Alkanolamide														
		Ethoxylated alcohol														
LPS Laboratories																No Data
	LPS Precision Cleaner				1.07	N. A.	80.00	12.5	Complete			212	n.a.			
		Sodium Metasilicate	10213-79-3	3 to 5							10					
		Dipropylene glycol methyl ether	34590-94-8	5 to 8	0.95					100	100	190	185			5,660
Kyzen Corp.																No Data
	Metalnox PC1				1.06	0.6		8.8	Complete			212	200	n. e.	n. e.	
		None identified														
International Products Corporation										No Data	No Data	No Data	No Data	No Data	No Data	No Data
	Micro				1.14	Not stated		9.7	Miscible							
		Glycine, N, N'-1,2-ethanedilybis-(N-(carboxymethyl)-, tetrasodium salt	64-02-8													
		Benzenesulfonic acid, dimethyl-, ammonium salt	26447-10-9													
		Benzenesulfonic acid, dodecyl-, cpd. with 2,2', 2"-nitrilotris (ethanol)	27323-41-7													
		Poly(oxy-1,2-ethanedilyl), alpha-(4-nonylphenyl)-omega-hydroxy branched	127087-87-0													

Appendix A Properties of Cleaners (Continued)

Supplier	Trade Name	Chemical Components	Acute Dermal LD50, mg/kg H<4,300	Acute Inhalation LC50, mg/m ³ H<10,000 ppm	Fish Toxicity 96 hr LC50, mg/L H<500 mg/L	Remarks	Hazards & Other Issues	Recommended Application	Recommended Application Methods	Alternate For	Cleaner Type
Alconox, Inc.	Liqui-nox		No Data	No Data	Untested	Odorless; high foaming; use as 1% sol'n.	Nonhazardous	Instruments; lab glassware; vacuum equipment, etc.	Manual or ultrasonic cleaning		Detergent & alcohol
		Sodium linear alkylaryl sulfonate									
		Sodium xylene sulfonate									
		Alkanolamide									
		Ethoxylated alcohol									
LPS Laboratories	LPS Precision Cleaner		No Data	No Data	Untested		Incompatible with strong oxidizers	Equipment cleaning - Dirt; grime; soot; stains	Spray; dip; ultrasonic immersion	Chlorinated solvents	Glycol ether & Silicate
		Sodium Metasilicate									
		Dipropylene glycol methyl ether	9,500								
Kyzen Corp.	Metalnox PC1		No Data	No Data	Untested	Mild odor	All ingredients are TSCA listed; none are TTO regulated				Unidentified
		None identified									
International Products Corporation	Micro		No Data	No Data							
		Glycine, N, N'-1,2-ethanedilybis-(N-(carboxymethyl)-, tetrasodium salt									
		Benzenesulfonic acid, dimethyl-, ammonium salt									
		Benzenesulfonic acid, dodecyl-, cpd. with 2,2', 2"-nitrioltris (ethanol)									
		Poly(oxy-1,2-ethanedilyl), alpha-(4-nonylphenyl)-omega-hydroxy branched									

Appendix A Properties of Cleaners (Continued)

Supplier	Trade Name	Chemical Components	CAS No.	Composition %	Sp. Gr.	Vapor Pressure, mm HG	Volatiles kg/kg	pH	Solubility in Water	OSHA PEL, ppm	ACGIH TLV, ppm	Boiling Point, F	Flash Point, F H<140F	LFL, %	UFL, %	Acute Oral LD50, mg/kg H<5,000
Mirachem Corp.	* Mirachem 100 Cleaner/Degreaser Concentrate				0.99	20	129 g/L		Emulsifies		1000	212	None	N/A	N/A	6,000
Sunshine Chemical Specialties,	Natra Sol D. C. D.				0.84	N/A	1.00		Emulsifies			352	122	0.7	6.1	No Data
		None identified														
Bidall Co.	* Natrastolve				0.81	0.8	1.00		Emulsifies			310	165(COC)	N/A	N/A	No Data
		C13-C14 Isoparaffins	68551-19-9	1												
Ramco Specialty Products	* NC-300				1.04			13.5	Complete			212	None	N/A	N/A	No Data
		Metasilicate	6834-92-0													
		Nonionic surfactants	9036-19-5													
Ford Technologies, Inc.	Nova Clean				1.04	17			Complete			200	None	N/A	N/A	No Data
		Surfactants		8												
		Pamak W-4		4												
		Sequestrene #40		2												
		Carbitol Solvent		4												
Oakite Products Inc.	Oakite Aluminum Cleaner NS				1.06	18	0.05	10.5	Complete	No data	No data	212	None	NA	NA	No data
		Tetrapotassium pyrophosphate	7320345	<5												
		Hydroxypropyl ethylene diamine	102603	<10												
		Diethylene glycol butyl ether	112345	<5												
		Ethoxylated cocoamine	61791148	<5												
		Trade secret registry (735517)		<5												

Appendix A Properties of Cleaners (Continued)

Supplier	Trade Name	Chemical Components	Acute Dermal LD50, mg/kg H<4,300	Acute Inhalation LC50, mg/m ³ H<10,000 ppm	Fish Toxicity 96 hr LC50, mg/L H<500 mg/L	Remarks	Hazards & Other Issues	Recommended Application	Recommended Application Methods	Alternate For	Cleaner Type
Mirachem Corp.	* Mirachem 100 Cleaner/Degreaser										Unidentified
Sunshine Chemical Specialties,			No Data	No Data	Untested @ 10% Failed @ 100%		Flammability	Degreaser & deodorant; removes gum, wax, tar			Unidentified
		Natra Sol D. C. D.									
		None identified									
Bidall Co.	* Natrastolve		No Data	No Data	Untested						Hydrocarbon
		C13-C14 Isoparaffins									
Ramco Specialty Products	* NC-300		No Data	No Data	Failed @ 100%			Carbon, grease, oils, algae, wax			Silicate
		Metasilicate									
		Nonionic surfactants									
Ford Technologies, Inc.			No Data	No Data	Untested						Surfactant
		Nova Clean									
		Surfactants									
		Pamak W-4									
		Sequestrene #40									
		Carbitol Solvent									
Oakite Products Inc.					Untested	Musty odor					Phosphate & glycol ether
		Oakite Aluminum Cleaner NS	No data	No data							
		Tetrapotassium pyrophosphate									
		Hydroxylpropyl ethylene diamine									
		Diethylene glycol butyl ether									
		Ethoxylated cocoamine									
		Trade secret registry (735517)									

Appendix A Properties of Cleaners (Continued)

Supplier	Trade Name	Chemical Components	CAS No.	Composition %	Sp. Gr.	Vapor Pressure, mm HG	Volatiles kg/kg	pH	Solubility in Water	OSHA PEL, ppm	ACGIH TLV, ppm	Boiling Point, F	Flash Point, F H<140F	LFL, %	UFL, %	Acute Oral LD50, mg/kg H<5,000
O.C.S. Manufacturing	* OCS Immersion Cleaner H2002				1.02	14.2	0.943	12.4	Complete			212	None			1,200
		2-Butoxyethanol (a.k.a. Butyl cellosolve or ethylene glycol monobutyl ether)	111-76-2	<20		300 @ 140C				25	25	340	140	1.1	10.6	240
O.C.S. Manufacturing	* OCS Electronics Cleaner H2002E				1.01		0.943		Complete							2,743
		2-Butoxyethanol (a.k.a. Butyl cellosolve or ethylene glycol monobutyl ether)	111-76-2	8.78		300 @ 140C				25	25	340	140	1.1	10.6	240
Titan Laboratories, Inc.	* Oil-Flo Safety Degreaser				0.93	0.078	522 g/L	7.86	100%		370	290	112(TCC) 145 (TOC) 140 (PMCC)	1.1	8.6	No Data
		Aromatic hydrocarbons	64742-95-6	40 to 70							200					
		Ethylene glycol monobutyl ether	111-76-2	2 to 5						50						
National Diagnostics	* Opticlear				0.85	6	1.00		Insoluble			355	140			5,000
		Unidentified Food Oil Distillates		100												
U. S. Polychemical Corp.	Perfect Way 147				0.98		0.88									No Data
		Terpenes	598927-5	4 to 10	0.84						n.e.					4,400
		1-T-Butoxy-2-Propanol	57018-52-7	2 to 4							n.e.					
		2-Hydroxyethyl Amine	141-43-5	2 to 5	1.02	6					3	170.5	200			2,140
		Dipropylene Glycol Monomethyl Ether	34590-94-8	2 to 5	0.95						100	190	185			5,660

Appendix A Properties of Cleaners (Continued)

Supplier	Trade Name	Chemical Components	Acute Dermal LD50, mg/kg H<4,300	Acute Inhalation LC50, mg/m ³ H<10,000 ppm	Fish Toxicity 96 hr LC50, mg/L H<500 mg/L	Remarks	Hazards & Other Issues	Recommended Application	Recommended Application Methods	Alternate For	Cleaner Type
O.C.S. Manufacturing	* OCS Immersion Cleaner H200		No Data	615 ppm/8H	Untested	Dilution 8:1	Aquatic toxicity		Immersion	CFC and TCA	Glycol ether
		2-Butoxyethanol (a.k.a. Butyl cellosolve or ethylene glycol monobutyl ether)		700ppm/7H							
O.C.S. Manufacturing	* OCS Electronics Cleaner H200		No Data	615 ppm/8H	Passed @ 100%	Dilution 8:1	Aquatic toxicity	Removes oils, greases, carbon	Immersion		Glycol ether
		2-Butoxyethanol (a.k.a. Butyl cellosolve or ethylene glycol monobutyl ether)		700ppm/7H							
Titan Laboratories, Inc.	* Oil-Flo Safety Degreaser		No Data	No Data			Flammable				Glycol ether
		Aromatic hydrocarbons									
		Ethylene glycol monobutyl ether									
National Diagnostics,	* Opticlear		5,000	No Data	Untested	Citrus odor	Flammable				Terpene
		Unidentified Food Oil Distillates									
U. S. Polychemical Corp.	* Perfect Way 147		No Data	No Data	Failed @ 100%		Aquatic toxicity	Remove tridolys, grime, oils, buffing compounds			Terpene, amine, alcohol, glycol ether
		Terpenes					Flammability				
		1-T-Butoxy-2-Propanol									
		2-Hydroxyethyl Amine	1,500			STEL=6ppm					
		Dipropylene Glycol Monomethyl Ether	9,500			STEL=150 ppm					

Appendix A Properties of Cleaners (Continued)

Supplier	Trade Name	Chemical Components	CAS No.	Composition %	Sp. Gr.	Vapor Pressure, mm HG	Volatiles kg/kg	pH	Solubility in Water	OSHA PEL, ppm	ACGIH TLV, ppm	Boiling Point, F	Flash Point, F H<140F	LFL, %	UFL, %	Acute Oral LD50, mg/kg H<5,000
3M Co.																No Data
	PF-5060															
		Perfluoro compounds	86508-42-1	100	1.70	79	1.00	NA				133	None	None	None	
U. S. Polychemical	Poly spray Jet 790				1.15		82.00					212-230	None	None	None	No Data
		Sodium silicate														
		Sodium borate														
		Sodium gluconedionate														
Dow Chemical	Primaclean 1000 (XUS-11269.01				1.07	ND			Soluble			212	None	None	None	No Data
		Surfactants														
		Corrosion inhibitors														
PURAC America, Inc.	Purasolv BL				0.98	1			340%	5	5	370	174	1	7.9	2,000
		Butyl lactate		97												
PURAC	Purasolv ELS															No Data
		None identified														
Environmental Technology	RB Degreaser				1.00			9.6@ 25%	Complete			212	NA	None	None	No Data
		None identified														
Envirosolv, Inc.	Re-entry KNI Solvent - 2000				0.88	0.28	1.00		<1%			374	148 TCC	ND	ND	No Data
		Terpene Mixture									100					
Envirosolv, Inc.	Re-entry RFS Solvent - 2000				0.94	0.26	1.00		~20%			374	150 TCC	ND	ND	No Data
		Terpene Mixture									100					
3M Co.	Rinsing Agent 6000				1.70	232	1.00	NA	Insoluble			132.8	None	None	None	No Data
		Perfluoro compounds	86508-42-1	100												

Appendix A Properties of Cleaners (Continued)

Supplier	Trade Name	Chemical Components	Acute Dermal LD50, mg/kg H<4,300	Acute Inhalation LC50, mg/m ³ H<10,000 ppm	Fish Toxicity 96 hr LC50, mg/L H<500 mg/L	Remarks	Hazards & Other Issues	Recommended Application	Recommended Application Methods	Alternate For	Cleaner Type
3M Co.			No Data	No Data	Passed @ 100%			Light duty cleaning; non-aqueous rinsing	Vapor degreasing; wipe, spray, dip, brush	CFC	Perfluorocarbon
	PF-5060	Perfluoro compounds			>1,000						
U. S. Polychemical	Polyspray Jet 790		No Data	No Data	Untested				Spray, pressure, hot immersion		Silicate
		Sodium silicate									
		Sodium borate									
		Sodium glucohedronate									
Dow Chemical *	Primaclean 1000 (XUS-1126)		No Data	No Data					Heat to 170 F; ultrasonic; spray		
		Surfactants									
		Corrosion inhibitors									
PURAC America, Inc.	Purasolv BL		No Data	No Data				PCB, greases, oils		Cellosolve acetate	Lactate ester
		Butyl lactate									
PURAC	Purasolv ELS		No Data	No Data							Lactate ester
		None identified									
Environmental Technology *	RB Degreaser		No Data	No Data	Untested	Normal dilution 5:1			Spray, pressure, hot or cold immersion		Alkaline
		None identified									
Envirosolv, Inc.	Re-entry KNI Solvent - 2000		No Data	No Data	Untested	Mild odor					Terpene
		Terpene Mixture					Flammability				
Envirosolv, Inc.	Re-entry RFS Solvent - 2000		No Data	No Data	Untested						Terpene
		Terpene Mixture					Flammability				
3M Co.	* Rinsing Agent 6000		No Data	No Data	>1,000			Nonaqueous rinsing	Vapor degreaser	Freon, TCA	Perfluorocarbon
		Perfluoro compounds									

Appendix A Properties of Cleaners (Continued)

Supplier	Trade Name	Chemical Components	CAS No.	Composition %	Sp. Gr.	Vapor Pressure, mm HG	Volatiles kg/kg	pH	Solubility in Water	OSHA PEL, ppm	ACGIH TLV, ppm	Boiling Point, F	Flash Point, F H<140F	LFL, %	UFL, %	Acute Oral LD50, mg/kg H<5,000
U. S. Polychemical	* Sameon				1.07		90.00	10.5				200	None			No Data
		Dipropylene glycol monomethyl ether	34590-94-8	5												
		Sodium hydroxide		2												
		Surfactants														
Sunshine Makers, Inc.	* Simple Green				1.04	30	0.00	9.5	Infinite	n.l.	n.l.	206	212	None	None	5,000
		Glycol ether	111-76-2	2												
		Surfactants														
Inland Technology	Skysol 500				0.77	<2	1.00		Insoluble @ 25C	n.l.	n.l.	>340	152 PMCC	0.6	7.0	No Data
		C12 - C13 Hydrocarbons	84742-48-9													
		d-limonene	5989-27-5													
Ramco Specialty Products	SSD-92 Synthetic Solvent Degreaser				0.95	ND	0.50	8.5	Miscible			307	150			No Data
		Terpene distillate	5989-27-5													
		Propylene glycol t-butyl ether	57018-52-7													
		SSD-92 RAMCO Blend														
Ramco Specialty Products	SSD-93 Synthetic Solvent Degreaser				0.99	ND	NA	9.4	Miscible			220	NA			No Data
		D-Limonene	5989-27-5							NE	NE					
		Alkanolamide	NA							NE	NE					
		Nonionic surfactants	NA							NE	NE					
S. W. I. International	Super Wash											215.6	None	None	None	2,600
		Unidentified organic & inorganic mixture		10	1.03	23			Miscible							

Appendix A Properties of Cleaners (Continued)

Supplier	Trade Name	Chemical Components	Acute Dermal LD50, mg/kg H<4,300	Acute Inhalation LC50, mg/m ³ H<10,000 ppm	Fish Toxicity 96 hr LC50, mg/L H<500 mg/L	Remarks	Hazards & Other Issues	Recommended Application	Recommended Application Methods	Alternate For	Cleaner Type
U. S. Polychemical	Samson		No Data	No Data	Untested			Grease, oils, buffing compounds			Glycol ether
		Dipropylene glycol monomethyl ether									
		Sodium hydroxide									
		Surfactants									
Sunshine Makers, Inc.	Simple Green		No Data	No Data	Untested						Surfactant & Glycol ether
		Glycol ether									
		Surfactants									
Inland Technology	Skysol 500		No Data	No Data	Untested			General solvent cleaner		CFCs and Chlorinated solvents	Hydrocarbon & Terpene
		C12 - C13 Hydrocarbons									
		d-limonene					Flammability				
Ramco Specialty Products	SSD-92 Synthetic Solvent De		No Data	No Data		VOC = 190.4 g/l		Spray gun cleaning, degreasing, printing presses	Immersion, wiping, non-atomizing spray	Mineral spirits, kerosene, perchloroethylene, TCA	Terpene & glycol ether
		Terpene distillate									
		Propylene glycol t-butyl ether									
		SSD-92 RAMCO Blend									
Ramco Specialty Products	SSD-93 Synthetic Solvent De		No Data	No Data	Untested	VOC = 340 g/l		Spray gun cleaning, degreasing, printing presses			Terpene
		D-Limonene									
		Alkanolamide									
		Nonionic surfactants									
S. W. I. International	Super Wash				Failed @ 100% Failed @ 20%		Toxicity				Alkaline
		Unidentified organic & inorganic mixture									

Appendix A Properties of Cleaners (Continued)

Supplier	Trade Name	Chemical Components	CAS No.	Composition %	Sp. Gr.	Vapor Pressure, mm HG	Volatiles kg/kg	pH	Solubility in Water	OSHA PEL, ppm	ACGIH TLV, ppm	Boiling Point, F	Flash Point, F H<140F	LFL, %	UFL, %	Acute Oral LD50, mg/kg H<5,000
Air Products and Chemicals, Inc.	Surfynol 61 Surfactant				0.85	4.5			120%			320	120			500
		3,5-Dimethyl-1-hexyn-3-ol	107-54-0	100	0.85	4.5						320	120			
Air Products and Chemicals, Inc.	Surfynol 104 Surfactant				0.89											4,600
		2,4,7,9-Tetramethyl-5-decyne-4,7-diol	126-86-3	100	0.89				10%	n.e.	n.e.	500				4,600
Air Products and Chemicals, Inc.	Surfynol TG Surfactant				1.00	4			1600%							2,800
		2,4,7,9-Tetramethyl-5-decyne-4,7-diol	126-86-3	30 to 60	0.89				10%	n.e.	n.e.	500				4,600
		1,2-Ethanediol	107-21-1	16												
Environmental Services Group	TASC				NA	NA	NA	No data	Complete	No data	No data	NA	NA	NA	NA	No data
		Sodium carbonate	5968-11-6													
		Sodium Metasilicate	6834-92-0													
		Tetrasodium EDTA	64-02-0													
Inland Technology	Teksol EP				0.77	<10	1.00		Insoluble @ 25C							No Data
		C10 - C11 Hydrocarbons	64742-48-9							n.l.	n.l.	>310	112 PMCC	0.6	7.0	
		d-limonene	5989-27-5													
QO Chemicals, Inc.	THFA								Complete	n.e.	n.e.	352	165 TOC	1.5	9.7	No Data
		Tetrahydrofurfuryl Alcohol	97-99-4	100	1.05	2.3@103F										

Appendix A Properties of Cleaners (Continued)

Supplier	Trade Name	Chemical Components	Acute Dermal LD50, mg/kg H<4,300	Acute Inhalation LC50, mg/m ³ H<10,000 ppm	Fish Toxicity 96 hr LC50, mg/L H<500 mg/L	Remarks	Hazards & Other Issues	Recommended Application	Recommended Application Methods	Alternate For	Cleaner Type
Air Products and Chemicals, Inc.	Surfynol 61 Surfactant	3,5-Dimethyl-1-hexyn-3-ol	1,000	19,000	Untested		Flammability				Alcohol
Air Products and Chemicals, Inc.	Surfynol 104 Surfactant	2,4,7,9-Tetramethyl-5-decyne-4,7-diol	1,000		Untested						Alcohol
Air Products and Chemicals, Inc.	Surfynol TG Surfactant	2,4,7,9-Tetramethyl-5-decyne-4,7-diol 1,2-Ethanediol	8,000 1,000		Untested	Contains ethylene glycol					Alcohol
Environmental Services Group	TASC	Sodium carbonate Sodium Metasilicate Tetrasodium EDTA	No data	No data	Untested	Powder - use 3 or 4 oz. per 5 gal. H ₂ O.		Machinery, floors, painted surfaces, metals	Parts washer, steam gun		Metasilicate
Inland Technology	Tekeol EP	C10 - C11 Hydrocarbons d-limonene	No Data	No Data	Untested		Flammability	Auto brakes, electronics, electrical		Chlorinated solvents	Hydrocarbon & Terpene
QO Chemicals, Inc.	THFA	Tetrahydrofurfuryl Alcohol	No Data	No Data	Untested						Alcohol

Appendix A Properties of Cleaners (Continued)

Supplier	Trade Name	Chemical Components	CAS No.	Composition %	Sp. Gr.	Vapor Pressure, mm HG	Volatiles kg/kg	pH	Solubility in Water	OSHA PEL, ppm	ACGIH TLV, ppm	Boiling Point, F	Flash Point, F H<140F	LFL, %	UFL, %	Acute Oral LD50, mg/kg H<5,000
Ciba-Geigy Corporation	* Tinuvin 622 LD		65447-77-0		1.18	4 x 10 (-5)@100C	0.005		Insoluble @ 25C			m.p. =131 to 158F	257			No Data
		Dimethyl Succinate Polymer								n.e.	n.e.	n. e.	n. e.			15,000
		4-Hydroxy-2,2,6,6-Tetramethyl-1-Piperidineethanol														
Titan Laboratories, Inc.	* Titan Gold Natural Solvent Cleaner & Degreaser				0.85	2			100%			330	142 (TCC)	0.7	6.1	
		None identified														
Titan Laboratories,	* Titan Green -- All Purpose Cleaner				1.04	ND	ND	12.7	Complete			213	None	None	None	No Data
		Ethylene glycol butyl ether	111762	4												
		EDTA	60004	1												
U. S. Polychemical	* Tropiclean				1.02		0.89					194	108 (CC)			No Data
		Isopropyl alcohol	67-63-0	2 to 5							400					
		Pentanol acetate isomers mixture	628-63-7	1							100					
		Monocyclic terpene hydrocarbons	5189-27-5	2 to 5							n.e.					
Uniclean Products, Inc.	* Uniclean VII				1.03	17			100%			200	None	None	None	No Data
		Glycol ethers	111-90-0	<5												
Universal Photonics, Inc.	* Uni-Clear Solvent				0.85	6	1.00		Insoluble			355	140 TCC			>5,000
		Unidentified solvents		100												
Inland Technology	* X-Caliber				0.92	<2	1.00		Very slight			370	155 (TCC)	1	N/A	No Data
		Limonene	5989-27-5		0.84											4,400
		Methylpyrrolidone	872-50-4		1.03							396	204 (OC)			4,200

Appendix A Properties of Cleaners (Continued)

Supplier	Trade Name	Chemical Components	Acute Dermal LD50, mg/kg H<4,300	Acute Inhalation LC50, mg/m ³ H<10,000 ppm	Fish Toxicity 96 hr LC50, mg/L H<500 mg/L	Remarks	Hazards & Other Issues	Recommended Application	Recommended Application Methods	Alternate For	Cleaner Type
Ciba-Geigy Corporation	* Tinuvin 622 LD		No Data	No Data	Untested; >100						Alcohol
		Dimethyl Succinate Polymer		1.1 mg/L							
		4-Hydroxy-2,2,6,6-Tetramethyl-1-Piperidineethanol									
Titan Laboratories, Inc.	* Titan Gold Natural Solvent C						Combustible				Unidentified
		None identified									
Titan Laboratories, Inc.	* Titan Green -- All Purpose C		No Data	No Data	Untested						Glycol ether
		Ethylene glycol butyl ether									
		EDTA									
U. S. Polychemical	Tropiclean		No Data	No Data	Untested		Flammable				Alcohol & terpene
		Isopropyl alcohol									
		Pentanol acetate isomers mixture									
		Monocyclic terpene hydrocarbons									
Uniclean Products, Inc.	Uniclean VII		No Data	No Data	Failed @ 100%						Glycol ether
		Glycol ethers									
Universal Photonics, Inc.	* Uni-Clear Solvent		>5,000	No Data		Attacks polyethylene, polystyrene		Remove wax, pitch from optical components		TCE, toluene, xylene	
		Unidentified solvents									
Inland Technology	X-Caliber		No Data	No Data	Untested	Very slow drying		Resins stripper		Methylene chloride	Terpene & NMP
		Limonene					Flammability				
		Methylpyrrolidone									

Appendix A Properties of Cleaners (Continued)

Supplier	Trade Name	Chemical Components	CAS No.	Composition %	Sp. Gr.	Vapor Pressure, mm HG	Volatiles kg/kg	pH	Solubility in Water	OSHA PEL, ppm	ACGIH TLV, ppm	Boiling Point, F	Flash Point, F H<140F	LFL, %	UFL, %	Acute Oral LD50, mg/kg H<5,000
Dow Chemical	* XUS 11289.01	Developmental Alkaline Cleaner			1.07	n.a.			Soluble			212	None			No Data
		Proprietary blend of surfactants and corrosion inhibitor in water														1,400
Dow Chemical	* XUS 11288.00	Developmental Alkaline Cleaner			1.07	=H ₂ O		12.0 to 13.5	Soluble			212	None			No Data
		Proprietary blend of alkylated imide		5 to 18												
		Alkylated aryl sulfonate		4 to 10												
		Alcohol ethoxylate		10 to 20												
		Sodium silicate		5 to 10												

Appendix A Properties of Cleaners (Continued)

Supplier	Trade Name	Chemical Components	Acute Dermal LD50, mg/kg H<4,300	Acute Inhalation LC50, mg/m ³ H<10,000 ppm	Fish Toxicity 96 hr LC50, mg/L H<500 mg/L	Remarks	Hazards & Other Issues	Recommended Application	Recommended Application Methods	Alternate For	Cleaner Type
Dow Chemical	* XUS 11269.01	Developmental	No Data	No Data	Untested						Surfactant
		Proprietary blend of surfactants and corrosion inhibitor in water									
Dow Chemical	* XUS 11288.00	Developmental	No Data	No Data	Untested						Alkaline
		Proprietary blend of alkylated imide									
		Alkylated aryl sulfonate									
		Alcohol ethoxylate									
		Sodium silicate									

TABLE B CONTACTS FOR ALTERNATIVE CLEANERS

Appendix B Suppliers of Alternative Cleaners

Supplier	Address	City	State	ZIP	Telephone	Contact Person	Trade Name	Cleaner Type	Tested by LLNL?
3M Co.	3M Center	St. Paul	MN	55144-1000	(800) 833-5045	Wayland Holloway	PF-5060	Perfluoro carbon	Yes
Air Products and Chemicals, Inc.					(800) 345-3148	L. G. Clarks	Surfynol 61 Surfactant	Alcohol	Yes
							Surfynol TG Surfactant	Alcohol	Yes
							Surfynol 104 Surfactant	Alcohol	No
Alconox, Inc.	9 E. 40th Street, #200	New York	NY	10016-0402	(212) 532-4040		Citranox	Amines & Surfactants	Yes
							Alconox	Detergent	Yes
							Liqui-Nox	Detergent	Yes
Bidall Co.		Milwaukee	WI	53224	(414) 355-4008		Natrasolve	Hydrocarbon	No
Bio Z Corp.		Half Moon Bay	CA		(415) 726-0300	Jerry Jackson	Bio Z	Enzyme & Surfactant	No
Brulin Corp.	P. O. Box 270	Indianapolis	IN	46206-0270	(800) 776-7149 (510) 828-6338	Dennis Zupan; Henry Bonsall	Brulin 1990GD	Unidentified	Yes
							Brulin 815GD	Detergent	Yes
							Brulin 815PCX	Ethanolamine	Yes
							Brulin Rosin-X	Ethanolamine & Glycol ether	Yes
							Brulin Safety Strip HT	Glycol ether	Yes
							Brulin SD 1291	Glycol ether	Yes
							MP 1793 (Initially called EXP1793)	Hydrocarbon	Yes
Castrol Industrial Central Inc.	630 W. Washington Blvd.	Chicago	IL	60606	(312) 454-1000		Castrol Kleen 3652	Ethanolamine	No
Church & Dwight Co.	P. O. Box CN5297	Princeton	NJ	08543-5297	(800) 824-0866	Robert Murphy	Armakleen E-2000	Unidentified	Yes
Ciba-Geigy Corporation	7 Skyline Drive	Hawthorne	NY	10532	(914) 785-2000		Tinuvin 622LD	Amine	No

Appendix B Suppliers of Alternative Cleaners (Continued)

Supplier	Address	City	State	ZIP	Telephone	Contact Person	Trade Name	Cleaner Type	Tested by LLNL?
Dow Chemical		Midland	M	48674			Primaclean 1000	Surfactant	No
							XUS 11269.01 Developmental Alkaline Cleaner	Alkaline	No
							XUS 11288.00 Developmental Alkaline Cleaner	Alkaline	No
Du Pont	1007 Market St.	Wilmington	DE	19898	(800) 441-9442/ (510) 930-0785	Phil Barton/ John Gardella	Axarel 32	Hydrocarbon & DBE	Yes
							DBE Solvent	DBE	Yes
							Axarel 38	Hydrocarbon & DBE	No
							Axarel 52	Hydrocarbon & DBE	No
							Axarel 6100	Hydrocarbon	No
Enviro Tech International		Alameda	CA		(510) 436-7603	Larry Clark	ART-210	Terpene	No
Environmental Technology	223 Hickman Drive	Sanford	FL	32771	(407) 321-7910		RB Degreaser	Unidentified	No
Envirosolv, Inc.	1840 Southside Blvd.	Jacksonville	FL	32216	(510) 796-9333 or (904) 724-1990	Mark Baker	Re-entry KNI Solvent - 2000	Terpene	Yes
							Re-entry RFS Solvent - 2000	Terpene	Yes
Exxon Chemical Americas	P. O. Box 3272	Houston	TX	77001	(713) 425-2115	James L. Schreiner	Actrel 1111L Cleaner	Hydrocarbon	No
							Actrel 3338L Cleaner	Hydrocarbon	No
							Actrel 4493L Cleaner	Hydrocarbon	No
Ford Technologies, Inc.	1515 W. MacArthur Blvd., #15	Costa Mesa	CA	92626			Nova Clean	Surfactant	No
Gaylord Chemical	P. O. Box 1209	Slidell	LA	70459-1209	(504) 649-5464	James Malone Sales Mgr.	DMSO (Dimethyl sulfoxide)	DMSO	Yes
Goode Chemical Co., Inc.	350 E. Orangethorpe #1	Placentia	CA	92670	(714) 993-3279		E. C. G. Marine	Alcohol	Yes

Appendix B Suppliers of Alternative Cleaners (Continued)

Supplier	Address	City	State	ZIP	Telephone	Contact Person	Trade Name	Cleaner Type	Tested by LLNL?
Graymills Corp.	3705 N. Lincoln Ave.	Chicago	IL	60613-3594	(312) 477-8673		Aquatene GM330	Glycol ether	No
							GM581	Caustic	No
Inland Technology	2621 Pacific Highway East	Tacoma	WA	98424	(800) 552-3100 or (206) 838-9869	Eric Lethe	Aero-Strip	Terpene & Methyl	Yes
							Citra Safe	Terpene	Yes
							EP-921	Terpene	Yes
							Skysol 500	Hydrocarbon & Terpene	Yes
							Teksol EP	Hydrocarbon & Terpene	Yes
							X-Caliber	Terpene	Yes
International Products Corp.	201 Connecticut Dr.	Burlington	NJ		(609) 386-8770		Micro	Detergent	No
Kyzen Corporation	413 Harding Industrial Dr.	Nashville	TN	37211	(800) 845-5524 or (615) 831-0889		Aquanox 101	Alcohol	Yes
							Metalnox PC1		No
LPS Laboratories, Inc.		Tucker	GA		(800) 241-8334		LPS Precision Cleaner	Glycol ether & silicate	No
Metalube Corp. (4U Products)	392 Jenks Dr.	Corona	CA	91720	(909) 279-9181		Multi-Purpose Cleaner-Degreaser	Unidentified	No
Mirachem Corp.	2107 E. Fifth St.	Tempe	AZ	85281-3034	(602) 966-3030		Mirachem 100		No
National Diagnostics, Inc.	1013-1017 Kennedy Blvd.	Manville	NJ	8835			Histo-Clear	Terpene	No
							Opticlear	Terpene	No
O.C.S. Manufacturing Inc.	429 Madera St.	San Gabriel	CA	91776	(818) 458-2471		OCS Electronics Cleaner H2002E	Glycol ether	Yes
O.C.S. Manufacturing Inc.	429 Madera St.	San Gabriel	CA	91776	(818) 458-2471		OCS Immersion Cleaner H2002	Glycol ether	No

Appendix B Suppliers of Alternative Cleaners (Continued)

Supplier	Address	City	State	ZIP	Telephone	Contact Person	Trade Name	Cleaner Type	Tested by LLNL?
Oakite Products, Inc.	50 Valley Road	Berkeley Heights	NJ	07922-2798	(800) 526-4473/ (908) 464-6900	Dennis Duncan	Oakite Aluminum Cleaner NST	Glycol ether, pyrophosphat	No
Omega Laboratories, Inc.	8732 Clay Road, Suite 103	Houston	TX	77080	(713) 462-3606		Citri Solve	Terpene	No
Penetone Co.	74 Hudson Ave.	Tenafly	NJ	7670	(201) 567-3000		Citrikleen	Terpene, amine & glycol	Yes
Petroform Inc.	5400 First Coast Hwy	Fernandina Beach	FL	32034	(904) 261-8286	Steven B. Hayes	Bioact EC-7 Semi-Aqueous Terpene Defluxer		No
							Bioact EC-7M Manual Terpene Defluxer		No
							Bioact EC-7R Semi-Aqueous Terpene Defluxer		No
							Bioact EC-Ultra Semi-Aqueous Defluxer		No
PURAC America, Inc.		Lincolnshire	IL		(708) 634-6330	Ron Cozijnsen	Purasolv BL; Purasolv ELS	Lactate ester	Yes
QO Chemicals, Inc.	P. O. Box 2500	West Lafayette	IN	47906	(800) 621-9521 or (317) 497-6100	Laura Dodge or Jim Williams	Furfuryl Alcohol (FA)	Alcohol	Yes
							Tetrahydrofurfuryl Alcohol (THFA)	Alcohol	Yes
Ramco Specialty Products	5956 State Road	Bakersfield	CA	93308	(800) 334-7071	Sandra Keena	Citra-Zapp	Terpene	Yes
							NC-300	Detergent	Yes
							SSD-92 Synthetic Solvent Degreaser	Detergent	Yes
							SSD-93 Synthetic Solvent Degreaser	Terpene	No
S. W. I. International Inc.	487 Division St.	Boonton	NJ	7005	(800) 334-2524 or (201) 334-2525	Michael Giacomantonio	Super Wash	Detergent	Yes
Spartan Chemical Co., Inc.		Toledo	OH		(800) 537-8990	Ron Afdal @ Skill Supply (510) 676-3478	All-Safe	Unidentified	Yes
Sunshine Chemical Specialties, Inc.	P. O. Box 540	Pennsauken	NJ	8110	(609) 488-1111		Natra Sol D. C. D.	Unidentified	Yes
Sunshine Makers, Inc.	15922 Pacific Coast Hwy.	Huntington Beach	CA	92649	(213) 592-2844		Simple Green	Surfactant & glycol ether	No

Appendix B Suppliers of Alternative Cleaners (Continued)

Supplier	Address	City	State	ZIP	Telephone	Contact Person	Trade Name	Cleaner Type	Tested by LLNL?
U. S. Polychemical Corp.	Route 45	Spring Valley	NY	10977	(800) 431-2072 or (914) 356-5530	Mark Paul	J.A.L.S.A.C.	Detergent	Yes
							Perfect Way 147	Terpene & glycol ether	Yes
							Polyspray Jet 790	Silicate	Yes
							Tropiclean	Alcohol & Terpene	Yes
							ASP #13L	Alcohol	No
U. S. Polychemical Corp.	Route 45	Spring Valley	NY	10977	(800) 431-2072 or (914) 356-5530	Mark Paul	ASP #1M	Alcohol	No
							Samson	Glycol ether	No
Ultra-Chem, Inc.	8043 Flint	Lenexa	KS	66214	(800) 451-0726	Chris Louie	Conquer	Glycol ether & sodium silicate	No
Uniclean Products, Inc.	3700 Osuna NE, Suite 703	Albuquerque	NM	87109	(505) 344-9673		Uniclean VII	Glycol ether	Yes
Universal Photonics, Inc.	495 W. John St.	Hicksville	NY	11801	(516) 935-4000		Uni-Clear Solvent	Unidentified	No