Engineering and Technical Services for Joint Group on Acquisition Pollution Prevention (JG-APP) Pilot Projects

Potential Alternatives Report HM-A-1-1

Alternatives to Chrome Conversion Coatings on Aluminum Alloys 2024, 6061, 7075, and Ion Vapor Deposited Aluminum on Steel

January 29, 1998

Contract No. DAAA21-93-C-0046
Task No. N.072
CDRL No. A004

Prepared by:
National Defense for Environmental Excellence (NDCEE)
Operated by Concurrent Technologies Corporation (CTC)

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TABLE OF CONTENTS

LIST OF FIGURES

Page

LIST OF TABLES

LIST OF APPENDICES

PREFACE

This report was prepared by Concurrent Technologies Corporation (*CTC*) through the National Defense Center for Environmental Excellence (NDCEE) under Contract Number DAAA21-93-C-0046. This report was prepared on behalf of, and under guidance provided by the Joint Group on Acquisition Pollution Prevention (JG-APP) through the Joint Pollution Prevention Advisory Board (JPPAB). The structure, format, and depth of this report's technical content were determined by the JPPAB, Hughes Missile Systems Company (HMSC), and government technical representatives in response to the specific needs of this project.

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Advanced Medium Range Air to Air Missile Program Office (AMRAAM)
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Air Force Materiel Command (HQ AFMC/DRIE)
Air Force Research Laboratory – Materials Laboratory
Air to Ground Missile Systems Program Office (AGMS)
Army Materiel Command, Headquarters (AMC HQ)
Chief of Naval Operation, Environmental Programs Division
Close Combat Anti-Armor Weapon System Program Office (CCAWS)
Comanche Program Office
Cruise Missile Program Office
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Defense Contract Management Command (DCMC)— Hughes, Tucson
Defense Contract Management District West (DCMDW/DACO)
Defense Logistics Agency, Headquarters (HQ DLA)
Hughes Missile Systems Company (HMSC)
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Lead Maintenance Technology Center for the Environment (LMTCE)
National Aeronautics and Space Administration (NASA)
National Defense Center for Environmental Excellence (NDCEE)
Naval Air Warfare Center—China Lake
Naval Air Warfare Center—Lakehurst
Naval Aviation Depot—Cherry Point
Naval Facilities Engineering Service Center (NFESC)
Navy Air Systems Command, Shore Station Management (NAVAIR Code AIR 8.0Y4)
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EXECUTIVE SUMMARY

Chrome conversion coating involves the treatment of a metal substrate with a chrome solution to produce an adherent coating. The metal substrate is changed to a layer of chromium salts to produce the desired decorative or functional properties. Chrome conversion coatings are used for three general purposes:

- Increase corrosion resistance
- Improve paint (primer) adhesion
- Minimize electrical resistance.

Although chrome conversion coating offers many advantageous coating properties, its use of hexavalent chromium is strictly regulated due to the compound's toxicity and suspected carcinogenicity. For this reason, manufacturers have begun to identify, evaluate, and implement acceptable alternatives for chrome conversion coating where feasible. These alternative technologies commonly generate less pollution than chrome conversion coatings and have fewer associated health and safety risks.

At the Hughes Missile Systems Company (HMSC), Tucson, Arizona, a Joint Group on Acquisition Pollution Prevention (JG-APP) project site, chrome in chemical conversion coatings was identified as a hazardous material of concern, and targeted for elimination or reduction. HMSC uses chrome conversion coatings in its production of tactical missile systems, and related equipment for use in air, land, and sea defense applications. The corresponding substrates that are coated at HMSC are aluminum alloys 2024, 6061, and 7075, and aluminum deposited on steel by ion vapor deposition.

This Potential Alternatives Report (PAR) provides an analysis of identified alternatives to chrome conversion coating and recommended alternatives for testing and possible implementation at HMSC.

Twenty potential alternatives to chrome conversion coatings were identified in November 1995 through literature searches and direct vendor queries. Four of these identified alternatives were classified as technically viable based on available information. These viable alternatives were Alodine 2000, Alumicoat 6788, Chrome-Free Conversion Coating (CFCC), and Sanchem FP. The environmental, safety, and occupational health characteristics of these viable alternatives were evaluated. In addition, the key process characteristics of these alternatives were compared to those of the existing process. As a result of the analyses, all four of these alternatives were classified as potential alternatives and chosen for testing in accordance with the approved *Joint Test Protocol for the Validation of Alternatives to Chrome Conversion Coatings for Aluminum Alloys 2024, 6061, 7075, and Ion Vapor Deposited Aluminum on Steel*, dated May 21, 1996. Test results are then reported in the *Joint Test Report for the Validation of Alternatives to Chrome Conversion Coatings for Aluminum Alloys 2024, 6061, 7075, and Ion Vapor Deposited Aluminum on Steel*.

1. INTRODUCTION

On September 15, 1994, the Joint Logistics Commanders (JLC) chartered the Joint Group on Acquisition Pollution Prevention (JG-APP) to coordinate joint service activities affecting pollution prevention issues identified during a defense system's acquisition process. The primary objectives of the JG-APP are to:

- Reduce or eliminate the use of Hazardous Materials (HazMats)
- Avoid duplication of efforts in actions required to reduce or eliminate HazMats through joint service cooperation and technology sharing.

The focus of JG-APP is on contractor design, manufacturing, and remanufacturing locations, with transfer of technology to the Sustainment Community.

To reduce HazMats, the JG-APP process first identifies the HazMat, related process, and affected substrates or parts at an original equipment manufacturer (OEM) facility. Details identified include equipment requirements; material and energy usage; waste and emission generation; environmental, safety, and occupational health (ESOH) issues; and capital and operating costs. This information is provided by the OEM and is documented in a Potential Alternatives Report (PAR) (refer to Section 2).

Identifying and selecting alternative processes that have the potential to reduce the identified HazMats can be a complicated task due to the fast pace at which new technologies emerge, and the ever-increasing volume of published and unpublished documentation. In the JG-APP process, a technology survey is performed to identify commercially available or near commercially available alternative technologies. The alternatives are identified through literature searches, electronic database searches, Internet searches, customized surveys, and/or personal and professional contacts. The technology survey, which is documented in the PAR, serves as a foundation for the remainder of the PAR and for selection of alternative processes (refer to Appendix A).

After reviewing technical and ESOH information in the technology survey, project-related U.S. Department of Defense (DoD) and OEM technical representatives select a shortened list of viable alternative technologies. The selection rationale and conclusions are documented in the PAR, and vendors of the selected technologies are contacted concerning their specific products. DoD and OEM technical representatives then select a shortened list of vendor products to be further considered, based on information in the PAR (refer to Section 3 and Appendix B).

The identified vendor products then undergo a more in-depth technical and preliminary ESOH analysis. The technical analysis includes determining how well the alternatives match the OEM's operations and future needs. Examples of evaluation criteria may include expected additional equipment, material and energy usage, waste and emission generation, and capital and operating costs (refer to Section 4). The preliminary ESOH analysis provides an initial qualitative assessment of viable alternatives, identifying conspicuous ESOH issues that may be a factor when selecting an alternative to the current process (refer to Section 5).

After reviewing the technical and ESOH analyses, DoD and OEM technical representatives jointly select potential alternatives for testing in accordance with the *Joint Test Protocol for the Validation of Alternatives to Chrome Conversion Coatings for Aluminum Alloys 2024, 6061, 7075, and Ion Vapor Deposited Aluminum on Steel,* dated May 21, 1996, developed for the OEM (refer to Section 6). Test results are reported in the *Joint Test Report for the Validation of Alternatives to Chrome Conversion Coatings for Aluminum Alloys 2024, 6061, 7075, and Ion Vapor Deposited Aluminum on Steel.*

This PAR has been developed for the Hughes Missile System Company (HMSC), Tucson, Arizona. At this site, chrome in chemical conversion coatings was identified as the target HazMat to be eliminated or reduced. HMSC uses chrome conversion coatings in its production of tactical missile systems and related equipment for use in air, land, and sea defense applications. Chrome conversion coatings are used to increase corrosion resistance, improve paint (primer) adhesion, and increase the resistance to corrosion while minimizing electrical resistance. The substrates involved are aluminum alloys 2024, 6061, and 7075, and aluminum deposited on steel by ion vapor deposition. Table 1 summarizes the target HazMat, process and material, applications, current specifications, affected programs, and candidate substrates.

Table 1. HMSC Target HazMat Summary

Target HazMat	Process/ Material	Applications	Current Specifications	Affected Programs	Candidate Substrates
Chrome - 7,850 lb/yr	Chemical Conversion Coatings	• Corrosion Resistance • Paint Adhesion • Electrical Resistance	MIL-C-5541 MIL-C-81706	Navy: Std Missile, Phalanx, RAM, Tomahawk Air Force: ACM, AMRAAM Army: TOW, Stinger	• Aluminum Alloys 2024, 6061, 7075 • Ion Vapor Deposition of Aluminum on Steel

2. BASELINE PROCESS

The present chrome conversion coating process used at the identified HMSC site is located in Building 814, which is also Air Force Plant 44. The process has eight steps, excluding part cleaning (aqueous clean and rinse), loading, and unloading. The following baseline information was provided by HMSC.

The current process used to provide low to moderate resistance to corrosion of aluminum surfaces is described in Military Specification (MIL SPEC) MIL-C-5541 (*Chemical Conversion Coatings on Aluminum and Aluminum Alloys*, issued November 30, 1990). This process involves applying a series of aqueous solutions to the metal parts. Some of these solutions contain chromated and other inorganic salts. A thin, nonelectrolytically formed, hydrated oxide gel is deposited on the metal surface. Treatment is restricted to nonelectrolytic methods, and materials used must be qualified to MIL-C-81706 (*Chemical Conversion Materials for Coating Aluminum and Aluminum Alloys*, issued November 13, 1979). A very important requirement in MIL-C-5541 is the corrosion resistance requirement of 168 hours of salt spray exposure. In addition, paint adhesion requirements and tests are given. Two classes of coatings are specified; one for maximum corrosion protection (Class 1A) and one where some electrical conductivity is required, i.e., for static discharge (Class 3).

HMSC has placed a high priority on replacing the chrome conversion coating process with a more environmentally benign process. Currently, the chrome conversion coating process lines are the largest, single source of hexavalent chromium emissions at both the Tucson, Arizona, and the El Segundo, California, operations of HMSC. Hexavalent chromium in significant percentages is found in both the deoxidizer and the chrome conversion baths of the process. Because hexavalent chromium is emitted from these baths, special health monitoring of process technicians must be performed regularly. In addition, yearly computerized plume modeling is required by local air and water quality regulations. Special handling and treatment of spent chrome baths is also required.

Besides the environmental, health, and safety disadvantages of the present chrome conversion coating process, there are some process-related drawbacks. Exposure to elevated temperatures reduces corrosion resistance of the hydrated amorphous gel coating formed by this process. Unpainted chrome conversion coatings will begin losing corrosion resistance properties if exposed to temperatures of 140^{o}F (60^{o}C) or above. This restricts subsequent drying processes especially for partially painted parts. Another process restriction is the time between the conversion coat treatment and the painting processes. Paint adhesion declines significantly if surfaces are not painted within 72 hours after the chrome conversion coating is applied.

2.1. Baseline Process Flow

The sequence of steps for the HMSC Iridite 14 chrome conversion coating process is shown in Figure 1.

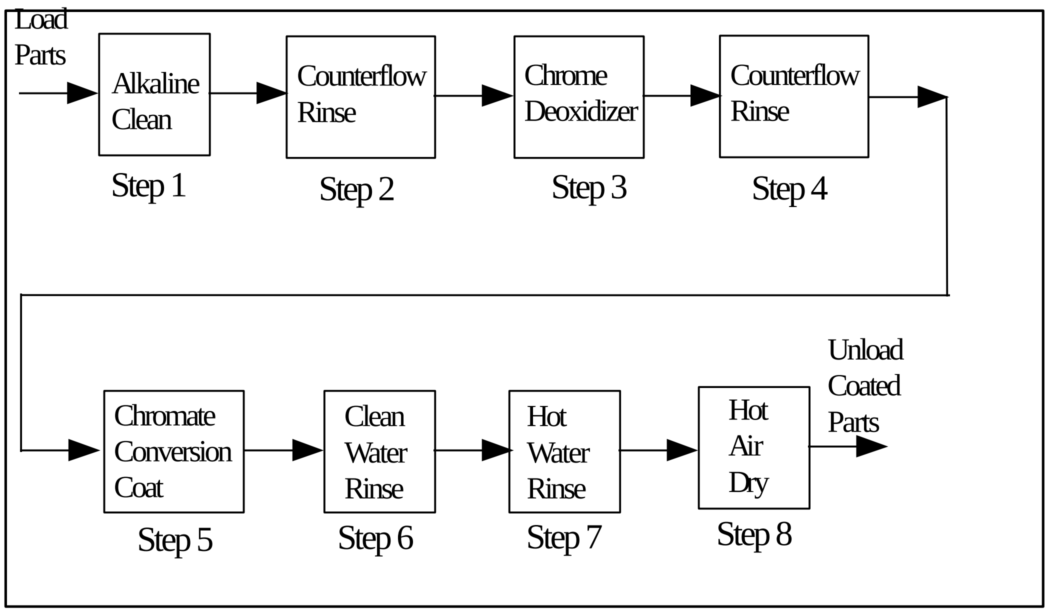

Figure 1. Flow of Baseline Chrome Conversion Coating Process

2.2. Baseline Process Description

All parts are initially degreased off-line in an automated Ransohoff Aqueous Cleaning System using W.R. Grace Daraclean 282. After precleaning, the parts are loaded onto the hoist. This process is automated and the coating of 2024, 6061, 7075, and 356 castings makes up the bulk of all work. Deionized water is used to make up the rinses and the process baths. Table 2 shows the specific operating parameters for each step of the process.

Table 2. Steps of Baseline Chrome Conversion Coating Process

Step No.	Description	Dwell Time (min)	Temperature
1	Alkaline Clean	10-12	150°F
2	Counterflow Rinse	0.5-1	Room Temp
3	Chrome Deoxidizer	8-10	Room Temp
4	Counterflow Rinse	0.5-1	Room Temp
5	Chrome Conversion Coat	0.75	Room Temp
6	Clean Water Rinse	0.5-1	Room Temp
7	Hot Water Rinse	0.5-1	130°F
8	Hot Air Dryer	As Required	130°F

The following describes each step of the current chrome conversion coating process.

1. *Alkaline Clean:* This is performed to remove all traces of organic contamination. Alkaline nonetch and etch (for special sequences) cleaners are used. For heat-treatable alloys to be cleaned by alkaline etching, an acid deoxidizer predip is used from 15 seconds to 2 minutes to ensure a uniform etch. Cleaner temperature and transfer time from cleaner to rinse is closely monitored to avoid drying the cleaner on the work surface before rinsing. The currently used cleaner is Parker Amchem's Ridoline 322.
2. *Counterflow Rinse:* Thorough rinsing after each processing step is essential. Clean, fresh water immersion rinses are used. A counterflow rinse process is used to control drag-out and evaporation, which can affect rinse water quality. After the cleaning and rinsing, the part should have a water break-free surface.
3. *Chrome Deoxidizer:* This removes metal oxides, leaving the surface chemically clean and receptive to chemical coating. When a nonetch alkaline cleaner is used, a chromic acid deoxidizer step is used for all heat-treated alloys, but is optional for nonheat-treated alloys and die castings. If the deoxidizer step is omitted, rinsing must be particularly thorough. When an alkali etch cleaner is used, a chromic acid deoxidizer for desmutting follows. For desmutting of alloys containing more than 1% silicon, a nitric-hydrofluoric acid mix is used.
4. *Counterflow Rinse:* This is the same as step 2, but uses separate tanks. Thorough rinsing before the chrome treatment step is essential.
5. *Chrome Treatment:* Alodine 1200 and Alodine 1500 are used for chrome treatment. The chrome bath is made up with deionized water. The concentration of active ingredients (primarily

hexavalent chromium) in the bath is maintained within ±10% of the initial value. The acidity (as measured by pH) of the bath must be maintained to produce uniform results. The final criterion for satisfactory bath performance is the property of the coating itself, particularly color, satisfactory adherence to the metal surface, freedom from powderiness, and performance, as indicated by a salt spray test.

6. *Clean Water Rinse:* This is the same as step 2.
7. *Hot Water Rinse:* The final rinse is hot, deionized water at a maximum temperature of 54°C (130°F). An adequate flow of water is maintained to prevent concentration of impurities by evaporation.
8. *Hot Air Dryer:* A conventional drying oven is used, and the chrome surface does not attain a temperature greater than 54°C (130°F) in the drying process.

2.3. Baseline Process Equipment

The current equipment is an automated, dual-hoist, U-shaped tank line. This multiple process line has 43 stations, each having a 450-gallon tank. Most of the tanks are made of 316 stainless steel. Some stations, like the alkaline cleaner and deoxidizer tanks, are dual stations with a capacity of 900 gallons per tank. There are three stations available for full-scale testing of non-chrome alternative processes. Two of these stations can be heated.

2.4. Baseline Material and Energy Usage

More than 24,000,000 square inches of parts are coated at this HMSC site in a typical year. The total material costs for the continuous chrome conversion coating process are approximately $18,000 per year. These costs include all the chemicals and other materials, except parts, needed to operate the process on a continuous basis. The total utilities and facility costs are approximately $88,000 per year. These costs include all electrical and closed-loop wastewater treatment costs.

2.5. Baseline Waste and Emissions Summary

This HMSC site has an ion exchange unit on the rinse water tanks to remove much of the chromium from the rinse water. After passing through the ion exchange unit, wastewater from the conversion coating line goes to a central water treatment facility for all HMSC facilities, and is then reutilized in a closed-loop system. Spent dip tank solutions are checked weekly and maintained at optimal performance. When solutions become contaminated to a degree that they cannot acceptably perform, the tank is dumped and refreshed. The dumped bath is disposed of as hazardous waste.

2.6. Environmental, Safety, and Occupational Health (ESOH) Status for the Baseline Process

Although chrome conversion coating offers many advantages, its use of hexavalent chromium is strictly regulated due to the compound's toxicity and suspected carcinogenicity. For example, regulations pursuant to the Clean Air Act (CAA), Clean Water Act (CWA), and the Resource Conservation and Recovery Act (RCRA) contain provisions regulating waste streams from metallic finishing operations that contain hexavalent chromium. The U.S. Environmental Protection Agency (EPA) also lists chromium as one of the 17 materials that are targeted for strict regulation. In addition, worker exposure to hexavalent chromium in the work place is regulated by the Occupational Safety and Health Administration (OSHA) because it can be harmful to workers who maintain and operate the treatment and rinse baths. Continued use of the chrome process carries a growing risk of workplace and environmental liability, along with increased costs for trucking inventories, monitoring emissions, and reporting usage of chromium compounds and resulting wastes. These regulatory driving forces are increasing manufacturing costs and hazardous material liability, leading industry to identify, evaluate, and implement acceptable alternatives for the chrome conversion coating.

2.6.1. Environmental Issues

The baseline chrome conversion coating process as described above contains many chemicals regulated, restricted, or otherwise listed by the U.S. EPA. The use of these chemicals requires environmental reporting, permits, fees, and/or other initiatives. The constituents of Ridoline 322, Isoprep 188, and Iridite 14, are the main sources of these chemicals that require EPA compliance.

Due to their toxicity, potassium dichromate (Isoprep 188) and chromic acid (Iridite 14) are listed as characteristic hazardous wastes (D007) under RCRA. The use of Daraclean 282 and Ridoline 322 does not appear to generate any RCRA hazardous wastes.

The CAA lists both potassium dichromate (Isoprep 188) and chromic acid (Iridite 14) as hazardous air pollutants (HAPs) under the general category of chromium compounds. Ridoline 322 contains 2-butoxyethanol, which is also listed as a HAP. While certain glycol ethers are regulated as HAPs under Section 112(b) of the CAA, the particular structure of the glycol ethers found in Daraclean 282 does not appear to be regulated. Classifying a stationary source as a "major" source depends upon the amount of HAPs emitted from that source.

The CWA lists 2-butoxyethanol as a pretreatment pollutant, trisodium phosphate as a hazardous substance, and potassium dichromate and chromic acid as toxic pollutants, priority pollutants, and hazardous substances. If discharged to a publicly owned treatment works (POTW), pretreatment pollutants, toxic pollutants, and priority pollutants must undergo pretreatment to ensure that their discharge is compatible with the capabilities of the POTW. In addition, toxic and priority pollutants must be treated before they can be directly discharged to receiving waters. Spills or other discharges of hazardous substances into navigable waters must be reported when the amount spilled exceeds the substance's reportable quantity. The use of Daraclean 282 does not appear to generate any regulated wastewaters.

EPA includes chromium compounds on the "33/50 Program" list of 17 high-priority chemicals targeted for strict regulation. Both Isoprep 188 and Iridite 14 are sources of chromium.

Section 313 of the Emergency Planning and Community Right-to-Know Act (EPCRA) lists glycol ethers (Daraclean 282), 2-butoxyethanol (Ridoline 322), potassium dichromate (Isoprep 188), and chromic acid (Iridite 14) as reportable on Toxic Release Inventory (TRI) reports.

The Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) lists 2-butoxyethanol, trisodium phosphate (Ridoline 322), potassium dichromate (Isoprep 188), and chromic acid (Iridite 14) as hazardous substances. Spills or other releases of these substances must be reported when the amount spilled exceeds the substance's reportable quantity.

2.6.2. Health and Safety Issues

OSHA has set Permissible Exposure Limits (PELs), and the American Conference on Governmental Industrial Hygienists (ACGIH) has set Threshold Limit Values (TLVs), for chemical hazards in the workplace. Table 3 lists those chemicals used in the baseline conversion coating process and their worker exposure limits.

Table 3. Chemicals in Baseline Conversion Coating Process and Worker Exposure Limits

Chemical	OSHA PEL	ACGIH TLV
Borax	None	5 mg/m^3
2-Butoxyethanol (Ethylene Glycol Monobutyl Ether)	50 ppm (Skin)	25 ppm (Skin)
Ethanolamine	3 ppm	3 ppm (TWA) 6 ppm (STEL)
Calcium Silicate	15 mg/m^3 Total 5 mg/m^3 Respirable	10 mg/m^3 Total
Potassium Dichromate	0.1 ppm as CrO_3 (Ceiling)	0.05 mg/m^3 as Cr(VI)
Potassium Fluoroborate	2.5 mg/m^3 as F	2.5 mg/m^3 as F
Chromic Acid	0.1 ppm as CrO_3 (Ceiling)	0.05 mg/m^3 as Cr(VI)

TWA = Time-Weighted Average concentration for a normal eight-hour workday
STEL = Short-Term Exposure Limit, defined as a 15-minute TWA exposure which should not be exceeded at any time during a workday

The chemicals used in the baseline conversion coating process were also examined for their potential adverse effects on human health.

- The glycol ethers used in Daraclean 282 are human neurotoxins and experimental animal teratogens, but not carcinogenic or genotoxic.
- Ridoline 322 contains no known or suspected human carcinogens or teratogens. However, borax, 2-butoxyethanol, and ethanolamine are reproductive toxicants in laboratory animals.
- Ethanolamine is a known human genotoxin, and mutation data has been reported for borax and trisodium phosphate.
- 2-Butoxyethanol and ethanolamine are known human neurotoxins.
- Isoprep 188 contains no known or suspected human neurotoxins or teratogens. However, potassium dichromate is an experimental animal teratogen and a known human carcinogen and genotoxin.
- Mutation data has been reported for sodium bisulfate.
- Iridite 14 contains no known or suspected human neurotoxins or teratogens. However, chromic acid is an experimental animal teratogen and a known human carcinogen and genotoxin.

Ventilation is required to maintain airborne contaminants below the PELs and TLVs. In addition, personal protective equipment is required, such as eye goggles or face shields, neoprene or polyvinyl gloves, appropriate protective clothing, and a dust filter mask or respirator.

2.7. Baseline Capital and Operating Costs

A cost-benefit analysis (CBA) methodology was developed and used to capture costs of the current chrome conversion coating process. The CBA established the baseline for those operations affected by the possible non-chrome conversion coating alternatives.

A new Environmental Life-Cycle Cost Analysis Tool (ELCCAT) developed by Hughes Environmental Systems, Inc. was used to conduct this evaluation. The process line for the HMSC chrome conversion coating was used to provide actual data on typical production costs. Extensive data was collected on the current process, including operating and environmental costs. Information was collected on every part processed through the chrome conversion coating line at the Tucson facility covering the two-year period from January 1994 to December 1995. Process times, labor, material, and equipment costs, and costs pertaining to hazardous waste generation were obtained.

Table 4 provides life-cycle costs for the current chrome process. This table illustrates the various cost categories considered by the ELCCAT model in developing the actual as well as collected costs. Projected values were determined by first establishing costs on a per unit area of part basis. Annual costs were then determined by multiplying the per unit area costs for each factor considered by the total surface area of all parts processed during a typical year. The results indicate that the current chrome process costs approximately $420,000 on an annual basis.

The costs provided here are unique to the HMSC manufacturing operation. Environmental regulations in some areas will differ. Also, the extensive wastewater reclamation and recycling capability of the HMSC operations may not be necessary elsewhere. Factors such as these would tend to result in a different life-cycle cost for other sites.

Table 4. Annual Costs for Baseline Chrome Conversion Coating

Category	Cost (dollars/year)
Equipment	110,000
Utilities/ Facilities	88,000
Material	18,000
Labor	94,000
Hazardous Waste	27,000
Wastewater	86,000
TOTAL	420,000

The cost impact of the use of chrome conversion coating on the DoD Sustainment Community is difficult to estimate without conducting a thorough analysis. Due to chrome's strength in resisting corrosion, very little depot repair is required. System inspections can take place every six, eight, or ten years depending on system requirements. Touch-up and repair is simple using a brush-on method of applying the conversion coating. The use of a self-contained "high-lighter" containing chrome conversion coating for touch-up areas has dramatically reduced waste and possible worker exposure to chemicals doing maintenance and repair. Therefore, from the strict viewpoint of labor and operating costs, chrome conversion coating can be an inexpensive way of providing lasting corrosion resistance for parts not directly exposed to the environment. It also represents a way for improving paint adhesion on parts that will be exposed. However, if the life-cycle costs and future liability of chrome conversion coating on the Sustainment Community were evaluated, it is anticipated that the process would reveal itself to be expensive.

3. IDENTIFIED ALTERNATIVES AND PRELIMINARY SCREENING

To identify alternatives to chrome conversion coatings, Concurrent Technologies Corporation (*CTC*) was tasked to perform a technology survey. Alternatives were desired that could pass one or more of the corrosion resistance or contact-electrical resistance performance requirements of MIL-C-5541 or MIL-C-81706 for Class 1A or Class 3 coatings. Nine commercially available or near-commercially available alternative technologies were identified through a technology survey. The results of this survey are detailed in Appendix A and summarized in Section 3.1.

Vendors of these alternative technologies were identified, and vendor product information was obtained for 20 available products in November 1995. Vendor product information is provided in Appendix B and summarized in Section 3.2. Further screening of these products was conducted to refine the list to those that appeared most viable, as listed in Table 5 below. A discussion of the screening process is presented in Section 3.3.

Table 5. Most Viable Alternatives to Chrome Conversion Coating

Product	Technology	Company
Alodine 2000	Cobalt-Based Coating	Parker Amchem
Alumicoat 6788	Proprietary Technique	Elf Atochem
Chrome-Free Conversion Coating (CFCC)	Proprietary Technique	Hughes Aircraft Company
Sanchem FP (Full Process)	Manganese Oxide Film	Sanchem

These viable alternative products were selected by DoD and OEM technical representatives to undergo further evaluation (refer to Sections 4 and 5). The following sections explain how these products were selected.

3.1. Alternative Technology Selection

Nine commercially or near-commercially available alternative technologies were identified in the technology survey, as summarized in Table 6. The selection of these technologies was based on an evaluation of historical test results, and experience from DoD and OEM technical representatives. Additional information regard these technologies is provided in Appendix A.

Table 6. Identified Alternative Technologies to Chrome Conversion Coating

Alternative Technology	Reference Section in Appendix A
Sol-Gel Coatings	A.2.1
Fluorozirconium Coatings	A.2.2
Cobalt-Based Coatings	A.2.3
Rare Earth Metal Salts	A.2.4
Manganese Oxide Films	A.2.5
Fluotitanic Coatings	A.2.6
Talc Coatings	A.2.7
Anodizing	A.2.8
Proprietary Techniques	A.2.9

A brief description of each alternative technology is provided below.

Sol-Gel technology uses polymers or metal oxides either alone or mixed to form complexes by the hydrolysis of appropriate precursor compounds. Sol-Gels can form powders or thin films that inhibit corrosion on substrates.

Fluorozirconium coating technology uses complexed transition metal salts to create a thin film on a substrate material similar to a conversion coating. Specifically, zirconium is mixed with fluorine to create fluorozirconium, which reacts with the part surface to form a coating.

Cobalt-based coatings use cobalt and molybdenum to treat substrate materials. The coatings created are low in electrical resistance and are good for corrosion resistance.

Rare Earth Metal (REM) salts may be applied by heated immersion to create protective layers on substrate materials. REMs provide corrosion resistance by producing a protective oxide film.

Potassium permanganate solutions can be used to create manganese oxide films on substrates. Manganese oxide films resulting from potassium permanganate treatment closely match the corrosion resistance of traditional chromic oxide films used in conversion coatings. Potassium permanganate coatings are very effective in protecting aluminum alloys.

Fluotitanic coatings, deposited from acid solutions with organic polymers, require few process steps, and can usually be done at ambient temperatures. Although these coatings have been widely used in a variety of applications, they have not been used in the aerospace industry.

Talc coatings, which are typically applied to aluminum substrates, are resistant to corrosion. These polycrystalline coatings are applied by precipitating aluminum-lithium compounds and other anions in an alkaline salt solution.

Anodizing is a process in which a metal surface is converted to an oxide layer, producing a tough, adherent surface layer. A thick oxide layer can be produced by immersing a part in an electrolytic solution and passing an electrical current through it, similar to electroplating. Then, by placing the part in boiling water, the film's pores can be sealed. As a result, the oxide changes from one form to another.

Proprietary techniques to replace chrome conversion coatings are available commercially, or are in a final development stage. Since these techniques are kept secret, little is known about the chemical or physical changes that occur in the processing. Historical data shows that these techniques have significant value. Because they are available for general use as possible alternatives to chrome conversion coatings, they were identified as alternatives.

3.2. Product Identification

After the nine alternative technologies were selected, commercially or near-commercially available alternative products associated with the technology categories were identified as part of the technology survey. Twenty alternative products to chrome conversion coatings were identified in November 1995, as shown in Table 7 below. Information collected and evaluated during the survey indicated that these alternative coatings and processes commonly generate less pollution than chrome conversion coating, and have less health and safety risks associated with them.

Table 7. Identified Alternative Products to Chrome Conversion Coatings

	Product	Manufacturer/Distributor	Technology
1	Aeroglaze	Lord Corporation	Sol-Gel Coatings
2	Alcoat 1470	Circle-Prosco, Inc.	Fluorozirconium Coatings
3	Alcoat 3000	Circle-Prosco, Inc.	
4	Alcoat 4000	Circle-Prosco, Inc.	
5	Alcoat 5000	Circle-Prosco+669, Inc.	
6	Alodine 2000	Parker Amchem	Cobalt-Based Coatings
7	Ce-Mo 6061	University of Southern California	Rare Earth Metal Salts
8	Patclin 1910B	Patclin Chemical Company, Inc.	Manganese Oxide Films

(Table 7 continued on next page)

Table 7. Identified Alternatives Products to Chrome Conversion Coatings (Continued)

	Product Name	Manufacturer/Distributor	Technology
9	Sanchem FP (Full Process)	Sanchem	Manganese Oxide Films
10	Permatreat 611	Betz Laboratories	Fluotitanic Coatings
11	Sandia 1	Sandia National Laboratories	Talc Coatings
12	Sandia 2	Sandia National Laboratories	
13	Sulfuric-Boric Acid Anodizing	Boeing Aerospace Corporation	Anodizing
14	Alumitec	Alumitec Products Corporation	
15	Alumicoat 6788	Elf Atochem -- Turco Products Division	Proprietary Techniques
16	Chemcote L497260A	Brent America, Inc.	
17	Chrome-Free Conversion Coating (CFCC)	Hughes Aircraft Company	
18	E-CLPS 923	Bulk Chemicals, Inc.	
19	E-CLPS 923X	Bulk Chemicals, Inc.	
20	Turco 2438-28D	Elf Atochem -- Turco Products Division	

To provide a basis for determining which of these products may be most viable, technical, environmental, health, safety, and market information was collected on each of the alternatives during the technology survey. This information is summarized in Table 8, and briefly discussed below. (A more detailed description of each product, including historical test results and associated environmental, health, and safety concerns for each identified product, is presented in Appendix B.).

3.2.1 Technical Criteria

In MIL-C-5541 and MIL-C-81706, two classes of coatings are discussed. Class 1A coatings are for maximum corrosion resistance with or without paint. Class 3 coatings are for corrosion resistance that has a contact electrical resistance requirement. For Class 1A coatings, there are two significant differences between MIL-C-5541 and MIL-C-81706. For corrosion resistance, MIL-C-5541 requires a 168-hour salt spray test, and MIL-C-81706 requires a 336-hour salt spray test. For paint adhesion, MIL-C-81706 requires both the wet tape test and the knife test while MIL-C-5541 only requires the wet tape test. Class 3 coatings in both specifications require the contact electrical resistance test and a 168-hour salt spray test for corrosion resistance.

In Table 8, an indication is provided whether an alternative passed or failed a particular military specification to which it was tested. An alternative is listed as “passed” if the required alternative passed all the performance requirements in the listed military specification and coating class. Special notes are given for alternatives that were not tested according to the specification.

3.2.2. Environmental Criteria

The results of the environmental review performed by the technical representatives are shown in Table 8. A product is noted as having “passed” environmental regulatory criteria if it contained no constituents that are banned, or scheduled to be banned, by the EPA. No alternatives identified in this report contained banned substances; therefore, all products passed this screening criterion.

3.2.3. Health and Safety Criteria

Material safety data sheets (MSDSs) were reviewed to determine whether any constituent or agent (part of an alternative product) has been identified in *Sax’s Dangerous Properties of Industrial Materials* as a known or suspected human carcinogen, genotoxin, teratogen, or neurotoxin. A product was deemed to have “failed” health and safety criteria if it exhibited any of these health hazards. As shown in Table 8, 10 of the 20 alternatives passed the health and safety criteria. Although a constituent (and the corresponding product) may be considered “toxic” by the above criteria, the hazard it presents (a function of toxicity and exposure) can be mitigated through exposure controls.

3.2.4. Commercial Availability

Sixteen of the identified products are commercially available, as indicated in Table 8.

Table 8. Key Characteristics of the Identified Chrome Conversion Coating Alternatives

Product	Technical Criteria: Class 1A Requirement MIL-C-5541	Technical Criteria: Class 1A Requirement MIL-C-81706	Technical Criteria: Class 3 Requirement	Environmental Criteria	Health and Safety Criteria[a]	Commercially Available[b]
Aeroglaze Sol-Gel	Failed	Failed	Passed[c]	Passed	Failed	Yes
Alcoat 1470	Failed	Failed	Failed	Passed	Passed	Yes
Alcoat 3000	Failed	Failed	Failed	Passed	Passed	Yes
Alcoat 4000	Failed	Failed	Failed	Passed	Passed	Yes
Alcoat 5000	Failed	Failed	Passed[c]	Passed	Passed	Yes
Alodine 2000	Passed	Passed	Passed[c]	Passed	Failed	Yes
Alumicoat 6788	Passed	Failed	Failed	Passed	Failed	Yes
Alumitec	Passed[d]	Passed[d]	Failed	Passed	Failed	Yes
Ce-Mo 6061	Failed	Failed	Failed	Passed	Failed	Yes
Chemcote L497260A	Failed	Failed	Passed[c]	Passed	Failed	Yes
CFCC	Passed	Passed	Passed	Passed	Failed[e]	No
E-CLPS 923	Failed	Failed	Failed	Passed	Passed	Yes
E-CLPS 923X	Failed	Failed	Failed	Passed	Passed	Yes
Patclin 1910B	Failed	Failed	Failed	Passed	Passed	Yes
Permatreat 611	Failed	Failed	Failed	Passed	Passed	Yes
Sanchem FP	Failed	Failed	Failed	Passed	Passed	Yes
Sandia 1	Failed	Failed	Failed	Passed	Failed	No
Sandia 2	Failed	Failed	Failed	Passed	Failed	No
SBAA	Passed	Passed	Failed	Passed	Failed	Yes
Turco 2438-28D	Failed	Failed	Passed[c]	Passed	Passed[e]	No

[a] A “Failed” in this category means the product contains constituents determined to be known or suspected toxins based on available literature.
[b] As of November 1995
[c] The coating passed pre-salt spray contact electrical resistance tests; however, the military specification was not followed for post-salt spray tests.
[d] Passed salt spray tests only. No wet tape test was performed.
[e] Compound is not commercially available and compound constituents are proprietary property.

3.3. Preliminary Technical Screening of Identified Alternatives

The technical representatives for the HMSC JG-APP site determined that it would not be feasible to conduct complete JTP testing and analysis for all 20 identified alternatives. Therefore, the alternatives underwent a multiple-step, initial screening process by the technical representatives to reduce the number of alternatives to be tested. The information used as a basis for this preliminary screening is presented in Table 9, and is discussed in this section.

The *Joint Test Protocol for the Validation of Alternatives to Chrome Conversion Coatings for Aluminum Alloys 2024, 6061, 7075, and Ion Vapor Deposited Aluminum on Steel (JTP),* dated May 21, 1996, contains the requirements for three groups of chemical conversion coatings. Each group corresponds to one of the three general uses of chemical conversion coatings. The three groups are:

- Group 1: Unpainted surfaces requiring maximum corrosion resistance
- Group 2: Painted surfaces requiring maximum primer-to-substrate adhesion
- Group 3: Unpainted surfaces requiring lower electrical resistance.

According to the JTP, Group 1 coatings must pass the corrosion resistance test (336-hour salt spray); Group 2 must pass the paint adhesion test (wet tape value of 5); and Group 3 must pass the contact electrical resistance test (less than 5 milliohms/in^2 resistance as applied). The results obtained for these three critical tests were reviewed in detail and used to prescreen the identified alternatives. A summary of this existing data is presented in Table 9.

The DoD and HMSC technical representatives agreed that the primary objective was to identify and validate a chrome-free conversion coating that could be used on all affected production programs; one alternative would need to work on all substrates and meet all performance requirements. Therefore, alternatives shown by historical tests results to have passed all three tests were most desirable. As shown in Table 9, few alternatives previously passed the 336-hour test for salt spray corrosion resistance, and in most cases passed for just one alloy. None of the identified processes met the performance criteria for all alloys and all tests. (Ion vapor deposition of aluminum on steel had not been previously tested as a substrate with these alternative coatings.)

Using the historical test data, the technical representatives selected the top seven most-promising alternative processes for further consideration. These alternatives were:

1. Alcoat 4000
2. Alodine 2000
3. Alumicoat 6788
4. Allumitec
5. Chemcote L497260A
6. CFCC
7. SBAA.

A summary of the test results for the seven alternatives is shown in Table 10, along with results for the baseline conversion coating process (Alodine 600), for comparison. Although none of the selected alternatives met all the JTP criteria, neither did the baseline process. Therefore, for the purposes of prescreening, the requirement of passing all three tests on all three substrates was dropped.

After selecting the seven alternatives, a further evaluation of these alternatives was conducted by the technical representatives, which involved a closer examination of the prior performance data and the relative ease of process implementation (i.e., "drop in" replacement). As a result of this analysis, four alternatives (Alcoat 4000, Alumitec, Chemcote L497260A, and SBAA) were dropped from further consideration, and one product, Sanchem FP, was added to the list of alternatives. The following subsections of this PAR discuss this further evaluation of the seven screened alternatives, plus the Sanchem FP product.

Table 9. Chrome Conversion Coating Alternatives – Existing Performance Data

Product									
	JTP Criteria								
	≥336			5			≤5		
	Aluminum Alloy								
	2024	**6061**	**7075**	**2024**	**6061**	**7075**	**2024**	**6061**	**7075**
Aeroglaze Sol-Gel	24	168	24	0	0	0	41.5	0.23[b]	3.49
Alcoat 1470	48	168	24	0	0	0	597	9.93	909
Alcoat 3000	24	168	24	4	5	5	901	8.00	238000
Alcoat 4000	24	336	24	4	3	3	1820	3800	266
Alcoat 5000	24	24	24	3	3	3	807	1.88[b]	296
Alodine 2000	168	336	240	5	3	3	764	2.08[b]	1740
Alumicoat 6788	240	1008	1008	5	5	5	3130	2640	737
Alumitec	>816	N.T.	N.T.	N.T.	N.T.	N.T.	N.T.	174	N.T.
Ce-Mo 6061	24	24	24	3	5	5	1400	1.60	66.0
Chemcote L497260A	24	504	24	5	4	5	9.45	0.43[b]	4.70
CFCC	≥336	264	432	5	5	5	N/T	57	N/T
E-CLPS 923	24	24	24	4	5	3	3.55	0.77	29.6
E-CLPS 923X	24	24	24	5	3	5	6.10	0.40	7.9
Patclin 1910B	24	24	24	4	1	4	13.1	1.68	38.0
Permatreat 611	24	24	24	5	5	5	37.2	0.54	253
Sanchem FP	24	24	24	4	5	5	24.4	1.31	55.0
Sandia 1	24	24	24	3	4	3	3.84	0.48	3.98
Sandia 2	24	168	24	3	3	3	2370	7.16	529000
SBAA	>336	N.T.	>336	5	N.T.	5	N.T.	> 5	N.T.
Turco 2438-28D	96	240	48	0	0	0	22900	1.53[b]	839

[a] Reference MIL-C-5541 and MIL-C-81706
[b] The coating passed pre-salt spray contact electrical resistance tests; however, standard procedures were not followed for post-salt spray tests.
N.T. = Not Tested

Table 10. Screened List of Alternative Products

	Product	Corrosion Resistance (Hours of Salt Spray)			Paint Adhesion (Scale 1-5)			Contact Elec. Resistance (milliohms/in^2)		
		JTP Criteria								
		≥336			5			≤5		
		Aluminum Alloy								
	Baseline	**2024**	**6061**	**7075**	**2024**	**6061**	**7075**	**2024**	**6061**	**7075**
	Alodine 600	336	1008	1008	4	5	4	2.07	0.61	19.7
	Alternative									
1	Alcoat 4000	24	336	24	4	3	3	1820	3800	266
2	Alodine 2000	168	336	240	5	3	3	764	2.08	1740
3	Alumicoat 6788	240	1008	1008	5	5	5	3130	2640	737
4	Alumitec	>816	N.T.	N.T.	N.T.	N.T.	N.T.	N.T.	174	N.T.
5	Chemcote L497260A	24	504	24	5	4	5	9.45	0.43	4.70
6	CFCC	≥336	264	432	5	5	5	N.T.	57	N.T.
7	SBAA	>336	N/T	>336	5	N.T.	5	N.T.	N.T.	N.T.

N.T. = Not Tested

3.3.1. Alcoat 4000

Alcoat 4000 by Circle-Prosco Inc. is a simple “drop-in” replacement. This alternative is being used at Chrysler to coat heat exchangers. Though this alternative met the 336-hour requirement for 6061 aluminum, it failed corrosion resistance on the other alloys. Neither paint adhesion nor contact electrical resistance test results were favorable. Because this alternative has shown poor performance in the past, it is not being considered for further review. Table 11 shows the historical test results for Alcoat 4000.

Table 11. Historical Test Results for Alcoat 4000

Test	Salt Spray (hours)	Wet Tape Adhesion	Contact Elec. Resistance (milliohms/in^2)
Passing Value	≥336	5	≤5
Alloy 2024	24	4	1,820
Alloy 6061	336	3	3,800
Alloy 7075	24	3	266

3.3.2. Alodine 2000

Alodine 2000 by Parker Amchem uses chromic acid in the etching step. However, materials other than chromic acid can be used to etch aluminum. One example is Deoxalum 2200 by Parker Amchem, in which nitric acid is the main component. By using Deoxalum 2200 to etch, chrome is eliminated. Thus, the inclusion of Deoxalum 2200 makes the Alodine 2000 process more environmentally friendly, while still maintaining equivalent coating performance. For these reasons, Alodine 2000 was retained for further consideration. Table 12 shows the historical test results for Alodine 2000.

Table 12. Historical Test Results for Alodine 2000

Test	Salt Spray (hours)	Wet Tape Adhesion	Contact Elec. Resistance (milliohms/in^2)
Passing Value	≥336	5	≤5
Alloy 2024	168	5	764
Alloy 6061	336	3	2
Alloy 7075	240	3	1,740

3.3.3. Alumicoat 6788

Elf Atochem's Alumicoat 6788 is considered a "drop-in" type replacement coating. Alumicoat 6788 has very good paint adhesion characteristics, and resists corrosion on 6061 and 7075 aluminum alloys very well. However, performance on 2024 aluminum falls short and the coating's contact electrical resistance characteristics are very poor for a Group 3 coating. Despite its shortcomings, the DoD and HMSC technical representatives recommended additional testing of Alumicoat 6788 to verify historical results and to evaluate process improvements by Elf Atochem. Table 13 shows the historical test results for Alumicoat 6788.

Table 13. Historical Test Results for Alumicoat 6788

Test	Salt Spray (hours)	Wet Tape Adhesion	Contact Elec. Resistance (milliohms/in^2)
Passing Value	≥336	5	≤5
Alloy 2024	240	5	3,130
Alloy 6061	1,008	5	2,640
Alloy 7075	1,008	5	737

3.3.4. Alumitec

Alumitec is marketed by Alumitec Products Corporation. These coatings are actually sealers to be used with anodizing. For example, Sulfuric-Boric Acid Anodize could use these sealants (see Section 3.3.8 for SBAA). This alternative has not been tested as extensively as the other screened alternatives. In addition, this type of coating cannot independently meet requirements without the aid of anodizing. Therefore, for these reasons it was deleted from the list of alternatives. Table 14 shows the historical test results for Alumitec.

Table 14. Historical Test Results for Alumitec

Test	Salt Spray (hours)	Wet Tape Adhesion	Contact Elec. Resistance (milliohms/in^2)
Passing Value	≥336	5	≤5
Alloy 2024	816	N.T.	N.T.
Alloy 6061	N.T.	N.T.	174
Alloy 7075	N.T.	N.T.	N.T.

N.T. = Not Tested

3.3.5. Chemcote L497260A

Brent America's Chemcote L497260A quickly failed salt spray tests for 2024 and 7075 alloys, and paint adhesion for 6061. It was also considered undesirable because it requires the use of proprietary cleaners and etchants in addition to the proprietary deoxidation and conversion coating chemicals. For these reasons, Chemcote L487260A was not retained for further consideration. Table 15 shows the historical test results for Chemcote L497260A.

Table 15. Historical Test Results for Chemcote L497260A

Test	Salt Spray (hours)	Wet Tape Adhesion	Contact Elec. Resistance (milliohms/in^2)
Passing Value	≥336	5	≤5
Alloy 2024	24	5	9.45
Alloy 6061	504	4	0.43
Alloy 7075	24	5	4.7

3.3.6. Chrome-Free Conversion Coating (CFCC)

Hughes Aircraft Company has developed the Chrome-Free Conversion Coating (CFCC). An agreement between Hughes and the federal government for royalty-free usage of the proprietary process is being considered.

Previous testing of the coating showed that CFCC passed the 336-hour requirement on 2024 and 7075 aluminum alloys, but it only lasted 264 hours on 6061 aluminum. Presently, this alternative has marginal corrosion resistance performance, and improvements are needed before it can meet the 336-hour minimum requirements. Because progress was being made by HMSC in optimizing the process, CFCC was recommended for further testing. Table 16 shows the historical test results for CFCC.

Table 16. Historical Test Results for CFCC

Test	Salt Spray (hours)	Wet Tape Adhesion	Contact Elec. Resistance (milliohms/in^2)
Passing Value	≥336	5	≤5
Alloy 1100	≥168	5	N.T.
Alloy 2024	≥336	5	N.T.
Alloy 6061	264	5	57
Alloy 7075	432	5	N.T.

N.T. = Not Tested

3.3.7. Sanchem FP (Full Process)

Although the findings of the technology survey indicated relatively poor performance of Sanchem FP, Air Force engineers indicated that they have had significant success with this alternative. As a result of these technical discussions, Sanchem FP was added to the list of alternatives for further consideration. Table 17 shows the historical test results for Sanchem FP.

Table 17. Historical Test Results for Sanchem FP

Test	Salt Spray (hours)	Wet Tape Adhesion	Contact Elec. Resistance (milliohms/in^2)
Passing Value	≥336	5	≤5
Alloy 2024	24	4	24.4
Alloy 6061	24	5	1.31
Alloy 7075	24	5	55

3.3.8. Sulfuric-Boric Acid Anodizing (SBAA)

Sulfuric-Boric Acid Anodizing (SBAA), patented by the Boeing Aerospace Corporation, provides good corrosion and paint adhesion. However, the tough oxide layer has difficulty passing the contact electrical resistance requirement. It is believed that with some minor adjustments to dwell time, this requirement could be met. Because this process is electrolytic, it is not considered a viable alternative to the non-electrolytic chrome conversion coatings. Therefore, this alternative was dropped from further consideration. Table 18 shows the historical test results for SBAA.

Table 18. Historical Test Results for SBAA

Test	Salt Spray (hours)	Wet Tape Adhesion	Contact Elec. Resistance (milliohms/in^2)
Passing Value	≥336	5	≤5
Alloy 2024	>336	5	N.T.
Alloy 6061	N.T.	N.T.	>5
Alloy 7075	>336	5	N.T.

N.T. = Not Tested

3.3.9. Summary

As a result of the more detailed technical review of the screened alternatives, four alternatives — Alodine 2000, Alumicoat 6788, CFCC, and Sanchem FP — were deemed *viable alternatives*, and were recommended for further evaluation (see Table 19).

Table 19. Viable Alternatives to Chrome Conversion Coating

Product	Company
Alodine 2000	Parker Amchem
Alumicoat 6788	Elf Atochem
CFCC	Hughes Aircraft Company
Sanchem FP	Sanchem

Because of the limited scope of this screening, it is understood that this assessment may not reveal every possible deficiency or hazard. *CTC* assumes no responsibility for the safe operation and maintenance of the manufacturing technology or for any environmental, safety, and occupational health hazards or releases resulting from operation and maintenance of the alternative manufacturing technology.

4. PROCESS DESCRIPTIONS FOR VIABLE ALTERNATIVES

In further evaluating the alternatives to chrome conversion coating, it was necessary to identify differences in the operating conditions of the alternative processes as compared to the baseline process. For example, differences in the number of processing steps, dwell times, and operating temperatures, as well as material and energy usage, are important to document and consider. More detailed process information was generally unavailable for the alternatives because such data varies from facility to facility. However, as discussed below, fundamental information about each of the viable alternatives was obtained for comparison.

All the viable alternatives use dip tanks, and therefore, would be expected to use essentially the same type of processing equipment as the current coating process. The number of steps is important because each step represents another dip tank in the production line, which translates to higher capital equipment costs for implementation. The number of steps is also an indicator of the processing time, especially because part handling is frequently the major portion of the overall cycle time. Temperature is also important because the lower the processing temperatures, the less material and energy use during sustained operations (all things being equal). This translates into lower operating costs. Finally, rework is an important part of any production line. Without a developed method of touching up parts, the process could be impractical for field use. The existence of a touch-up method is also an indicator of how well the process has been developed. A summary of the key process parameters for each of the viable alternatives is shown in Table 20.

Table 20. Process Parameters for Viable Alternatives

	Baseline Process	**Alodine 2000**	**Alumicoat 6788**	**CFCC**	**Sanchem FP**
Number of Process Steps	12	9	7	11	12
Highest Processing Temperature (^{o}F)	165	160	180	212	212
Developed Touch-up Method	Yes	No	Yes	No	Yes

As shown by Table 20, the alternative processes require no more steps, and in some cases significantly fewer steps, than the current conversion coating process. In addition, two of the four alternatives have established touch-up procedures in place. As a result, it is anticipated that these benefits would help reduce the capital and operating cost of the alternative processes.

Further process-related information for each of the four alternatives can be found in Appendix B.

Use of nonchrome conversion coating is expected to lead to other benefits that cannot easily be quantified for HMSC's process. Many of these items would also benefit the

Sustainment Community. These items would include (in order of estimated impact on cost):

1. Lower waste handling, storage, and disposal costs from the reduction or elimination of process hazardous waste
2. Reduced need to develop environmental strategies
3. Reduced likelihood of having to re-engineer the process to meet new environmental requirements
4. Lower wastewater treatment costs from the reduction or elimination of toxic materials in the wastewater
5. Reduced cost to maintain environmental permits
6. Increased savings in developing and administering training programs.

Two operational disadvantages of the alternative processes are the operating temperature and the material purchase cost. Three of the four viable alternatives exhibit maximum processing temperatures greater than the baseline process temperature. This has the potential to increase energy usage and therefore operating costs. In addition, all the potential alternatives currently cost more per gallon than the present chrome conversion coating, which would tend to increase operating costs. However, when comparing these limitations to the number of potential advantages of the alternative processes, it seems that the long-term benefits should easily outweigh the limitations.

5. PRELIMINARY ESOH ANALYSIS OF VIABLE ALTERNATIVES

As part of the analysis of alternatives, each of the viable alternatives was qualitatively assessed for associated ESOH concerns. This initial assessment was conducted to determine whether there were any conspicuous ESOH issues that may need to be addressed when selecting alternatives for testing. The results of this ESOH analysis are contained in Appendix C and summarized below.

5.1. Environmental Issues

Each viable alternative was evaluated to determine the extent of their regulation under the major federal environmental laws. Using available resources, each alternative was evaluated based on the specified criteria:

- *Air Emissions:* Each alternative was analyzed to determine if it is regulated under the CAA as a HAP, a VOC, or an ODS.
- *Solid/Hazardous Waste Generation:* Each alternative was evaluated to determine whether its use generates solid waste, and, if so, whether that waste may be regulated, as hazardous or otherwise, under Subtitle C of RCRA.
- *Regulated Wastewaters:* Each viable alternative was analyzed to determine whether its use would cause the discharge of any wastewaters regulated under the CWA.
- *Reporting Requirements*: The viable alternatives were examined to determine whether any of the constituents are required to be listed on TRI reports under Section 313 of EPCRA.
- *CERCLA Hazardous Substances*: Each alternative was assessed to determine if its constituents are listed as hazardous substances under CERCLA.
- *EPA 17:* The constituents of each alternative were compared to the "EPA 17" list. Those substances on the EPA 17 list have been targeted by EPA because they are released in large quantities each year; they are generally identified as toxic or hazardous pollutants; and pollution prevention practices have the potential to diminish releases of these chemicals. The EPA 17 are likely to be targeted for more stringent regulation.

5.2. Safety and Occupational Health Issues

Each viable alternative was given a toxicity ranking, exposure ranking, and an overall hazard ranking based on the criteria set forth in Appendix C. Toxicity was qualitatively reviewed, and each viable product was given a final toxicity ranking of high, medium, or low based on the analysis of available product information. Parameters reviewed included median lethal concentration 50 (LC_{50}) and/or median oral lethal dose 50 (LD_{50}). The exposure criteria used in the screening and ranking are OSHA PELs and the ACGIH TLVs. Three exposure ranking levels and associated TLV and PEL intervals were chosen based on the ACGIH recommendations. Exposure rankings of high, medium, or low were assigned to candidate products. The hazard ranking is a combination of the toxicity ranking and exposure ranking, and gives an overall ESOH ranking to the viable alternative. A summary of the results of the ESOH analysis can be found in Table 21.

As shown by the data in Table 21, all four alternative processes, in general, have ESOH benefits over the current chrome conversion coating process. For example, the hazard ranking is lower in all cases, the number of EPA 17 and TRI reportable chemicals are fewer, and a fewer number of HAPs are emitted. In the other ESOH categories, the alternatives either faired as well as, or better than, the baseline process.

Table 21. Summary of ESOH Analysis for Viable Chrome Conversion Coating Alternatives

Product	TR[a]	ER[a]	HR[a]	Air Emissions		Wastes Generated		Waste-water	TRI Report	CERCLA HazSub	EPA 17 List
				HAP	VOC	Solid	Hazardous				
Baseline Process											
Alodine 600	H	H	H	3	U	Yes	Yes	Yes	4	4	2
Alternative Products											
Alodine 2000	M	H	M-H	1[b]	0	Yes	Yes	No	2	1	0[c]
Alumicoat 6788	M	M	M	0	0	Likely	No	Yes	2	0	0
CFCC[d]	M	M	M	0	0	Yes	Yes	U	1	4	0
Sanchem FP	M	H	M-H	1	U	Yes	U	Yes	1	1	0

[a] The toxicity ranking (TR), exposure ranking (ER), and hazard ranking (HR) are described in Appendix C.
[b] If chromic acid is replaced with Deoxalum, only one HAP will be generated during the Alodine 2000 process; otherwise, 2 HAPs are emitted.
[c] If chromic acid is replaced with Deoxalum, no EPA 17 chemicals will be generated during the Alodine 2000 process; otherwise one EPA 17 chemical is present.
[d] CFCC is a proprietary process; ESOH analysis is based on information on steps known at this time.
M =Medium
H = High
U = Unknown.

6. SELECTION OF POTENTIAL ALTERNATIVES

The process comparisons (Section 4) and the ESOH analysis (Section 5) were used as final criteria for determining those products that should undergo testing in accordance with the JTP. As discussed in Sections 4 and 5, the alternative processes generally are no worse, and in most cases fair much better, than the current chrome conversion coating process in terms of operational and ESOH issues, based on the available information. From this analysis, the technical stakeholders determined that all the viable alternatives should be carried through as candidates. As a result, the following is the list of *potential alternatives* recommended for testing (see Table 22).

Table 22. Potential Alternatives to Baseline Chrome Conversion Coating

Product	Company
Alodine 2000	Parker Amchem
Alumicoat 6788	Elf Atochem
CFCC	Hughes Aircraft Company
Sanchem FP	Sanchem

7. SUMMARY

At the HMSC JG-APP project site, chrome in chemical conversion coatings was identified as a hazardous material of concern, and targeted for elimination or reduction. Twenty alternatives to chrome conversion coatings were identified. Four of these alternatives were considered viable alternatives based on historical test results. Technical and ESOH aspects of these viable alternatives were analyzed. As a result of the analysis, the technical stakeholders recommend that the following four potential alternatives be tested according to the *Joint Test Protocol for the Validation of Alternatives to Chrome Conversion Coatings for Aluminum Alloys 2024, 6061, 7075, and Ion Vapor Deposited Aluminum on Steel (HM-P-1-1)*, dated May 21, 1996.

- Alodine 2000 (Parker Amchem)
- Alumicoat 6788 (Elf Atochem)
- CFCC (Hughes Aircraft Company)
- Sanchem FP (Sanchem)

If nonchromate conversion coatings successfully pass the JTP testing and are implemented, both HMSC and the Sustainment Community will be expected to receive a number of benefits, many of which have a positive impact on operating costs. These cost benefits might include:

1. Reduced labor and increased efficiency resulting from fewer processing steps
2. Lower waste handling, storage, and disposal costs from the reduction or elimination of process hazardous waste
3. Reduced need to develop environmental strategies
4. Reduced likelihood of having to re-engineer the process to meet new environmental requirements
5. Lower wastewater treatment costs from the reduction or elimination of toxic materials in the wastewater
6. Reduced cost to maintain environmental permits
7. Increased savings in developing and administering training programs.

APPENDIX A

TECHNOLOGY SURVEY TO IDENTIFY POTENTIAL ALTERNATIVES

TABLE OF CONTENTS

LIST OF TABLES

A.1 INTRODUCTION

HMSC follows military specifications for conversion coatings. The two main specifications are MIL-C-5541 (Chemical Conversion Coatings on Aluminum and Aluminum Alloys) and MIL-C-81706 (Chemical Conversion Coating Materials for Coating Aluminum and Aluminum Alloys). These specifications describe chrome conversion coatings that can be used for aluminum and aluminum alloys. These military specifications categorize coatings as either Class 1A or Class 3. Class 1A coatings are for maximum protection against corrosion. Surfaces that are treated with Class 1A coatings may be painted or unpainted. Class 3 coatings are for applications that require corrosion and electrical resistance.

A.2. DESCRIPTION OF SEARCH

Various information sources are available to *CTC*. Among the information sources used to identify potential chrome conversion coating alternatives are database searches, Internet searches, vendor contacts, the *CTC* Information Resource Centers, and personal contacts. Three main searches were performed on databases. Two searches were on the DIALOG® database, which has access to 370 individual databases. The DIALOG® database contains over 260 million records, all of which are available with a variety of search strategies. The DIALOG® database search strategies used are named Search A and Search B. The third search was performed on the National Center for Manufacturing Sciences (NCMS) database. The NCMS search strategy is referred to as Search C. Searches A, B, and C are described below in Tables A-1 through A-3.

Table A-1. Search A – DIALOG® Database

Search Sequence	Search Term	Number of Matches
A1	Chromate	22,889
A2	Conversion	464,267
A3	Chromate_conversion	665
A4	Alternat?	519,646
A5	Search A3 and Search A4	40
A6	Remove duplicates	23
Results	Applicable Articles	13

Table A-2. Search B – DIALOG® Database

Search Sequence	Search Term	Number of Matches
B1	Mil	8,862
B2	C	733,006
B3	5541	8
B4	Search B1_Search B2_Search B3	8
B5	81706	6
B6	Search B1_Search B2_Search B5	6
B7	Alternat?	200,193
B8	Replace?	80,025
B9	Traditional?	44,337
B10	(Search B4 *or* Search B6) *and* (Search B7 *or* Search B8 *or* Search B9)	5
B11	Remove Duplicates	1
Results	Applicable Articles	1

Table A-3. Search C – NCMS Database

Search Sequence	Search Term	Number of Matches
C1	Chromate_Conversion	18
Results	Applicable Articles	12

In addition to the database searches, Internet sources were scanned with search engines such as InfoSeek, Lycos, Savvy Search, Web Crawler, and Yahoo. Search strategies on these search engines are listed below. The actual syntax for performing searches varies for each search engine, so Boolean search descriptors are listed for simplicity:

1. MIL-C-5541 *and* MIL-C-81706
2. MIL-C-5541 *or* MIL-C-81706
3. (MIL-C-5541 *or* MIL-C-81706) *and* alternative
4. (MIL-C-5541 *or* MIL-C-81706) *and* alternative *and* conversion
5. MIL-C-5541 *and* chrome *and* conversion *and* coating *and* alternative
6. MIL-C-81706 *and* chrome *and* conversion *and* coating *and* alternative
7. MIL-C-5541 *or* MIL-C-81706 *or* chromium coating
8. MIL-C-5541 *and* MIL-C-81706 *and* alternative *and* chromium *and* coating alternative *and* chrome *and* coatings.

The relevant articles that were identified during the literature searches are listed in Section A.4.

A.3. IDENTIFIED ALTERNATIVES

Nine alternative technologies with twenty commercially or near-commercially available alternative products were identified with the technology survey. A description of each identified alternative technology is in this section. The historic test results, and associated environmental, health, and safety concerns for each identified product are presented in Appendix B.

Conversion coating is the chemical treatment of metal substrates that produces an adherent surface coating consisting of substances such as chromates, oxides, or phosphates. The chemical treatment used during the process depends on the coating desired. For instance, chrome conversion coatings are produced by combining chromium compounds (including hexavalent chromium) with other water-soluble inorganic materials. During the treatment process, the surface of the substrate material (typically aluminum, cadmium, copper, magnesium, silver, or zinc) is changed to a layer of chromium salts to produce the desired decorative or functional properties. Decorative coatings are typically thin coatings that are used as a sealant over phosphate, oxide, or metallic coatings. Functional coatings are thicker coatings that are commonly used for corrosion protection. In addition, both decorative and functional chrome conversion coatings exhibit other favorable attributes, including chemical polishing, low electrical resistivity, and enhanced bonding of organic finishes to substrates.

Although chrome conversion coating offers many advantageous coating properties, its use of hexavalent chromium is strictly regulated due to the compound's toxicity and suspected carcinogenicity. For example, regulations pursuant to the CAA, CWA, and RCRA contain provisions regulating waste streams from metallic finishing operations that contain hexavalent chromium. In addition, worker exposure to hexavalent chromium in the work place is regulated by OSHA through permissible exposure limits. These regulatory driving forces are increasing manufacturing costs and causing industry to identify, evaluate, and implement acceptable alternatives for chrome conversion coating.

Several chrome conversion coating alternatives are currently available. Alternatives were desired that passed at least one of the performance requirements for MIL-C-5541 (Chemical Conversion Coatings on Aluminum and Aluminum Alloys) or MIL-C-81706 (Chemical Conversion Coating Materials for Coating Aluminum and Aluminum Alloys) concerning corrosion resistance or contact electrical resistance. These alternative technologies commonly generate less pollution than chrome conversion coating and have fewer health and safety risks associated with them. Identified alternative technologies for chrome conversion coating are shown below in Table A-4.

Table A-4. Identified Alternative Technologies to Chrome Conversion Coating

Alternative Technology
Sol-Gel Coatings
Fluorozirconium Coatings
Cobalt-Based Coatings
Rare Earth Metal Salts
Manganese Oxide Films
Fluotitanic Coatings
Talc Coatings
Anodizing
Proprietary Techniques

Details of the technical, environmental, occupational health, and safety considerations identified for the alternative technologies are presented below. A brief description of each identified alternative technology then follows.

A.3.1. Technical Considerations

Each identified alternative technology needs to be assessed for corrosion resistance, contact electrical resistance, and paint adhesion. These are critical requirements for Class 1A and Class 3 coatings for MIL-C-5541 and MIL-C-81706. MIL-C-5541 requires that testing be performed on 2024 aluminum alloy panels for Class 1A coatings. To qualify as a Class 3 coating, 6061 or 2024 aluminum alloys must be used as test panels. A summary of the corrosion resistance, contact electrical resistance, and paint adhesion requirements of MIL-C-5541 is provided in Table A-5.

Table A-5. Corrosion Resistance, Contact Electrical Resistance, and Paint Adhesion Requirements of MIL-C-5541

Coating	Corrosion Resistance	Contact Electrical Resistance	Paint Adhesion
Class 1A	168-Hour Salt Spray Test	N/A	Wet Tape Adhesion
Class 3	168-Hour Salt Spray Test	$<5{,}000\ \mu\Omega/in^2$ (as applied) $<10{,}000\ \mu\Omega/in^2$ (After Salt Spray Test)	Wet Tape Adhesion

N/A = Not Applicable

MIL-C-81706 requires testing on 2024 and 7075 aluminum alloy panels for Class 1A coatings. Class 3 coatings require testing on 6061 aluminum alloy panels.

Refer to the following table for the corrosion resistance, contact electrical resistance, and paint adhesion requirements for MIL-C-81706 coatings.

Table A-6. Corrosion Resistance, Contact Electrical Resistance, and Paint Adhesion Requirements of MIL-C-81706

Coating	Corrosion Resistance	Contact Electrical Resistance	Paint Adhesion
Class 1A	336-Hour Salt Spray Test	N/A	Knife and Wet Tape Adhesion
Class 3	168-Hour Salt Spray Test	$<5,000\ \mu\Omega/in^2$ (as applied) $<10,000\ \mu\Omega/in^2$ (after salt spray test)	Knife and Wet Tape Adhesion

N/A = Not Applicable

A.3.2. Environmental Issues

Each alternative technology will be governed, to a greater or lesser extent, by federal environmental laws and regulations. Therefore, a regulatory review of each alternative was conducted as part of the ESOH analysis. Each alternative was reviewed to determine the extent of its regulation under the CAA, CWA, RCRA, the EPCRA, the CERCLA and the Occupational Safety and Health Act. Alternatives were also compared to the EPA 17 list. Even constituents that are heavily regulated under one or more of these laws are still available for use by facilities, although most facilities wisely restrict their use.

A.3.3. Health and Safety Issues

As part of the technology survey, each identified alternative was assessed for associated occupational health and safety concerns. Each identified constituent of the alternative, as available, was reviewed in terms of its potential toxicity as a known or suspected human carcinogen, human genotoxin, human teratogen, or human neurotoxin. Each of these categories is briefly defined and described below.

- *Human Carcinogen:* Those agents, including organic and inorganic compounds, which have an ability to induce carcinomas (cancer) in humans are considered human carcinogens. For this assessment, those constituents which show clear or suspected evidence of carcinogenic activity in humans as concluded by the National Toxicology Program (NTP), EPA's Office of Science and Technology Weight-of Evidence Policy, and/or the International Agency for Research on Cancer (IARC) guidelines are considered to be human carcinogens.

- *Human Genotoxin:* Those agents determined or suspected to be DNA-reactive (genotoxic), where available information is sufficient, are considered to be human genotoxins.
- *Human Teratogen:* Those agents which are determined or suspected to cause any detrimental effect (structural or functional) to developing organisms during embryonic development after exposure (which may occur before conception, during pregnancy, or directly to the developing organism) are considered to be human teratogens.
- *Human Neurotoxin:* Those agents which are determined, or suspected to cause toxic effects to the human nervous system from toxic exposure at expected occupational concentrations are considered to be neurotoxins.

A.3.4. Sol-Gel Coatings

Sol-Gel technology uses polymers or metal oxides either alone or mixed to form complexes by the hydrolysis of appropriate precursor compounds. The most appropriate compounds are metal alkoxides. Sol-Gels can form powders or thin films that can inhibit corrosion on substrates. The Sol-Gel technology is a potential alternative technology for chrome conversion coatings.

A.3.5. Fluorozirconium Coatings

This technology uses complexed transition metals salts to create a thin film on a substrate material similar to a conversion coating. Specifically, zirconium is mixed with fluorine to create fluorozirconium, which reacts with the part surface to create a coating. Fluorozirconium coatings are a potential alternative technology to chrome conversion coatings.

A.3.6. Cobalt-Based Coatings

A technology exists which uses cobalt and molybdenum to treat substrate materials. The coatings created are low in electrical resistance and are good for corrosion resistance. Cobalt-based coating technology is a potential alternative technology to chrome conversion coatings.

A.3.7. Rare Earth Metal Salts

The use of rare earth metal salts (REMs) is a potential alternative technology to chrome conversion coating. As with other coatings, these materials may be applied by immersion, although the bath requires heating, to create protective layers on substrate materials. REMs provide corrosion resistance by producing a protective REM oxide film.

A.3.8. Manganese Oxide Films

Potassium permanganate solutions can be used to create manganese oxide films on substrates. Since manganese oxides and chromic oxides are very similar, the manganese oxide films resulting from potassium permanganate treatment closely matches the corrosion resistance of traditional chromic oxide films used in conversion coatings. Potassium permanganate coatings are very effective in protecting aluminum alloys.

A.3.9. Fluotitanic Coatings

Another alternative technology to chrome conversion coating is the use of fluotitanic acid solutions with organic polymers. This technology requires few processing steps, and can usually be done at ambient temperatures. Although these coatings have been widely used in a variety of applications, they have not been used in the aerospace industry.

A.3.10. Talc Coatings

Talc coatings, which are typically applied to aluminum substrates, are resistant to corrosion. These polycrystalline coatings are applied by the precipitation of aluminum-lithium compounds and other anions in an alkaline salt solution. The outer layers of the resultant coating are porous, but the pores do not reach the substrate surface. Talc coatings are a good alternative technology for chrome conversion coating.

A.3.11. Anodizing

Anodizing is a process that produces a tough, adherent surface layer by converting a metal surface to an oxide layer. A thick oxide layer can be produced by immersing a part in an electrolytic solution and passing an electrical current through it, similar to electroplating. The resulting film is nearly colorless, and can be easily dyed because it is very porous at the molecular level. Then, by placing the part in boiling water, the film's pores can be sealed; the oxide changes from one form to another as a result. Several metals such as aluminum, titanium, niobium, and possibly magnesium and others, can be anodized. Appropriate current is then applied, i.e., 1.5 amps per decimeter. This lasts 15-25 minutes if no drying is planned, or 45-60 minutes for dying.

A.3.12. Proprietary Techniques

There are several proprietary techniques that are commercially or near commercially available. Because these techniques are kept secret, little is known about the chemical or physical changes that occur in the processing, and therefore these techniques are grouped together. However, historical data shows that these techniques have significant value, and since they are available for general use as possible alternatives to chrome conversion coatings, they are included in this technology survey. The proprietary processes identified are listed below, and further information on each can be found in Appendix B.

- Alumicoat 6788 by Elf Atochem
- Chemcote L497260A by Brent America, Inc.
- CFCC by Hughes Aircraft Company
- E-CLPS Coatings from Bulk Chemicals, Inc.

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APPENDIX B

PRODUCT IDENTIFICATION

TABLE OF CONTENTS

Page

LIST OF TABLES

Page

B.1. INTRODUCTION

From information gathered in the technology survey in 1995, available products and processes were identified for each of the identified technologies. Product specific information for each alternative product, including general process information, is provided in Sections B.2 through B.10. In addition, technical considerations, environmental issues, and health and safety issues that concern each alternative are discussed in each section.

Touch-up techniques for parts that are scratched while in use are also discussed for each alternative. When available, any other pertinent information, such as abrasion resistance, is also provided.

B.2. SOL-GEL COATINGS

Though there are many types of Sol-Gel coatings, only one was found to have relevant historical test results.

B.2.1. Aeroglaze (Lord Corporation)

The Aeroglaze Sol-Gel process, patented by Lord Corporation, varies slightly from typical Sol-Gel processes that use polymers to cast a coating. The patented process treats parts by immersing them into a bath, much like anodizing or phosphatizing processes. The overall process is as follows:

1. *Cleaning and Rinsing:* This step removes bulk contaminants such as thick wax.
2. *Sol-Gel Process:* The part is dipped into a bath that consists of 70% alcohol (e.g., ethanol), 25% water, 2-3% ammonium hydroxide catalyst, and the remainder as tetraethoxysilane (TEOS). This bath make-up may be varied, depending on the end application (as required for a paintable or nonpaintable surface). The make-up listed above is for corrosion protection applications. The part is then removed from the bath after allowing it to react for 5 to 20 minutes.
3. *Drying:* Parts can be dried with a variety of methods, including hanging, blowing, or oven drying.

The reaction that proceeds during the Sol-Gel process converts the surface metal oxide layer to a silicon oxide layer. For example, aluminum parts would form an aluminum silicate coating on the surface. The resultant coating is a glass layer that is 1,000 Angstroms (Å) (0.004 mils) thick.

B.2.1.1. Technical Considerations

National Center for Manufacturing Sciences (NCMS) issued a study (NCMS, 1995) that compared nonchromate conversion coatings to Alodine 600 and 1200 series coatings (chrome conversion coatings manufactured by Parker Amchem) on aluminum substrates. Among the alternatives tested was a paintable Aeroglaze Sol-Gel coating. Below is a summary of the findings.

- *Corrosion Resistance:* Aeroglaze Sol-Gel coatings passed corrosion resistance tests on aluminum alloy 6061. However, they did not pass tests on alloys 2024 and 7075. Tests followed MIL-C-5541 procedures.

- *Contact Electrical Resistance:* Aeroglaze Sol-Gel coatings passed contact electrical resistance tests on alloy 6061 before a salt spray. Tests followed MIL-C-81706 procedures. Substrates coated with Aeroglaze Sol-Gel were also tested until failure after a salt spray. The coatings had a mean contact electrical resistance of 49.3 $m\Omega/in^2$.
- *Paint Adhesion:* Aeroglaze Sol-Gel coatings passed the dry paint adhesion test on alloy 6061, but failed the wet paint adhesion test on that alloy. They failed dry and wet paint adhesion tests on alloys 2024 and 7075. Tests followed MIL-C-5541 and MIL-C-81706 procedures.

Although the Sol-Gel coatings offer corrosion resistance and a good bonding surface, they offer little abrasion resistance. A formal procedure for touch-up is not in place; however, various techniques for touch-up may be successful (e.g., a chrome pen).

Aeroglaze Sol-Gel coatings recently became available commercially. Lord Corporation is currently searching for facilities that would like to test these coatings in actual production. However, Lord Corporation is not currently manufacturing these coatings on a full-scale production line.

B.2.1.2. Environmental Issues

The constituents of the Aeroglaze Sol-Gel baths are not listed as one of the 189 hazardous air pollutants (HAPs) under Title III of the Clean Air Act (CAA), as amended in 1990. In addition, they are not considered to be ozone-depleting substances (ODSs). Sludge from this process may be required to be managed in accordance with the requirements of Subtitle C of the Resource Conservation and Recovery Act (RCRA).

B.2.1.3. Health and Safety Issues

Only one constituent in these processes is listed by OSHA as an airborne contaminant that must be regulated with PELs; ethanol must be maintained below 1,000 ppm. In addition, the ACGIH recommends a PEL of 1,000 ppm for ethanol. Ventilation may be required to maintain airborne ethanol below these concentrations. It should be noted that ethanol is a known human carcinogen via oral exposure, as well as a known human teratogen, genotoxin, and neurotoxin. Methanol is a suspected human teratogen and genotoxin (human data reported), as well as a known human neurotoxin. Methanol is listed on EPA's Genetic Toxicity Program.

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B.3. FLUOROZIRCONIUM COATINGS

Circle-Prosco, Inc. provides a family of products using fluorozirconium coating technology for a wide range of applications. Four such products are described in the following sections.

B.3.1. Alcoat 1470 (Circle-Prosco, Inc.)

Alcoat 1470, manufactured by Circle-Prosco, Inc., uses complexed transition metal salts to treat parts. To treat parts with this product, the steps listed below are performed.

1. *Cleaning:* One cleaning agent that can be used for cleaning is Alcoat 1470C. However, other cleaners may be appropriate for specific applications. Alcoat 1470C contains nitric acid, hydrofluoric acid, and zirconium salt.
2. *Water Rinsing*
3. *Conversion Coating with Alcoat 1470B:* Alcoat 1470B also contains nitric acid, hydrofluoric acid, and zirconium salt. It is maintained between 70°F and 150°F.
4. *Water Rinsing*
5. *Sealing:* Alcoat 1470S is recommended by Circle-Prosco, Inc. Alcoat 1470S contains potassium hydroxide. It is maintained between 70°F and 150°F.
6. *Drying:* After conversion coating, parts are oven dried for 10 minutes at 250°F.

B.3.1.1. Technical Considerations

NCMS issued a study that compared nonchromate conversion coatings to Alodine 600 and 1200 series coatings (chrome conversion coatings manufactured by Parker Amchem) on aluminum substrates. Among the alternatives tested was Alcoat 1470. Below is a summary of the findings.

- *Corrosion Resistance:* Alcoat 1470 passed corrosion resistance tests on aluminum alloy 6061. However, it failed tests on aluminum alloy 2024 and alloy 7075. Tests followed MIL-C-5541 procedures.
- *Contact Electrical Resistance:* Alcoat 1470 failed contact electrical resistance tests on alloy 6061 before a salt spray. Tests followed MIL-C-81706 procedures. Substrates coated with Alcoat 1470 were also tested until failure after a salt spray. The coatings had a mean contact electrical resistance of 426 mΩ/in^2.

- *Paint Adhesion:* Alcoat 1470 failed dry and wet paint adhesion tests on aluminum alloys 2024, 6061, and 7075. Tests followed MIL-C-5541 and MIL-C-81706 procedures.

Circle-Prosco, Inc. is currently performing salt spray tests with scratched and re-coated panels. It is expected that coatings with a scratch to the bare metal can be repaired by brushing on the Alcoat 1470 solution with a paint brush. After Alcoat 1470 coating is dry, it must be repainted.

B.3.1.2. Environmental Issues

The Alcoat 1470 process, specifically Alcoat 1470B, contains two chemicals that are regulated as HAPs under Title III of the CAA. Due to the acidic and basic nature of the wastewaters from the Alcoat 1470 process, the wastewater must be neutralized to meet Clean Water Act (CWA) permitting guidelines for the Metal Finishing Point Source category. Sludge from this process may be required to be managed in accordance with the requirements of RCRA Subtitle C.

B.3.1.3. Health and Safety Issues

OSHA has set PELs and the ACGIH has set TLVs for chemicals in the Alcoat 1470 process, as listed in Table B-1.

Table B-1. PELs and TLVs for Chemicals in Alcoat 1470 Process

Chemical	OSHA PEL	ACGIH TLV
Nitric Acid	2 ppm	2 ppm
Hydrofluoric Acid	3 ppm, as F	3 ppm, as F (Ceiling)
Potassium Hydroxide	None NIOSH: 2 mg/m^3	2 mg/m^3 (Ceiling)

Ventilation is required to maintain airborne contaminants below the PELs and TLVs. In addition, personal protection, such as goggles, neoprene rubber gloves, and respirators, is required. No suspected human carcinogens, genotoxins or neurotoxins are present in the Alcoat 1470 process. However, it should be noted that nitric acid and hydrofluoric acid are experimental animal teratogens. Hydrofluoric acid appears in EPA's Genetic Toxicology Program.

B.3.1.4. Additional Supporting Literature

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- Parker, Doug. Circle-Prosco, Inc. Telephone Conversation. November 22, 1995 and April 3, 1996.
- 40 CFR part 261 *et seq.*
- 40 CFR part 400 *et seq.*
- 40 CFR part 129 *et seq.*
- 42 USC §7412(b)

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B.3.2. Alcoat 3000 (Circle-Prosco, Inc.)

Alcoat 3000, manufactured by Circle-Prosco, Inc., uses complexed transition metal salts to treat parts. To treat parts with this chemical, the steps listed below are performed.

1. *Cleaning:* One cleaning agent that can be used is Alcoat 3000C. However, other cleaners may be appropriate, depending on the specific application.
2. *Water Rinsing*
3. *Conversion Coating with Alcoat 3000B*
4. *Water Rinsing*
5. *Drying:* After conversion coating, parts are oven dried for 10 minutes at 250°F.

B.3.2.1. Technical Considerations

NCMS issued a study that compared nonchromate conversion coatings to Alodine 600 and 1200 series coatings (chrome conversion coatings manufactured by Parker Amchem) on aluminum substrates. Among the alternatives tested was Alcoat 3000. Below is a summary of the findings

- *Corrosion Resistance:* Alcoat 3000 passed corrosion resistance tests on aluminum alloy 6061. However, it failed tests on aluminum alloys 2024 and 7075. Tests followed MIL-C-5541 procedures.
- *Contact Electrical Resistance:* Alcoat 3000 failed contact electrical resistance tests on alloy 6061 before a salt spray. Tests followed MIL-C-81706 procedures. Substrates coated with Alcoat 3000 were also tested until failure after a salt spray. The coatings had a mean contact electrical resistance of 644 $m\Omega/in^2$.
- *Paint Adhesion:* Alcoat 3000 passed dry and wet paint adhesion tests on aluminum alloys 6061 and 7075. It also passed the dry paint adhesion test for alloy 2024; however, it failed the wet paint adhesion test on that alloy. Tests followed MIL-C-5541 and MIL-C-81706 procedures.

Circle-Prosco, Inc. is currently performing salt spray tests with scratched and re-coated panels. It is expected that coatings with a scratch to the bare metal can be repaired by brushing on the Alcoat 3000 solution with a paint brush. After Alcoat 3000 coating is dry, it must be repainted.

B.3.2.2. Environmental Issues

The Alcoat 3000 process, specifically Alcoat 3000B, contains one chemical that is regulated as a HAP under Title III of the CAA. Due to the acidic and basic nature of the wastewater from the Alcoat 3000 process, the wastewater must be neutralized to meet CWA permitting guidelines for the

Metal Finishing Point Source category. Sludge from this process may be required to be managed in accordance with the requirements of RCRA Subtitle C.

B.3.2.3. Health and Safety Issues

OSHA has set PELs and the ACGIH has set TLVs for chemicals in the Alcoat 3000 process, as listed in Table B-2 below.

Table B-2. PELs and TLVs for Chemicals of Alcoat 3000

Chemical	OSHA PEL	ACGIH TLV
Sodium Tripolyphosphate	5 mg/m^3	None
Hydrofluoric Acid	3 ppm, as F	3 ppm, as F (Ceiling)
Fluoride Salt	2.5 mg/m^3, as F	2.5 mg/m^3, as F

Ventilation is required to maintain airborne contaminants below the PELs and TLVs. In addition, personal protection, such as goggles, gloves, and respirators, is required. No suspected human carcinogens, genotoxins or neurotoxins are present in the Alcoat 3000 process. However, hydrofluoric acid is an experimental animal teratogen and appears in EPA's Genetic Toxicology Program.

B.3.2.4. Additional Supporting Literature

- ACGIH, 1995, *Industrial Ventilation: A Manual of Recommended Practice*. 22nd ed. Cincinnati, OH.
- ACGIH, 1991, *Documentation of the Threshold Limit Values and Biological Exposure Indices*. 6th ed. Vols I-III. Cincinnati, OH.
- Lewis, Richard J., Sr., 1992, *Sax's Dangerous Properties of Industrial Materials*. 8th ed. Vols I-III. Van Nostrand Reinhold, New York.
- Manard, Jack. Circle-Prosco, Inc. Telephone Conversation. November 20, 1995.
- MSDS Information Systems Inc., 1996, *OHS MSDS on Disk*.
- National Center for Manufacturing Sciences, 1995, *Alternatives to Chromium for Metal Finishing,* Ann Arbor, Michigan.
- NIOSH, 1994, *NIOSH Pocket Guide to Chemical Hazards*. U.S. Government Printing Office, Washington, DC.

- Parker, Doug. Circle-Prosco, Inc. Telephone Conversation. November 22, 1995 and April 3, 1996.
- 40 CFR part 261 *et seq*.
- 40 CFR part 400 *et seq*.
- 40 CFR part 129 *et seq*.
- 42 USC §7412(b)

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B.3.3. Alcoat 4000 (Circle-Prosco, Inc.)

Alcoat 4000, manufactured by Circle-Prosco, Inc., uses complexed transition metal salts to treat parts. To treat parts with this chemical, the steps listed below are performed.

1. *Cleaning:* One cleaning agent that may be used is Alcoat 4000C. However, other cleaners may be appropriate for specific applications. Alcoat 4000C contains sodium tripolyphosphate.
2. *Water Rinsing*
3. *Etching:* Etching may be performed with Alcoat 4000B, which contains nitric acid and hydrofluoric acid.
4. *Water Rinsing*
5. *Conversion Coating with Alcoat 4000B1:* Alcoat 4000B1 contains nitric acid, hydrofluoric acid, and a zirconium salt.
6. *Water Rinsing*
7. *Sealing:* Circle-Prosco, Inc. recommends using Alcoat 4000S as a sealant. Alcoat 4000S contains potassium hydroxide.
8. *Drying:* After conversion coating, parts are oven dried for 10 minutes at 250°F.

All process steps are at ambient temperature, except for sealing, which is maintained at 120°F.

B.3.3.1. Technical Considerations

NCMS issued a study that compared nonchromate conversion coatings to Alodine 600 and 1200 series coatings (chrome conversion coatings manufactured by Parker Amchem) on aluminum substrates. Among the alternatives tested was Alcoat 4000. Below is a summary of the findings

- *Corrosion Resistance:* Alcoat 4000 exceeded corrosion resistance tests for aluminum alloy 6061. However, it failed tests on aluminum alloys 2024 and 7075. Tests followed MIL-C-5541 procedures.
- *Contact Electrical Resistance:* Alcoat 4000 failed contact electrical resistance tests on alloy 6061 before a salt spray. Tests followed MIL-C-81706 procedures. Substrates coated with Alcoat 4000 were also tested until failure after a salt spray. The coatings had a mean contact electrical resistance of 376,000 $m\Omega/in^2$.
- *Paint Adhesion:* Alcoat 4000 failed dry and wet paint adhesion tests on aluminum alloys 2024, 6061, and 7075. Tests followed MIL-C-5541 and MIL-C-81706 procedures.

Circle-Prosco, Inc. is currently performing salt spray tests with scratched and re-coated panels. It is expected that coatings with a scratch to the bare metal can be repaired by brushing on the Alcoat 4000 solution with a paint brush. After Alcoat 4000 coating is dry, it must be repainted.

B.3.3.2. Environmental Issues

The Alcoat 4000 process contains two chemicals that are regulated as HAPs under Title III of the CAA. The HAPs are present in Alcoat 4000B and Alcoat 4000B1. Due to the acidic and basic nature of the wastewater from the Alcoat 4000 process, the wastewater must be neutralized to meet CWA permitting guidelines for the Metal Finishing Point Source category. Sludge from this process may be required to be managed in accordance with the requirements of RCRA Subtitle C.

B.3.3.3. Health and Safety Issues

OSHA has set PELs and the ACGIH has set TLVs for chemicals in the Alcoat 4000 process, as listed in Table B-3.

Table B-3. PELs and TLVs for Chemicals in Alcoat 4000 Process

Chemical	OSHA PEL	ACGIH TLV
Sodium Tripolyphosphate	5 mg/m^3	None
Nitric Acid	2 ppm	2 ppm
Hydrofluoric Acid	3 ppm, as F	3 ppm, as F (Ceiling)
Potassium Hydroxide	None NIOSH: 2 mg/m^3	2 mg/m^3 (Ceiling)

Ventilation is required to maintain airborne contaminants below the PELs and TLVs. In addition, personal protection, such as goggles, rubber gloves, and respirators, is required. No suspected human carcinogens, genotoxins or neurotoxins are present in the Alcoat 4000 process. However, nitric acid and hydrofluoric acid are experimental animal teratogens and hydrofluoric acid appears in the EPA's Genetic Toxicology Program.

B.3.3.4. Additional Supporting Literature

- ACGIH, 1995, *Industrial Ventilation: A Manual of Recommended Practice*. 22nd ed. Cincinnati, OH.
- ACGIH, 1991, *Documentation of the Threshold Limit Values and Biological Exposure Indices*. 6th ed. Vols I-III. Cincinnati, OH.
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- MSDS Information Systems Inc., 1996, *OHS MSDS on Disk*.
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- NIOSH, 1994, *NIOSH Pocket Guide to Chemical Hazards*. U.S. Government Printing Office, Washington, DC.
- Parker, Doug. Circle-Prosco, Inc. Telephone Conversation. November 22, 1995 and April 3, 1996.
- 40 CFR part 261 *et seq*.
- 40 CFR part 400 *et seq*.

- 40 CFR part 129 *et seq*.
- 42 USC §7412(b)

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B.3.4. Alcoat 5000 (Circle-Prosco, Inc.)

As with Alcoat 1470, 3000, and 4000, Alcoat 5000 treats parts by using a zirconium-based conversion coating process. When using Alcoat 5000 as a chrome conversion coating alternative, several process steps must be performed for an adequate coating. These steps are listed below.

1. *Cleaning:* Cleaning may be performed with Alcoat 5000C, which contains sodium tripolyphosphate. However, other cleaners may be appropriate depending on the specific applications.
2. *Water Rinsing*
3. *Conversion Coating with Alcoat 5000B:* This bath contains hydrofluoric acid, a fluoride salt, and a zirconium salt.
4. *Water Rinsing*
5. *Sealing:* Circle-Prosco, Inc. recommends that sealing be performed with Alcoat 5000S. This bath, which contains potassium hydroxide, is maintained at 120°F.
6. *Drying:* After conversion coating, parts are oven dried for 10 minutes at 250°F.

B.3.4.1. Technical Considerations

NCMS issued a study that compared nonchromate conversion coatings to Alodine 600 and 1200 series coatings (chrome conversion coatings manufactured by Parker Amchem) on aluminum substrates. Among the alternatives tested was Alcoat 5000. Below is a summary of the findings.

- *Corrosion Resistance:* Alcoat 5000 failed corrosion resistance tests on aluminum alloys 2024, 6061, and 7075. Tests followed MIL-C-5541 procedures.

- *Contact Electrical Resistance:* Alcoat 5000 passed contact electrical resistance tests on alloy 6061 before a salt spray. Tests followed MIL-C-81706 procedures. Substrates coated with Alcoat 5000 were also tested until failure after a salt spray. The coatings had a mean contact electrical resistance of 137 $m\Omega/in^2$.
- *Paint Adhesion:* Alcoat 5000 passed dry paint adhesion tests on aluminum alloys 2024 and 7075. However, it failed the dry paint adhesion test on alloy 6061, and failed wet paint adhesion tests on alloys 2024, 6061, and 7075. Tests followed MIL-C-5541 and MIL-C-81706 procedures.

Circle-Prosco, Inc. is currently performing salt spray tests with scratched and re-coated panels. It is expected that coatings with a scratch to the bare metal can be repaired by brushing on the Alcoat 5000 solution with a paint brush. After Alcoat 5000 coating is dry, it must be repainted.

B.3.4.2. Environmental Issues

The Alcoat 5000 process, specifically Alcoat 5000B, contains one chemical that is regulated as a HAP under Title III of the CAA. Due to the acidic and basic nature of the wastewater from the Alcoat 5000 process, the wastewater must be neutralized to meet CWA permitting guidelines for the Metal Finishing Point Source category. Sludge from this process may be required to be managed in accordance with the requirements of RCRA Subtitle C.

B.3.4.3. Health and Safety Issues

OSHA has set PELs and the ACGIH has set TLVs for chemicals in the Alcoat 5000 process, as listed in Table B-4.

Table B-4. PELs and TLVs for Chemicals in Alcoat 5000 Process

Chemical	OSHA PEL	ACGIH TLV
Sodium Tripolyphosphate	5 mg/m^3	None
Hydrofluoric Acid	3 ppm, as F	3 ppm, as F (Ceiling)
Fluoride Salt	2.5 mg/m^3, as F	2.5 mg/m^3, as F
Potassium Hydroxide	None NIOSH: 2 mg/m^3	2 mg/m^3 (Ceiling)

Ventilation is required to maintain airborne contaminants below the PELs and TLVs. In addition, personal protection, such as goggles, neoprene rubber gloves, and respirators, is required. No suspected human carcinogens, genotoxins or neurotoxins are present in the Alcoat 5000 process. However, hydrofluoric acid is an experimental animal teratogen and appears in the EPA Genetic Toxicology Program.

B.3.4.4. Additional Supporting Literature

- ACGIH, 1995, *Industrial Ventilation: A Manual of Recommended Practice*. 22nd ed. Cincinnati, OH.
- ACGIH, 1991, *Documentation of the Threshold Limit Values and Biological Exposure Indices*. 6th ed. Vols I-III. Cincinnati, OH.
- Lewis, Richard J., Sr., 1992, *Sax's Dangerous Properties of Industrial Materials*. 8th ed. Vols I-III. Van Nostrand Reinhold, New York.
- Manard, Jack. Circle-Prosco, Inc. Telephone Conversation. November 20, 1995.
- MSDS Information Systems Inc., 1996, *OHS MSDS on Disk*.
- National Center for Manufacturing Sciences, 1995, *Alternatives to Chromium for Metal Finishing*, Ann Arbor, Michigan.
- NIOSH, 1994, *NIOSH Pocket Guide to Chemical Hazards*. U.S. Government Printing Office, Washington, DC.
- Parker, Doug. Circle-Prosco, Inc. Telephone Conversation. November 22, 1995 and April 3, 1996.
- 40 CFR part 261 *et seq*.
- 40 CFR part 400 *et seq*.
- 40 CFR part 129 *et seq*.
- 42 USC §7412(b)

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B.4. COBALT-BASED COATINGS

Several cobalt-based coatings are commercially available, but only Alodine 2000 has been historically tested for aerospace applications.

B.4.1. Alodine 2000 (Parker Amchem)

Alodine 2000 is a coating that is currently commercially available from Parker Amchem specifically designed for aerospace applications. It was originally developed and patented by Boeing Aircraft Company. The Alodine 2000 process uses cobalt and molybdenum to treat aluminum surfaces. When using Alodine 2000, the process steps listed below are recommended.

1. *Cleaning:* Parker Amchem recommends using Ridoline 53. Ridoline 53 contains sodium metasilicate and tetrasodium pyrophosphate. This bath is maintained between 140°F and 160°F.
2. *Water Rinsing*
3. *Deoxidizing:* Parker Amchem recommends Deoxidizer 6 with Replenisher 16. Hydrofluoric acid, chromic acid, magnesium acetate, and triethanolamine are present during this process step. The bath is maintained between 50°F and 90°F.
4. *Water Rinsing*
5. *Conversion Coat with Alodine TD 2000H:* Although a complete list of constituents of Alodine 2000H is not available, regulated and hazardous chemicals include cobalt nitrate, hydrogen peroxide, magnesium acetate, and triethanolamine. The conversion coating bath should be maintained between 120°F and 140°F.
6. *Water rinsing*
7. *Post-Treatment:* A proprietary tungsten/vanadium seal (TD 3095Y) is recommended by Parker Amchem for post-treatment. This seal enhances both the corrosion resistance and the paint adhesion of the final coating.
8. *Water Rinsing*
9. *Drying:* Drying may be performed with heat or by air drying.

B.4.1.1. Technical Considerations

NCMS issued a study that compared nonchromate conversion coatings to Alodine 600 and 1200 series coatings (chrome conversion coatings manufactured by Parker Amchem) on aluminum substrates. Among the alternatives tested was Alodine 2000. Below is a summary of the findings.

- *Corrosion Resistance:* Alodine 2000 passed corrosion resistance tests on aluminum alloy 2024 and alloy 7075, and exceeded test requirements for alloy 6061. Tests followed MIL-C-5541 procedures.

- *Contact Electrical Resistance:* Alodine 2000 passed contact electrical resistance tests on alloy 6061 before a salt spray. Tests followed MIL-C-81706 procedures. Substrates coated with Alodine 2000 were also tested until failure after a salt spray. The coatings had a mean contact electrical resistance of 1,620 mΩ/in^2.
- *Paint Adhesion:* Alodine 2000 passed dry and wet paint adhesion tests on aluminum alloys 2024 and 6061. It passed the dry paint adhesion test on alloy 7075, but failed the wet paint adhesion test on this alloy. Tests followed MIL-C-5541 and MIL-C-81706 procedures.

The MITRE Corporation performed a study to identify alternatives to chrome conversion coatings for the McClellan Air Force Base. Alodine 2000 was one of the three alternatives studied. The information listed below was reported.

- *Corrosion Resistance:* Salt spray testing was performed with unpainted and painted Alodine 2000 coatings. Unpainted substrates had a salt spray resistance of over 336 hours (the requirement for MIL-C-81706). In addition, painted substrates had a salt spray resistance of over 1,500 hours.
- *Contact Electrical Resistance:* Alodine 2000 had a contact electrical resistance of over 5 mΩ/in^2 before the salt spray, and under 10 mΩ/in^2 after the salt spray.
- *Paint Adhesion:* Alodine 2000 passed both cross-hatch and wet tape tests.

To date, parts that have been coated with Alodine 2000 have not required repair. Brush-up techniques are not available with this coating. However, Parker Amchem recommends using any repair techniques that are required by military specifications for chrome conversion coatings. One example is a ChemFilm Alodine Pen, which contains chromium.

B.4.1.2. Environmental Issues

The Alodine 2000 process contains three chemicals that are regulated as HAPs under Title III of the CAA. The HAPs are present in the deoxidizer step (Step 3) and the conversion coating step (Step 5). Due to the acidic and basic nature of the wastewaters from the Alodine 2000 process, the wastewaters must be neutralized to meet CWA permitting guidelines for the Metal Finishing Point Source category. Sludge from this process may be required to be managed in accordance with the requirements of RCRA Subtitle C.

B.4.1.3. Health and Safety Issues

OSHA has set PELs and the ACGIH has set TLVs for chemicals in the Alodine 2000 process, as listed in Table B-5.

Table B-5. PELs and TLVs for Chemicals in Alodine 2000 Process

Chemical	OSHA PEL	ACGIH TLV
Nitric Acid	2 ppm	2 ppm
Cobalt Nitrate	None	0.02 mg/m^3 as Co
Sodium Ammonium Vanadate	None NIOSH: 0.05 mg V/m^3/ 15 minutes	None
Hydrogen Peroxide	1 ppm	1 ppm
Triethanolamine	None	5 mg/m^3

Table B-6 lists the chemical products of the Alodine 2000 process as well as the constituent chemicals present during the process.

Table B-6. Chemical Products of Alodine 2000 Process

Product	Constituent	CAS Number	Percent by Mass
TD-3072-W	N-Octyl 2-Pyrrolidone	07425-87-8	1-10
	Sodium Metasilicate	06834-92-0	1-10
	Surfactants	N.A.	10-30
Ridoline 53 LF	Surfactants	N.A.	1-10
Deoxalume ® 2200	Nitric Acid	07697-37-2	10-30
Deoxalume ® 2200 Replenisher	Hydrogen Peroxide	07722-84-1	30-40
	Surfactant	N.A.	1-10

(Table B-6 continued on next page)

Table B-6. Chemical Products of Alodine 2000 Process (Continued)

Product	Constituent	CAS Number	Percent by Mass
PTD 2000H	Cobalt Nitrate	10141-05-6	1-10
	Magnesium Acetate	00142-72-3	10-30
Alodine 2600 Toner	Hydrogen Peroxide	07722-84-1	30-40
PTD 2000I	Triethanolamine	00102-71-6	10-30
PTD 3095Y	Sodium Ammonium Vanadate	12055-09-3	N.A.

N.A. = Not Available

Ventilation is required to maintain airborne contaminants below the PELs and TLVs. In addition, personal protection, such as goggles and respiratory equipment, is required. Dermal contact with the chemicals can cause allergic skin reactions. In addition, inhalation of the chemicals in dust form can cause illness and respiratory disease. Cobalt nitrate and triethanolamine are suspected human carcinogens. Hydrogen peroxide is a confirmed human genotoxin. Sodium metasilicate, nitric acid, hydrogen peroxide, and cobalt nitrate are experimental animal teratogens and/or reproductive toxicants. No other known or suspected carcinogens, teratogens, mutagens, or neurotoxins were noted in Alodine 2000.

B.4.1.4. Additional Supporting Literature

- ACGIH, 1995, *Industrial Ventilation: A Manual of Recommended Practice*. 22nd ed. Cincinnati, OH.
- ACGIH, 1996, *1996 TLVs and BEIs*. *Threshold Limit Values for Chemical Substances and Physical Agents. Biological Exposure Indices*. Second Printing. ACGIH, Cincinnati, OH.
- Lewis, Richard J., Sr., 1996, *Sax's Dangerous Properties of Industrial Materials*. 9th ed. Vols I-III. Van Nostrand Reinhold, New York.
- MSDS Information Systems Inc., 1996, *OHS MSDS on Disk*.
- Meyers, Barry R., MITRE Corporation; Steve C. Lynn, MITRE Corporation; and Elwin Jang, McClellan Air Force

Base. “Case Study - Alternatives to the Use of Chromium in Plating and Conversion Coating at McClellan Air Force Base, California.” *9th Annual Aerospace Hazardous Materials Management Conference*. Denver, Colorado. September 28-30, 1994.

- National Center for Manufacturing Sciences, 1995, *Alternatives to Chromium for Metal Finishing,* Ann Arbor, Michigan.
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- Nylen, Jon. Parker Amchem. Telephone Conversation. November 14, 1995 and April 4, 1996.
- Parker Amchem, 1992. *Deoxalume® 2200 Additive Material Safety Data Sheet*, Parker Amchem, Madison Hts., MI.
- Parker Amchem, 1994. *PTD-2000-H Material Safety Data Sheet*, Parker Amchem, Madison Hts., MI.
- Parker Amchem, 1994. *PTD-2000-I Material Safety Data Sheet*, Parker Amchem, Madison Hts., MI.
- Parker Amchem, 1995. *Alodine 2000 Material Safety Data Sheet*, Parker Amchem, Madison Hts., MI.
- Parker Amchem, 1995. *Alodine 2600 Toner Material Safety Data Sheet*, Parker Amchem, Madison Hts., MI.
- Parker Amchem, 1995. *Deoxalume® 2200 Material Safety Data Sheet*, Parker Amchem, Madison Hts., MI.
- Parker Amchem, 1995. *PTD-3095-Y Material Safety Data Sheet*, Parker Amchem, Madison Hts., MI.
- Parker Amchem, 1995. *Ridoline 53 LF Material Safety Data Sheet*, Parker Amchem, Madison Hts., MI.
- 40 CFR part 261 *et seq*.
- 40 CFR part 400 *et seq*.
- 40 CFR part 129 *et seq*.
- 42 USC §7412(b)

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B.5. RARE EARTH METAL SALTS

Several products in development use the technology of rare earth metal salts. One such product, Ce-Mo 6061, was identified, and is described below.

B.5.1. Ce-Mo 6061 (University of Southern California)

As with other coatings, these materials may be applied by immersion, although the bath requires heating. Ce-Mo 6061, developed by the University of Southern California, uses cerium nitrate ($Ce(NO_2)^3$) or cerium chloride ($CeCl_3$) as the rare earth metal. When applying a Ce-Mo 6061 coating, many steps must be followed to produce an adequate coating. These steps are listed below.

1. *Cleaning:* Alconox with hexane is recommended for cleaning by the University of Southern California. Alconox contains alkyl aryl sulfonates.
2. *Water Rinsing*
3. *Deoxidizing:* The University of Southern California recommends using Diversey 560 for deoxidation.
4. *Water Rinsing*
5. *Removing Copper:* Copper must be removed from the part surface. The University of Southern California recommends using Deoxidizer 7 with hydrochloric acid. Deoxidizer 7 contains sodium bifluoride, potassium nitrate, and potassium dichromate.
6. *Water Rinsing*
7. *Desmutting:* The University of Southern California recommends that desmutting be performed with nitric acid that is maintained between 104°F and 113°F.
8. *Water Rinsing*
9. *Oxidizing:* Part surfaces are oxidized by baking them at 212°F for 2 days.
10. *Surface Modification 1:* During this step, parts are immersed in a bath containing $CeCl_3$ that is maintained at 212°F.
11. *Water Rinsing*
12. *Surface Modification 2:* During this step, parts are immersed in a bath containing $Ce(NO_2)^3$. The bath is maintained at 212°F.
13. *Water Rinsing*
14. *Surface Modification 3:* For this surface modification, 500 mV is applied to parts for 2 hours.
15. *Water Rinsing*
16. *Drying*

Although Ce-Mo 6061 is not currently marketed by the University of Southern California, it has the potential to be distributed because it is patented and licensed.

B.5.1.1. Technical Considerations

NCMS issued a study that compared nonchromate conversion coatings to Alodine 600 and 1200 series coatings (chrome conversion coatings manufactured by Parker Amchem) on aluminum substrates. Among the alternatives tested was Ce-Mo 6061. Below is a summary of the findings.

- *Corrosion Resistance:* Ce-Mo 6061 failed corrosion resistance tests on aluminum alloys 2024, 6061, and 7075. Tests followed MIL-C-5541 procedures.
- *Contact Electrical Resistance:* Ce-Mo 6061 passed contact electrical resistance tests on alloy 6061 before a salt spray. Tests followed MIL-C-81706 procedures. Substrates coated with Ce-Mo 6061 were also tested until failure after a salt spray. The coatings had a mean contact electrical resistance of 2,180 $m\Omega/in^2$.
- *Paint Adhesion:* Ce-Mo 6061 passed wet paint adhesion tests on aluminum alloy 6061, but failed dry paint adhesion tests on that alloy. Results were not available for other aluminum alloys. Tests followed MIL-C-5541 and MIL-C-81706 procedures.

This coating has been tested for corrosion resistance after scratching the coating. Tests were performed by placing the scratched parts in a sodium chloride solution. The parts did not corrode; therefore, the University of Southern California believes that touch-up techniques may not be necessary. If touch-up is necessary, it is expected that cerium nitrate may be able to be brushed on to repair the coating; however, this has not been tested.

B.5.1.2. Environmental Issues

The Ce-Mo 6061 process contains four chemicals in the sixteen-step process that are regulated as HAPs under Title III of the CAA. One HAP is in the cleaning step, two are in the copper removal step, and one is in the desmutting step. Wastewater from the acidic process steps, including copper removal and desmutting, must be neutralized under the CWA. In addition, hexane, Alconox, chromium compounds, and fluoride compounds from the process will require further treatment. Sludge from this process may be required to be managed in accordance with the requirements of RCRA Subtitle C.

B.5.1.3. Health and Safety Issues

OSHA has set PELs and the ACGIH has set TLVs for chemicals in the Ce-Mo 6061 process, as listed in Table B-7.

Table B-7. PELs and TLVs for Chemicals in Ce-Mo 6061 Process

Chemical	OSHA PEL	ACGIH TLV
Hexane	n-Hexane: 500 ppm Other Isomers: None NIOSH: 100 ppm	n-Hexane: 50 ppm Other Isomers: 500 ppm
Sodium Bifluoride	2.5 mg/m^3, as F	2.5 mg/m^3, as F
Potassium Dichromate	0.1 mg/m^3, as CrO_3	0.05 mg/m^3 as Cr
Hydrochloric Acid	5 ppm	5 ppm
Nitric Acid	2 ppm	2 ppm

Ventilation is required to maintain airborne contaminants below the PELs and TLVs. In addition, personal protection, such as goggles, face shields, gloves and respirators, is required. Potassium dichromate, used during copper removal, is a suspected carcinogen. Nitric acid and hexane are experimental teratogens. Hexane is a suspected animal genotoxin. Hexane has demonstrated detrimental effects on the human central nervous system.

B.5.1.4. Additional Supporting Literature

- ACGIH, 1995, *Industrial Ventilation: A Manual of Recommended Practice*. 22nd ed. Cincinnati, OH.
- ACGIH, 1991, *Documentation of the Threshold Limit Values and Biological Exposure Indices*. 6th ed. Vols I-III. Cincinnati, OH.
- Lewis, Richard J., Sr., 1992, *Sax's Dangerous Properties of Industrial Materials*. 8th ed. Vols I-III. Van Nostrand Reinhold, New York.
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- 40 CFR part 261 *et seq*.
- 40 CFR part 400 *et seq*.
- 40 CFR part 129 *et seq*.
- 42 USC §7412(b)

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B.6. MANGANESE OXIDE FILMS

Two products were identified that utilize potassium permanganate solutions to create a manganese oxide coating. Patclin 1910 and Sanchem FP are described below.

B.6.1. Patclin 1910B (Patclin Chemical Company, Inc.)

Patclin 1910B, currently available from Patclin Chemical Company, Inc., is one of a family of products that utilize potassium permanganates to treat surfaces. The Patclin 1910B process is described below.

1. *Cleaning:* Patclin Chemical Company recommends using Patclin 342 for cleaning parts. Patclin 342 contains sodium metasilicate and sodium tripolyphosphate. The cleaning bath is maintained at 160°F.
2. *Water Rinsing*
3. *Etching:* Patclin Chemical Company, Inc. recommends using Patclin 366G for etching parts to be conversion coated. This etchant contains sodium hydroxide and sodium gluconate. The bath is maintained at 140°F.
4. *Water Rinsing*
5. *Desmuttering*
6. *Water Rinsing*
7. *Conversion Coating with Patclin 1910B:* Patclin 1910B contains sodium fluoride and potassium permanganate. The bath is maintained at 170°F.
8. *Water Rinsing*
9. *Drying:* After conversion coating and rinsing, coatings are dried for 40 minutes at 430°F.

B.6.1.1. Technical Considerations

NCMS issued a study that compared nonchromate conversion coatings to Alodine 600 and 1200 series coatings (chrome conversion coatings manufactured by Parker Amchem) on aluminum substrates. Among the alternatives tested was Patclin 1910B. Below is a summary of the findings.

- *Corrosion Resistance:* Patclin 1910B failed corrosion resistance tests on aluminum alloys 2024, 6061, and 7075. Tests followed MIL-C-5541 procedures.
- *Contact Electrical Resistance:* Patclin 1910B passed contact electrical resistance tests on alloy 6061 before a salt spray. Tests followed MIL-C-81706 procedures.

Substrates coated with Patclin 1910B were also tested until failure after a salt spray. The coatings had a mean contact electrical resistance of 179 mΩ/in^2.

- *Paint Adhesion:* Patclin 1910B failed wet and dry paint adhesion tests on alloys 2024, 6061, and 7075. Tests followed MIL-C-5541 and MIL-C-81706 procedures.

Touch-up techniques for Patclin 1910B have not been identified by Patclin Chemical Company to date.

B.6.1.2. Environmental Issues

The Patclin 1910B process contains three chemicals that are regulated as HAPs under Title III of the CAA. One HAP is in Patclin 366G, one is in the desmuttering step, and one (manganese) is in Patclin 1910B. Wastewater from all process steps, except for cleaning and water rinsing, must be neutralized under the CWA. It is unknown if other chemicals in the wastewater will require further treatment. Although this process creates very little waste, sludge from the process baths may be considered to be a listed hazardous waste under RCRA.

B.6.1.3. Health and Safety Issues

OSHA has set PELs and the ACGIH has set TLVs for chemicals in the Patclin 1910B process, as listed in Table B-8.

Table B-8. PELs and TLVs for Chemicals in Patclin 1910B Process

Chemical	OSHA PEL	ACGIH TLV
Sodium Hydroxide	2 mg/m^3 (Ceiling)	2 mg/m^3 (Ceiling)
Nitric Acid	2 ppm	2 ppm
Ammonium Bifluoride	2.5 mg/m^3 as F	2.5 mg/m^3 as F
Sodium Fluoride	2.5 mg/m^3 as F	2.5 mg/m^3 as F
Potassium Permanganate	5 mg/m^3 as Mn	0.2 mg/m^3 as Mn

Ventilation is required to maintain airborne contaminants below the PELs and TLVs. In addition, personal protection, such as respirators and goggles, is required. No suspected carcinogens are present during the Patclin 1910B process. Sodium hydroxide is an experimental animal genotoxin. Nitric acid and hydrofluoric acid are experimental animal teratogens. Hydrofluoric acid appears in EPA's Genetic Toxicity Program.

B.6.1.4. Additional Supporting Literature

- ACGIH, 1995, *Industrial Ventilation: A Manual of Recommended Practice*. 22nd ed. Cincinnati, OH.
- ACGIH, 1991, *Documentation of the Threshold Limit Values and Biological Exposure Indices*. 6th ed. Vols I-III. Cincinnati, OH.
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- Reinecke, Ray. Patclin Chemical Company, Inc. Telephone Conversation. November 20, 1995 and April 4, 1996.
- 40 CFR part 261 *et seq*.
- 40 CFR part 400 *et seq*.
- 40 CFR part 129 *et seq*.
- 42 USC §7412(b)

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B.6.2. Sanchem FP (Sanchem)

Two processes that use potassium permanganate are the Sanchem FP (Full Process) and the Sanchem SD (Single Dip). Commercially, Sanchem SD has widespread use. Sanchem FP currently is being used by one facility. Only Sanchem FP is discussed in this document because it meets the selection criteria as an alternative to chrome conversion coating. The Sanchem FP process is described below.

1. *Cleaning*

2. *Water Rinsing*
3. *Deoxidizing*
4. *Water Rinsing*
5. *Forming Initial Oxide Film:* Parts may be placed in boiling de-ionized (DI) water to form an initial oxide film. An alternative to using boiling DI water is using 230°F steam.
6. *Safeguard 2000:* Safeguard 2000 consists of aluminum nitrate and lithium nitrate. This chemical is maintained at 190°F to 200°F. This can be an immersion or spray process, and parts are immersed or sprayed for 2 minutes. In actuality, this step forms a light "anodize" coating.
7. *Water Rinsing*
8. *Safeguard 3000:* A potassium permanganate solution, Safeguard 3000, is used to increase the oxide thickness after conversion coating. In addition, it deposits a manganese oxide layer that provides corrosion resistance. The solution is maintained at 140°F to 150°F, and parts are immersed for 3 minutes.
9. *Water Rinsing*
10. *Sealing:* After conversion coating, parts are placed in a hot potassium silicate solution to seal the oxide film.
11. *Water Rinsing*
12. *Drying*

B.6.2.1. Technical Considerations

NCMS issued a study that compared nonchromate conversion coatings to Alodine 600 and 1200 series coatings (chrome conversion coatings manufactured by Parker Amchem) on aluminum substrates. Among the alternatives tested was Sanchem FP. Below is a summary of the findings.

- *Corrosion Resistance:* Sanchem FP failed corrosion resistance tests on aluminum alloys 2024, 6061, and 7075. Tests followed MIL-C-5541 procedures.
- *Contact Electrical Resistance:* Sanchem FP passed contact electrical resistance tests on alloy 6061 before a salt spray. Tests followed MIL-C-81706 procedures. Substrates coated with Sanchem FP were also tested until failure after a salt spray. The coatings had a mean contact electrical resistance of 471 $m\Omega/in^2$.
- *Paint Adhesion:* Sanchem FP passed dry and wet paint adhesion tests on alloy 7075. It passed the dry paint adhesion test on alloy 2024, but failed the wet paint adhesion test on that alloy. It passed the wet paint adhesion

test on alloy 6061, but failed the dry paint adhesion test. Tests followed MIL-C-5541 and MIL-C-81706 procedures.

The MITRE Corporation performed a study (MITRE, 1994) to identify alternatives to chrome conversion coatings for the McClellan Air Force Base. Safeguard CC, which is a generic Sanchem FP process, was one of the three alternatives discussed in the document. The information listed below was reported.

- *Corrosion Resistance:* Salt spray testing was performed with unpainted and painted Safeguard CC coatings. Unpainted substrates had a salt spray resistance of over 168 hours (the requirement for MIL-C-5541). In addition, painted substrates had a salt spray resistance of over 2,000 hours.
- *Contact Electrical Resistance:* Safeguard CC had a contact electrical resistance of over 5 $m\Omega/in^2$ before the salt spray, and over 10 $m\Omega/in^2$ after the salt spray.
- *Paint Adhesion:* Safeguard CC passed both cross-hatch and wet tape tests.

If this coating becomes scratched or marred, a substance such as Safeguard 6000, which is available from Sanchem, may be used to repair the coating. Safeguard 6000 is based on potassium permanganate and acetic acid. Safeguard 6000 is currently being tested by Alcan Aluminum in England and by Lockheed in the United States. It may be used to repair a wide variety of aluminum substrates.

Although Sanchem FP is a potential alternative, it is slower than the chrome conversion process. For example, the immersion process takes 30 minutes minimum, while the chrome conversion coating process takes 3 to 5 minutes.

B.6.2.2. Environmental Issues

The Sanchem process contains at least one chemical that is regulated as a HAP under Title III of the CAA. Specifically, the manganese that is in the potassium permanganate is regulated as a HAP. Under the CWA, wastewater from the process may require neutralization. Compounds may also be present in Sanchem FP that require further treatment. Sludge from this process may be required to be managed in accordance with the requirements of RCRA Subtitle C.

B.6.2.3. Health and Safety Issues

OSHA has set PELs and the ACGIH has set TLVs for chemicals in the Sanchem FP process, as listed in Table B-9.

Table B-9. PELs and TLVs for Chemicals in Sanchem FP Process

Chemical	OSHA PEL	ACGIH TLV
Powder	15 mg/m^3 Total 5 mg/m^3 Respirable	10 mg/m^3
Aluminum Nitrate	None NIOSH: 2 mg/m^3 Al	2 mg/m^3 Al
Potassium Permanganate	5 mg/m^3 as Mn	0.2 mg/m^3 as Mn

Table B-10 lists the chemical products of the Sanchem FP process as well as the constituent chemicals present during the process.

Table B-10. Chemical Products of Sanchem FP Process

Product	Constituent	CAS Number	Percent by Mass
Sanchem 500	White Powder	N.A.	N.A.
Sanchem CC-1000	Sodium Bromate	07789-38-0	N.A.
Safeguard 2000	Aluminum Nitrate	13473-90-0	N.A.
	Lithium Nitrate	N.A.	N.A.
Safeguard 3000	Potassium Permanganate	07722-64-7	N.A.
Safeguard 4000	N.A.	N.A.	N.A.

N.A. = Not Available

Ventilation is required to maintain airborne contaminants below the PELs and TLVs. In addition, personal protection, such as respirators and goggles, may be required. Mutation data exists for potassium permanganate and it is also an experimental animal teratogen/reproductive toxicant. No other known or suspected carcinogens, teratogens, mutagens, or neurotoxins were noted in Sanchem FP.

B.6.2.4. Additional Supporting Literature

- ACGIH, 1995, *Industrial Ventilation: A Manual of Recommended Practice*. 22nd ed. Cincinnati, OH.
- ACGIH, 1996, *1996 TLVs and BEIs. Threshold Limit Values for Chemical Substances and Physical Agents. Biological Exposure Indices.* Second Printing. ACGIH, Cincinnati, OH.
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- National Center for Manufacturing Sciences, 1995, *Alternatives to Chromium for Metal Finishing*, Ann Arbor, Michigan.
- NIOSH, 1994, *NIOSH Pocket Guide to Chemical Hazards*. U.S. Government Printing Office, Washington, DC.
- Sanchem, 1990. *Sanchem 500 Material Safety Data Sheet*, Sanchem, Chicago, IL.
- Sanchem, 1990. *Sanchem CC-1000 Material Safety Data Sheet*, Sanchem, Chicago, IL.
- Sanchem, 1994. *Safeguard 2000 Material Safety Data Sheet*, Sanchem, Chicago, IL.
- Sanchem, 1994. *Safeguard CC-3000 Material Safety Data Sheet*, Sanchem, Chicago, IL.
- 40 CFR part 261 *et seq*.
- 40 CFR part 400 *et seq*.
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- 42 USC §7412(b)

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B.7. FLUOTITANIC COATINGS

One product using fluotitanic coating technology, Permatreat 611, was identified as a promising alternative to chrome conversion coatings in aerospace applications.

B.7.1. Permatreat 611 (Betz Laboratories)

Permatreat 611, distributed by Betz Laboratories, is a possible alternative to chrome conversion coatings. Although Permatreat 611 has been widely used in a variety of applications, it has not been used in the aerospace industry to date. It requires only four steps, as listed below.

1. *Cleaning:* Betz Laboratories recommends using Betz Kleen 156 and Betz Sol 104 for cleaning parts. Betz Kleen 156 contains sodium hydroxide, while Betz Sol 104 contains alcohols and alkylated fatty alcohol. This bath is at ambient temperature.
2. *Water Rinsing*
3. *Conversion Coating with Permatreat 611:* Permatreat 611 contains fluotitanic acid and a proprietary, low-volatility organic polymer. It is a dry, in-place treatment in which the chemicals are applied to the part surface, and the chemicals are allowed to drain off. The chemicals are maintained at ambient temperature.
4. *Drying*

B.7.1.1. Technical Considerations

NCMS issued a study that compared nonchromate conversion coatings to Alodine 600 and 1200 series coatings (chrome conversion coatings manufactured by Parker Amchem) on aluminum substrates. Among the alternatives tested was Permatreat 611. Below is a summary of the findings.

- *Corrosion Resistance:* Permatreat 611 failed corrosion resistance tests on aluminum alloys 2024, 6061, and 7075. Tests followed MIL-C-5541 procedures.
- *Contact Electrical Resistance:* Permatreat 611 passed contact electrical resistance tests on alloy 6061 before a salt spray. Tests followed MIL-C-81706 procedures. Substrates coated with Permatreat 611 were also tested until failure after a salt spray. The coatings had a mean contact electrical resistance of 480 $m\Omega/in^2$.
- *Paint Adhesion:* Permatreat 611 passed dry and wet paint adhesion tests on alloys 2024 and 7075. It also passed the

wet paint adhesion test on alloy 6061, but failed the dry paint adhesion test on that alloy. Tests followed MIL-C-5541 and MIL-C-81706 procedures.

Scratches in the coating can be repaired by brushing on the original solution type (typically 1.5%) of Permatreat 611. After brushing on the solution, the part needs to dry thoroughly before using it again.

B.7.1.2. Environmental Issues

The Permatreat 611 process, specifically the cleaning step, contains one chemical that is regulated as a HAP under Title III of the CAA. Under the CWA, wastewater from the process must be neutralized. Compounds may also be present in Permatreat 611 that require further treatment. Sludge from this process may be required to be managed in accordance with the requirements of RCRA Subtitle C.

B.7.1.3. Health and Safety Issues

OSHA has set PELs and the ACGIH has set TLVs for chemicals in the Permatreat 611 process, as listed in Table B-11.

Table B-11. PELs and TVLs for Chemicals in Permatreat 611 Process

Chemical	OSHA PEL	ACGIH TLV
Sodium Hydroxide	2 mg/m^3 (Ceiling)	2 mg/m^3 (Ceiling)
Fluotitanic Acid	2.5 mg/m^3 as F	2.5 mg/m^3 as F

Ventilation is required to maintain airborne contaminants below the PELs and TLVs. In addition, personal protection, such as respirators and goggles, is required. Permatreat 611 may cause lung damage if respirators are not used. No suspected carcinogens are present during the Permatreat 611 process. However, sodium hydroxide is an experimental animal genotoxin.

B.7.1.4. Additional Supporting Literature

- ACGIH, 1995, *Industrial Ventilation: A Manual of Recommended Practice*. 22nd ed. Cincinnati, OH.
- ACGIH, 1991, *Documentation of the Threshold Limit Values and Biological Exposure Indices*. 6th ed. Vols I-III. Cincinnati, OH.

- Kasouff, Mitch. Betz Laboratories, Inc. Telephone Conversation. November 20, 1995 and April 4, 1996.
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- NIOSH, 1994, *NIOSH Pocket Guide to Chemical Hazards*. U.S. Government Printing Office, Washington, DC.
- 40 CFR part 261 *et seq*.
- 40 CFR part 400 *et seq*.
- 40 CFR part 129 *et seq*.
- 42 USC §7412(b)

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B.8. TALC COATINGS

Sandia National Labs has developed several talc coatings that may be considered alternatives to chrome conversion coatings. Two of these coatings are described below.

B.8.1. Sandia 1 and Sandia 2 (Sandia National Laboratories)

Sandia 1 and Sandia 2 are two talc coatings. The main difference between these alternatives is the treatment time. The Sandia 1 and Sandia 2 process steps are listed below.

1. *Cleaning:* Sandia National Laboratories recommends Alconox, which contains alkyl aryl sulfonates.
2. *Water Rinsing*
3. *Alkaline Degreasing:* Sodium metasilicate and sodium carbonate are recommended by Sandia National Laboratories for alkaline degreasing. This bath is maintained at 149°F.
4. *Water Rinsing*
5. *Etching:* Sandia National Laboratories recommends using Sanchem 1000 for etching prior to conversion coating. Sanchem 1000, which is maintained at 122°F, contains sodium bromate and nitric acid.
6. *Water Rinsing*
7. *Conversion Coating with Sandia 1 or Sandia 2:* Sandia 1 and Sandia 2 contain sodium aluminate and lithium carbonate. Processing time for Sandia 1 is 15 minutes, and for Sandia 2 is 5 hours. The process is maintained at 131°F.
8. *Water Rinsing*
9. *Drying*

Sandia 1 and Sandia 2 are not commercially available to date.

B.8.1.1. Technical Considerations

NCMS issued a study that compared nonchromate conversion coatings to Alodine coatings (chrome conversion coatings manufactured by Parker Amchem) on aluminum substrates. Sandia 1 and Sandia 2 were tested as alternatives to chrome conversion coatings. Below is a summary of the findings.

Sandia 1

- *Corrosion Resistance:* Sandia 1 coatings failed corrosion resistance tests on aluminum alloys 2024, 6061, and 7075. Tests followed MIL-C-5541 procedures.
- *Contact Electrical Resistance:* Sandia 1 coatings passed contact electrical resistance tests on alloy 6061 before a salt spray. Tests followed MIL-C-81706 procedures. Substrates coated with Sandia 1 were also tested until failure after a salt spray. The coatings had a mean contact electrical resistance of 397 $m\Omega/in^2$.
- *Paint Adhesion:* Sandia 1 failed dry and wet paint adhesion tests on alloys 2024, 6061, and 7075. Tests followed MIL-C-5541 and MIL-C-81706 procedures.

Sandia 2

- *Corrosion Resistance:* Sandia 2 coatings passed corrosion resistance tests on aluminum alloy 6061. However, they did not pass tests on alloy 2024 or alloy 7075. Tests followed MIL-C-5541 procedures.
- *Contact Electrical Resistance:* Sandia 2 coatings failed contact electrical resistance tests on alloy 6061 before a salt spray. Tests followed MIL-C-81706 performance requirements. Substrates coated with Sandia 2 were also tested until failure after a salt spray. The coatings had a mean contact electrical resistance of 23,700 $m\Omega/in^2$.
- *Paint Adhesion:* Sandia 2 failed dry and wet paint adhesion tests on alloys 2024, 6061, and 7075. Tests followed MIL-C-5541 and MIL-C-81706 procedures.

Sandia 1 and Sandia 2 have been evaluated for touch-up techniques. Brushing on the original solution was successful for repair of the coating.

B.8.1.2. Environmental Issues

Ozone-depleting substances (ODSs) and HAPs are not present in Sandia 1 or Sandia 2. Neutralization is not required for any of the wastewater, but the cleaning wastewater must be treated to remove Alconox. Sludge from the process baths may be considered to be a listed hazardous waste under RCRA.

B.8.1.3. Health and Safety Issues

Personal protection such as goggles and rubber gloves must be utilized. Respirators may be required, depending on the airborne concentration of the lithium carbonate. Carcinogens are not present in Sandia 1 or Sandia 2, and no OSHA PELs or ACGIH TLVs are applicable to the process. However, lithium carbonate is a suspected human carcinogen and a human teratogen and genotoxin. It should be noted that human mutation data has been reported, and lithium carbonate is a human teratogen by ingestion.

B.8.1.4. Additional Supporting Literature

- ACGIH, 1995, *Industrial Ventilation: A Manual of Recommended Practice*. 22nd ed. Cincinnati, OH.
- ACGIH, 1991, *Documentation of the Threshold Limit Values and Biological Exposure Indices*. 6th ed. Vols I-III. Cincinnati, OH.
- Buchheit, Rudy. Sandia National Laboratories. Telephone Conversation. November 27, 1995 and April 9, 1996.
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- 40 CFR part 261 *et seq*.
- 40 CFR part 400 *et seq*.
- 40 CFR part 129 *et seq*.
- 42 USC §7412(b)

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B.9. ANODIZING

Anodizing is not a new technology, but there have been some recent developments, and in many applications, anodizing can replace conversion coatings. One alternative product and one alternative sealer are described below.

B.9.1. Sulfuric-Boric Acid Anodizing (Boeing Aerospace Corporation)

Anodizing is a process that produces a tough, adherent surface layer by converting a metal surface to an oxide layer. Sulfuric-boric acid anodizing (SBAA) is one alternative to chrome conversion coating and is often preferred over other alternatives, since it provides good corrosion resistance and paint adhesion. SBAA was originally developed by Boeing Aerospace Corporation to replace chromic acid anodizing; however, it may also be used to replace chrome conversion coatings. To apply SBAA, the process steps listed below are typically followed.

1. *Cleaning:* Alkaline and/or solvent cleaning must be performed before anodizing.
2. *Water Rinsing*
3. *Deoxidizing:* Deoxidizing can be performed with a variety of nonchrome deoxidizers.
4. *Water Rinsing*
5. *Sulfuric-Boric Acid Anodizing:* After parts are prepared, they are dipped into a heated bath of sulfuric acid and boric acid.
6. *Water Rinsing*
7. *Sealing:* After anodizing, parts are sealed with hot water that contains 300 ppm chrome, such as magnesium chrome.

This process is patented; however, it is not currently licensed to any specific company for production.

B.9.1.1. Technical Considerations

The MITRE Corporation performed a study to identify alternatives to chrome conversion coatings for the McClellan Air Force Base. SBAA was one of the three alternatives evaluated. The information listed below was reported.

- *Corrosion Resistance:* Salt spray testing was performed with unpainted and painted SBAA coatings on 2024 and 7075 aluminum. Unpainted substrates had a salt spray resistance of over 336 hours (the requirement for MIL-C-81706). In addition, painted substrates had a salt spray resistance of over 2,000 hours.

- *Contact Electrical Resistance:* On 6061 aluminum, SBAA had a contact electrical resistance of over 5 $m\Omega/in^2$ before the salt spray, and over 10 $m\Omega/in^2$ after the salt spray.
- *Paint Adhesion:* SBAA passed both cross-hatch and wet tape tests on 2024 and 7075 aluminum alloys.

Similar tests were performed at the Naval Air Warfare Center (Westminster, Pennsylvania). The results are listed below.

- *Corrosion Resistance:* Corrosion resistance tests were performed for 336 hours, according to ASTM B-117 procedures. No surface corrosion occurred on panels coated with SBAA.
- *Paint Adhesion:* SBAA coatings passed wet tape paint adhesion tests. Panels were tested after 24, 96, and 168 hours, and no peeling or removal was identified on the panels.

If a part needs to be repaired, either Alodine (which contains chromium) or brush anodizing may be used. One disadvantage of anodizing processes is that they cannot be used for substrates that have sharp edges or geometries that can entrap the corrosive fluids.

B.9.1.2. Environmental Issues

The SBAA process contains compounds, specifically chromium and chromium compounds, that are regulated as HAPs under Title III of the CAA. Other HAPs may also be present in the cleaners and deoxidizers, depending on the type chosen. Under the CWA, wastewater from the process must be neutralized. In addition, metals that are present in the wastewater from several of the steps, including sealing, will require further treatment for removal. Sludge from this process may be required to be managed in accordance with the requirements of RCRA Subtitle C.

B.9.1.3. Health and Safety Issues

OSHA has set PELs and the ACGIH has set TLVs for chemicals in the SBAA process, as listed in Table B-12.

Table B-12. PELs and TVLs for Chemicals in SBAA Process

Chemical	OSHA PEL	ACGIH TLV
Sulfuric Acid	1 mg/m^3	1 mg/m^3
Chromium Metals and Insoluble Salts	1 mg/m^3	0.5 mg/m^3 as Cr, Cr Metal and Cr (III) Compounds 0.01 mg/m^3, Insoluble Cr (VI) Compounds
Trivalent Chromium	0.5 mg/m^3 as Cr	0.5 mg/m^3 as Cr

Other PELs and TLVs may be applicable, depending on the specific cleaners and deoxidizers used. Ventilation is required to maintain airborne contaminants below the PELs and TLVs. In addition, personal protection, such as respirators and goggles, may be required. Sulfuric acid and chromium compounds are suspected carcinogens. No teratogens, genotoxins, or neurotoxins are present in this alternative. Sulfuric acid is an experimental animal teratogen.

B.9.1.4. Additional Supporting Literature

- ACGIH, 1995, *Industrial Ventilation: A Manual of Recommended Practice*. 22nd ed. Cincinnati, OH.
- ACGIH, 1991, *Documentation of the Threshold Limit Values and Biological Exposure Indices*. 6th ed. Vols I-III. Cincinnati, OH.
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- National Center for Manufacturing Sciences, (NCMS), 1995, *Alternatives to Chromium for Metal Finishing*, Ann Arbor, Michigan.
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- Spadafora, Stephen J., Naval Air Warfare Center; and Frank R. Pepe, NAVMAR Applied Sciences Inc. "A Comparison of Sulfuric-Boric Acid Anodize and Chromic Acid Anodize Processes." *Metal Finishing*. April 1994. pp. 53-57.
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- 40 CFR part 400 *et seq*.
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- 42 USC §7412(b)

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B.9.2. Alumitec (Alumitec Products Corporation)

Alumitec Products Corporation currently markets a line of products referred to as Alumitec AC, D, E, FC, and I. These materials contain long-chain carboxylic acids to treat anodized aluminum parts. The types of Alumitec products are varied to fit specific applications, as listed bleow.

- *Alumitec AC*: This is an aircraft grade. It is specifically formulated for long bath life.
- *Alumitec D*: This is a standard grade. It consists of 99.9% isostearic acid and 0.1% benzotriazole.
- *Alumitec E*: This is a water emulsion for application over oily or dyed surfaces.
- *Alumitec FC*: This is acceptable for incidental food contact because it contains citric acid as a chelating agent.
- *Alumitec I*: This is acceptable when bath life is not a factor.

This product may be considered more of a sealant for anodizing than a conversion coating, but it is still included in this document for completeness. The vendor suggests that this chemical eliminates the need for a conversion coating. The process consists of the steps listed below.

1. *Cleaning:* If necessary, parts may be cleaned to remove excess contaminants.
2. *Water Rinsing and Drying:* If parts are cleaned, rinsing and drying may be necessary.
3. *Anodizing:* Only anodized aluminum parts can be treated with Alumitec products. Sulfuric acid anodizing may be performed, or sulfuric/oxalic acid anodizing may be performed for a harder coating. Sulfuric acid anodizing is performed at 70°F, and sulfuric/oxalic acid anodizing is performed at 35°F.
4. *Water Rinsing and Drying*
5. *Treatment with Alumitec Product:* Parts may be dipped, sprayed, or wiped with Alumitec products.
6. *Tumbling Absorbents or Immersing in NMP:* Isostearic acid can leave an oily residue on part surfaces. Oil may be removed by tumbling the parts with absorbents or dipping the parts in an aqueous n-methyl pyrrolidone (NMP) solution.
7. *Ambient Air Drying*

B.9.2.1. Technical Considerations

Alumitec Products Corporation reports the qualities of their coatings as listed below.

- *Corrosion Resistance:* Alumitec Products Corporation has tested Alumitec products by using ASTM B-117, and claims that they have between 816 and 1,650 hours corrosion resistance before getting five pits on aluminum alloy 2024. Therefore, these products pass corrosion resistance tests for MIL-C-5541.
- *Contact Electrical Resistance:* The only information concerning electrical resistance is that the coating has a electrical impedance spectroscopy reading of 26 to 27 $m\Omega/cm^2$ (approximately 174 $m\Omega/in^2$)
- *Paint Adhesion:* After treatment with NMP, parts were tested for paint adhesion with epoxy primer and paint. The requirement was that the salt spray should not drop below 336 hours. If parts were sealed using a 10%, 15%, or 25% isostearic solution, they took 300, 500, and 1,400 hours, respectively, for failure. Salt spray tests were in accordance

with ASTM B-117. Douglas Aircraft Company conducted the paintability studies.

This coating is actually a sealer to be used with anodized parts, and is not used independent of the anodize process. Sulfuric-Boric Acid Anodize could use these sealants. This alternative has not been tested as extensively as the others. This sealant is listed for completeness of identifying alternatives, but by itself, will not be considered a viable conversion coating alternative.

Although brush plating has not been successful for repair, Alumitec believes that brush anodizing will be a possible touch-up technique for scratched parts that were previously coated with Alumitec. After brush anodizing with a material such as sulfuric acid, the excess sealant should be wiped off of the part.

B.9.2.2. Environmental Issues

Benzotriazole, isostearic acid, and NMP are not listed as hazardous air pollutants, and are not considered to be ozone depleting substances. In addition, the chemicals are not listed as hazardous substances in the CWA, and are not on the CWA Priority Pollutant list. However, general requirements for the CAA, CWA, and RCRA may be applicable to this process.

B.9.2.3. Health and Safety Issues

Benzotriazole, isostearic acid, and NMP and are not regulated by OSHA or the ACGIH. Alumitec products have a reported LD_{50} of 25 g/kg. Benzotriazole was found to be an experimental animal genotoxin, and NMP was found to be an experimental teratogen. The available MSDS for NMP presents human neurotoxin concerns.

B.9.2.4. Additional Supporting Literature

- ACGIH, 1995, *Industrial Ventilation: A Manual of Recommended Practice*. 22nd ed. Cincinnati, OH.
- ACGIH, 1991, *Documentation of the Threshold Limit Values and Biological Exposure Indices*. 6th ed. Vols I-III. Cincinnati, OH.

- Lewis, Richard J., Sr., 1992, *Sax's Dangerous Properties of Industrial Materials*. 8th ed. Vols I-III. Van Nostrand Reinhold, New York.
- MSDS Information Systems Inc., 1996, *OHS MSDS on Disk.*
- National Center for Manufacturing Sciences, 1995, *Alternatives to Chromium for Metal Finishing*, Ann Arbor, Michigan.
- NIOSH, 1994, *NIOSH Pocket Guide to Chemical Hazards*. U.S. Government Printing Office, Washington, DC.
- Shulman, Garson P. and A. J. Bauman. Alumitec Products Corporation. "Organic Sealants for Anodized Aluminum - Chrome Free Corrosion Protection." *2nd Annual Techniques for Replacing Chromium: An Information Exchange*. Champion, Pennsylvania. November 7-8, 1995.
- Shulman, Garson. Alumitec Products Corporation. Telephone Conversation. November 20, 1995 and April 4, 1996.
- 40 CFR part 261 *et seq*.
- 40 CFR part 400 *et seq*.
- 40 CFR part 129 *et seq*.
- 42 USC §7412(b)

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B.10. PROPRIETARY TECHNIQUES

Six proprietary techniques for replacing chrome conversion coatings were identified by the technology survey. These products and/or processes are commercially available for general use, and are therefore possible alternatives to chrome conversion coatings.

B.10.1. Alumicoat 6788 (Elf Atochem - Turco Products Division)

Alumicoat 6788 is a proprietary conversion coating that requires the process steps listed below.

1. *Cleaning*
2. *Water Rinsing*
3. *Deoxidizing*
4. *Water Rinsing*
5. *Conversion Coating with Alumicoat 6788:* This is a nonorganic bath that contains acrylic and corrosion inhibitors. (It has been compared to a floor polish.) The conversion coating bath is held at ambient temperature.
6. *Drying:* Parts may be allowed to drip dry.
7. *Curing:* After parts are drip dried, they are cured in an oven for 30 minutes at 180°F.

Alumicoat 6788 is now commercially available from the Turco Products Division of Elf Atochem. It has been tested by Northrop and Boeing. However, it has not been purchased and used regularly in an industrial environment.

B.10.1.1. Technical Considerations

NCMS issued a study that compared nonchromate conversion coatings to Alodine 600 and 1200 series coatings (chrome conversion coatings manufactured by Parker Amchem) on aluminum substrates. One alternative tested was referred to as Alumicoat 6788. Below is a summary of the findings:

- *Corrosion Resistance:* Alumicoat 6788 coatings exceeded performance requirements for corrosion resistance tests on aluminum alloys 2024, 6061, and 7075. Tests followed MIL-C-5541 procedures.
- *Contact Electrical Resistance:* Alumicoat 6788 coatings failed contact electrical resistance tests on alloy 6061 before a salt spray. Tests followed MIL-C-81706 procedures. Substrates coated with Alumicoat 6788 were also tested until failure after a salt spray. The coatings had a mean contact electrical resistance of 6,150,000 mΩ/in^2.

- *Paint Adhesion:* Alumicoat 6788 passed dry and wet paint adhesion tests on aluminum alloys 2024, 6061, and 7075. Tests followed MIL-C-5541 and MIL-C-81706 procedures.

Elf Atochem expects that scratched parts previously treated with Alumicoat 6788 may be repaired by simply brushing on Alumicoat 6788 solution over the desired area. However, this touch-up technique has not been tested.

B.10.1.2. Environmental Issues

Although the constituents of this conversion coating process are proprietary, the mixture contains no ODSs or HAPs. It is unknown if HAPs are present during the cleaning, deoxidizing, or conversion coating steps. It is also unknown if wastewater from the process requires neutralization or further treatment. Sludge from this process may be required to be managed in accordance with the requirements of RCRA Subtitle C.

B.10.1.3. Health and Safety Issues

Worker exposure limits have been set for 2-propanol, which is one of the chemicals in the Alumicoat 6788 process. OSHA has set a PEL of 400 ppm for this chemical, and ACGIH has set a TLV of 400 ppm, as well.

Table B-13 lists the chemical products of the Alumicoat 6788 process as well as the constituent chemicals present during the process.

Table B-13. Chemical Products of Alumicoat 6788 Process

Product	Constituent	CAS Number	Percent by Mass
Alumicoat 6788	N-Methyl Pyrrolidone	00872-50-4	5
	2-Propanol	00067-63-0	<5

Although the constituents of this conversion coating process are proprietary, the mixture contains no suspected carcinogens. Turco recommends the use of gloves, respirators, rubber aprons, and goggles for personnel working with the cleaning and deoxidizing agents. Isopropyl alcohol is a suspected human carcinogen and a known human neurotoxin. N-methyl 2-pyrrolidone and isopropanol have been shown to be experimental animal teratogens and genotoxins. N-methyl pyrrolidone may have deleterious effects on the CNS. The likelihood of the agent containing other teratogens, genotoxins or neurotoxins is unknown.

B.10.1.4. Additional Supporting Literature

- ACGIH, 1995, *Industrial Ventilation: A Manual of Recommended Practice*. 22nd ed. Cincinnati, OH.
- ACGIH, 1996, *1996 TLVs and BEIs*. *Threshold Limit Values for Chemical Substances and Physical Agents. Biological Exposure Indices.* Second Printing. ACGIH, Cincinnati, OH.
- Elf Atochem - Turco Products Division, 1995. *Alumicoat 6788 Material Safety Data Sheet*, Elf Atochem - Turco Products Division, Westminster, CA.
- Grainger, John. Elf Atochem. Turco Products Division. Telephone Conversation. April 10, 1996.
- Lewis, Richard J., Sr., 1996, *Sax's Dangerous Properties of Industrial Materials*. 9th ed. Vols I-III. Van Nostrand Reinhold, New York.
- MSDS Information Systems Inc., 1996, *OHS MSDS on Disk*.
- Muller, Frank. Elf Atochem. Turco Products Division. Telephone Conversation. November 14, 1995.
- National Center for Manufacturing Sciences, 1995, *Alternatives to Chromium for Metal Finishing*, Ann Arbor, Michigan.
- NIOSH, 1994, *NIOSH Pocket Guide to Chemical Hazards*. U.S. Government Printing Office, Washington, DC.
- 40 CFR part 261 *et seq*.
- 40 CFR part 400 *et seq*.
- 40 CFR part 129 *et seq*.
- 42 USC §7412(b)

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B.10.2. Chemcote L497260A (Brent America, Inc.)

Chemcote L497260A is a proprietary chemical conversion coating that offers corrosion resistance and contact electrical resistance. The overall conversion coating process is listed below.

1. *Cleaning:* Brent America, Inc. recommends that Chem-Clean 1220 be used. Chem-Clean 1220 contains potassium hydroxide and potassium silicate. The bath is maintained at 68°F to 180°F.
2. *Water Rinsing*
3. *Etching:* Brent America, Inc. recommends that Chem-Etch 7002 is used for etching. Chem-Etch 7002 contains sodium hydroxide. The bath is maintained at 140°F to 180°F.
4. *Water Rinsing*
5. *Deoxidizing:* Brent America, Inc. recommends that ChemCid 2213 is used for deoxidation of the surface. ChemCid 2213 contains sulfuric acid, nitric acid, ferric sulfate, and hydrogen peroxide.
6. *Water Rinsing*
7. *Conversion Coating with Chemcote L497260A:* The composition of this bath is proprietary.
8. *Water Rinsing*
9. *Drying*

B.10.2.1. Technical Considerations

NCMS issued a study that compared nonchromate conversion coatings to Alodine 600 and 1200 series coatings (chrome conversion coatings manufactured by Parker Amchem) on aluminum substrates. Among the alternatives tested was Chemcote L497260A. Below is a summary of the findings.

- *Corrosion Resistance:* Chemcote L497260A exceeded performance requirements for corrosion resistance tests on aluminum alloy 6061. However, it did not pass the tests on alloys 2024 or 7075. Tests followed MIL-C-5541 procedures.
- *Contact Electrical Resistance:* Chemcote L497260A passed contact electrical resistance tests on alloy 6061 before a salt spray. Tests followed MIL-C-81706 procedures. Substrates coated with Chemcote L497260A were also tested until failure after a salt spray. The coatings had a mean contact electrical resistance of 75.5 $m\Omega/in^2$.
- *Paint Adhesion:* Chemcote L497260A passed dry and wet paint adhesion tests on aluminum alloys 2024 and 7075. It also passed the dry paint adhesion test for alloy 6061, but

failed wet paint adhesion tests on that alloy. Tests followed MIL-C-5541 and MIL-C-81706 procedures.

Studies have not been performed to evaluate touch-up techniques. However, Brent America believes that Chemcote L497260A can be brushed on to repair coatings.

B.10.2.2. Environmental Issues

The Chemcote L497260A process contains three chemicals in the nine-step process that are regulated as HAPs under Title III of the CAA. One HAP is in Chem-Etch 7002, and two are in ChemCid 2213. Wastewater from the process must be neutralized to meet CWA permitting guidelines for the Metal Finishing Point Source category. Additionally, metals that may be present in the wastewater from several of the steps, including Chem-Etch 7002 (aluminum only) and ChemCid 2213, will require further treatment to ensure proper removal from the wastewater. Sludge from this process may be required to be managed in accordance with the requirements of RCRA Subtitle C.

B.10.2.3. Health and Safety Issues

OSHA has set PELs and the ACGIH has set TLVs for chemicals in the Chemcote L497260A process, as listed in Table B-14.

Table B-14. PELs and TVLs for Chemicals in Chemote L497260A Process

Chemical	OSHA PEL	ACGIH TLV
Potassium Hydroxide	None NIOSH: 2 mg/m^3	2 mg/m^3 (Ceiling)
Sodium Hydroxide	2 mg/m^3 (Ceiling)	2 mg/m^3 (Ceiling)
Sulfuric Acid	1 mg/m^3	1 mg/m^3
Nitric Acid	2 ppm	2 ppm
Ferric Sulfate	None NIOSH: 1 mg/m^3 as Fe	None
Hydrogen Peroxide	1 ppm	1 ppm

Ventilation is required to maintain airborne contaminants below the PELs and TLVs. In addition, personal protection, such as OSHA-approved respirators and goggles, is required. Contact lenses cannot be worn in the area, and impermeable gloves should be worn. ChemCid 2213 gives off sulfuric acid fumes; sulfuric acid is a suspected carcinogen. Sodium hydroxide is an experimental genotoxin, and nitric acid is an experimental animal teratogen. Hydrogen peroxide is a suspected human genotoxin and an experimental animal teratogen.

B.10.2.4. Additional Supporting Literature

- ACGIH, 1995, *Industrial Ventilation: A Manual of Recommended Practice*. 22nd ed. Cincinnati, OH.
- ACGIH, 1991, *Documentation of the Threshold Limit Values and Biological Exposure Indices*. 6th ed. Vols I-III. Cincinnati, OH.
- Enright, David. Brent America, Inc. Telephone Conversation. April 9, 1996.
- Lewis, Richard J., Sr., 1992, *Sax's Dangerous Properties of Industrial Materials*. 8th ed. Vols I-III. Van Nostrand Reinhold, New York.
- MSDS Information Systems Inc., 1996, *OHS MSDS on Disk.*
- National Center for Manufacturing Sciences, 1995, *Alternatives to Chromium for Metal Finishing*, Ann Arbor, Michigan.
- NIOSH, 1994, *NIOSH Pocket Guide to Chemical Hazards*. U.S. Government Printing Office, Washington, DC.
- 40 CFR part 261 *et seq*.
- 40 CFR part 400 *et seq*.
- 40 CFR part 129 *et seq*.
- 42 USC §7412(b)

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B.10.3. Chrome-Free Conversion Coating (Hughes Aircraft Company)

The Hughes' Chrome-Free Conversion Coating (CFCC) process is a treatment sequence intended to provide a nonchrome "drop-in" replacement for the current chrome process. The Hughes process is actually comprised of two processes.

One of the processes (known as the "Long Form") is intended for use on aluminum surfaces that will be left bare. An abbreviated version of this process (known as the "Short Form") is intended for use on surfaces that will be painted following the CFCC treatment.

The objective of both processes is to strip off the native oxide present on all aluminum surfaces using a degreasing and deoxidizing series of baths. This is followed by boiling water seals and immersion in highly diluted baths of salts. This second set of baths is used to regrow a highly uniform, new oxide layer that provides the bulk of the corrosion protection for the substrate surface. Remaining surface imperfections are filled in and sealed using a dilute bath. A final drying step completes the process.

The Short Form process eliminates the diluted salt sealing baths, stopping after the boiling water immersion bath is complete.

The CFCC process is a developmental procedure that has been scaled up and readied for commercial use through a current U.S. Army MICOM program. The CFCC process uses proprietary chemicals that are commercially available and inexpensive. A license for royalty-free U.S. government use of the process is being negotiated. When using the CFCC process, the process steps listed below are followed for the bare metal protection version, or Long Form.

1. *Cleaning:* This currently uses step Parker Amchem Ridoline 322, an aqueous alkaline cleaner.
2. *Water Rinsing*
3. *Deoxidizing:* This step uses Turco Liquid SMUT-GO NC.
4. *Water Rinsing*
5. *Proprietary Step*
6. *Proprietary Seal #1*
7. *Water Rinsing*
8. *Proprietary Seal #2*
9. GN_2 *or Air Dry*

The process steps listed below are followed for the protection of aluminum alloy surfaces that will subsequently be painted. This process is known as the Short Form process.

1. *Cleaning:* This step uses Parker Amchem Ridoline 322.
2. *Water Rinsing*
3. *Deoxidizing:* This step uses Turco Liquid SMUT-GO NC.
4. *Water Rinsing*
5. *Proprietary Step*
6. GN_2 *or Air Dry*

B.10.3.1. Technical Considerations

A program to make a full-scale prototype of the Hughes CFCC process has been funded by MICOM. The results to date are provided below.

- *Corrosion Resistance:* The CFCC process passed corrosion resistance tests on aluminum alloy 2024, alloy 6061, alloy 7075, and alloy 1100. Tests followed the procedures in MIL-C-5541 and MIL-C-81706.
- *Paint Adhesion:* The CFCC process, when overcoated with an epoxy primer per MIL-P-23377 or with an epoxy powder paint (no primer), passed wet tape adhesion tests on alloys 2024, 6061, 7075, and 1100. Samples coated with the epoxy primer showed no degradation after 3,000 hours of salt spray. Powder coated samples showed no degradation after 3,000 hours of salt spray.
- *Contact Electrical Resistance:* The CFCC Long Form process (intended for bare metal exposure) had an average of 57 $m\Omega/in^2$ resistance before salt spray, and an average of 360 $m\Omega/in^2$ resistance after salt spray. Tests followed MIL-C-81706 and MIL-C-5541.

A rework or touch-up procedure has been developed to repair scratches in the CFCC coating from corroding in a salt fog environment. It should be noted that a CFCC coating can not be repaired with the present commonly used Alodine 1200 chrome conversion coating.

B.10.3.2. Environmental Issues

The CFCC process contains one chemical, specifically in the deoxidizing step, that is regulated as a HAP under Title III of the CAA. Due to the acidic and basic nature of the wastewater from the CFCC process, the wastewater must be neutralized to meet CWA permitting guidelines for the Metal Finishing Point Source category. Sludge from this process may be required to be managed in accordance with the requirements of RCRA Subtitle C.

B.10.3.3. Health and Safety Issues

OSHA has set PELs and the ACGIH has set TLVs for chemicals in the CFCC process, as listed in Table B-15.

Table B-15. PELs and TVLs for Chemicals in CFCC Process

Chemical	OSHA PEL	ACGIH TLV
Borax	None NIOSH: 5 mg/m^3	5 mg/m^3
2-Butoxyethanol	50 ppm (Skin)	25 ppm (Skin)
Monoethanolamine	3 ppm	3 ppm
Calcium Silicate	15 mg/m^3 Total 5 mg/m^3 Respirable	10 mg/m^3 Total
Ferrous Sulfate	1 mg/m^3 Fe	1 mg/m^3 Fe
Nitric Acid	2 ppm	2 ppm
Ferric Sulfate	1 mg/m^3 as Fe	1 mg/m^3 Fe
Sodium Biflouride	2.5 mg/m^3 as F	2.5 mg/m^3 as F

Table B-16 lists the chemical products of the CFCC process as well as the constituent chemicals present during the process.

Table B-16. Chemical Products of CFCC Process

Product	Constituent	CAS Number	Percent by Mass
Ridoline 322 (Parker Amchem)	Borax	01303-96-4	10-30
	2-Butoxyethanol	00111-76-2	1-10
	Monoethanol-amine	00141-43-5	1-10
	Trisodium Phosphate	07601-54-9	10-30
	Calcium Silicate	01344-95-2	1-10
Turco Liquid SMUT-GO NC	Ferric Sulfate	10028-22-5	25
	Sodium Bifluoride	01333-83-1	<5
	Nitric Acid	07697-37-2	5
	Ferrous Sulfate	07720-78-7	N.A.

N.A. = Not Available

Ventilation is required to maintain airborne contaminants below the PELs and TLVs. In addition, personal protection, such as goggles, neoprene rubber gloves, and respirators, is required. Ferrous sulfate is a suspected human carcinogen. Monoethanolamine, 2-butoxyethanol, and ferrous sulfate are known human neurotoxins. Mutation data exists for borax, trisodium phosphate, and ferrous sulfate; monoethanolamine is a known human genotoxin. Borax, 2-butoxyethanol, monoethanolamine, nitric acid and ferrous sulfate are experimental animal teratogens and/or reproductive toxicants. No other known or suspected carcinogens, teratogens, mutagens, or neurotoxins were noted in the CFCC process.

B.10.3.4. Additional Supporting Literature

- ACGIH, 1995, *Industrial Ventilation: A Manual of Recommended Practice*. 22nd ed. Cincinnati, OH.
- ACGIH, 1996, *1996 TLVs and BEIs*. *Threshold Limit Values for Chemical Substances and Physical Agents. Biological Exposure Indices.* Second Printing. ACGIH, Cincinnati, OH.
- Elf Atochem North America, Turco Products Division, 1995. Turco Liquid Smut-go NC Material Safety Data Sheet, Hughes Aircraft Company, El Segundo, CA
- Ike, Charles. Bulk Chemicals, Inc. Telephone Conversation. November 22, 1995 and April 9, 1996.
- Lewis, Richard J., Sr., 1996, Sax's Dangerous Properties of Industrial Materials. 9th ed. Vols. I-III. Van Nostrand Reinhold, New York.
- MSDS Information Systems Inc., 1996, *OHS MSDS on Disk*.
- National Center for Manufacturing Sciences, 1995, *Alternatives to Chromium for Metal Finishing,* Ann Arbor, Michigan.
- NIOSH, 1994, *NIOSH Pocket Guide to Chemical Hazards*. U.S. Government Printing Office, Washington, DC.
- Parker Amchem, 1989. *Ridoline 322 Material Safety Data Sheet*, Parker Amchem, Madison Hts., MI.
- 40 CFR part 261 *et seq*.
- 40 CFR part 400 *et seq*.
- 40 CFR part 129 *et seq*.
- 42 USC §7412(b)

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B.10.4. E-CLPS 923 and E-CLPS 923X (Bulk Chemicals, Inc.)

Two alternatives to chrome conversion coating are available from Bulk Chemicals, Inc.: E-CLPS 923 and E-CLPS 923X. Basically, E-CLPS 923X is E-CLPS 923 with a proprietary additive. Both alternatives require similar process steps listed below, which are maintained at ambient temperature.

1. *Cleaning:* Bulk Kleen 692, which contains phosphoric acid and monoammonium phosphate, is recommended by Bulk Chemicals, Inc. Bulk Kleen 695 may also be used for additional cleaning. Bulk Kleen 695 contains hydroxyacetic acid.
2. *Water Rinsing*
3. *Deoxidizing/Acid Conditioning:* Bulk Chemicals, Inc. recommends using Bulk Kleen 678, which contains hydrofluoric acid.
4. *Water Rinsing*
5. *Conversion Coating with E-CLPS 923 or E-CLPS 923X:* E-CLPS 923 contains fluotitanic acid.
6. *Drying:* After conversion coating, the coating is cured.

B.10.4.1. Technical Considerations

NCMS issued a study that compared nonchromate conversion coatings to Alodine 600 and 1200 series coatings (chrome conversion coatings manufactured by Parker Amchem) on aluminum substrates. Among the alternatives tested were E-CLPS 923 and E-CLPS 923X. Below is a summary of the findings.

- *Corrosion Resistance:* E-CLPS 923 and E-CLPS 923X failed corrosion resistance tests on aluminum alloys 2024, 6061, and 7075. Tests followed MIL-C-5541 procedures.
- *Contact Electrical Resistance:* E-CLPS 923 and E-CLPS 923X passed contact electrical resistance tests on alloy 6061 before a salt spray. Tests followed MIL-C-81706 procedures. Substrates coated with E-CLPS 923 and E-CLPS 923X were also tested until failure after a salt spray. The E-CLPS 923 coatings had a mean contact electrical resistance of 8.47 $m\Omega/in^2$, and the E-CLPS 923X coatings had a mean contact electrical resistance of 6.78 $m\Omega/in^2$.
- *Paint Adhesion:* E-CLPS 923 passed the dry paint adhesion tests on alloys 2024 and 7075, and wet paint adhesion test on alloy 6061. It failed the wet paint adhesion tests on alloys 2024 and 7075, and dry paint adhesion test on alloy 6061. E-CLPS 923X passed the dry and wet paint adhesion

tests on alloys 2024 and 7075, and the dry paint adhesion test on alloy 6061. It failed the wet paint adhesion test on alloy 6061. Results were not available for other aluminum alloys. Tests followed MIL-C-5541 and MIL-C-81706 procedures.

When a surface is scratched, it may be repaired by cleaning the surface (with detergent, phosphoric acid, or another cleaning agent), brushing on the E-CLPS 923 or 923X, curing (e.g., with a hair dryer), air drying, and then painting as needed.

B.10.4.2. Environmental Issues

The E-CLPS 923 and E-CLPS 923X processes contain two chemicals that are regulated as HAPs under Title III of the CAA. One HAP is in the cleaning step and one is in the deoxidizing step. Wastewater from the process must be neutralized to meet CWA permitting guidelines for the Metal Finishing Point Source category. In addition, fluoride must be removed from the wastewater if Bulk Kleen 678 is used. Sludge from this process may be required to be managed in accordance with the requirements of RCRA Subtitle C.

B.10.4.3. Health and Safety Issues

OSHA has set PELs and the ACGIH has set TLVs for chemicals in the E-CLPS 923 and E-CLPS 923X processes, as listed below.

Table B-17. PELs and TLVs for Chemicals in E-CLPS 923 and E-CLPS 923X Processes

Chemical	OSHA PEL	ACGIH TLV
Phosphoric Acid	1 mg/m^3	1 mg/m^3
Hydrofluoric Acid	2.5 mg/m^3 as F	3 ppm as F (Ceiling)
Fluotitanic Acid	2.5 mg/m^3 as F	2.5 mg/m^3 as F

Ventilation is required to maintain airborne contaminants below the PELs and TLVs. In addition, personal protection, such as goggles and respirators, is required. No suspected carcinogens are present during these processes. However, hydrofluoric acid is an experimental animal teratogen.

B.10.4.4. Additional Supporting Literature

- ACGIH, 1995, *Industrial Ventilation: A Manual of Recommended Practice*. 22nd ed. Cincinnati, OH.
- ACGIH, 1991, *Documentation of the Threshold Limit Values and Biological Exposure Indices*. 6th ed. Vols I-III. Cincinnati, OH.
- Ike, Charles. Bulk Chemicals, Inc. Telephone Conversation. November 22, 1995 and April 9, 1996.
- Lewis, Richard J., Sr., 1992, *Sax's Dangerous Properties of Industrial Materials*. 8th ed. Vols I-III. Van Nostrand Reinhold, New York.
- MSDS Information Systems Inc., 1996, *OHS MSDS on Disk*.
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- NIOSH, 1994, *NIOSH Pocket Guide to Chemical Hazards*. U.S. Government Printing Office, Washington, DC.
- 40 CFR part 261 *et seq*.
- 40 CFR part 400 *et seq*.
- 40 CFR part 129 *et seq*.
- 42 USC §7412(b)

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B.10.5. Turco 2438-28D (Elf Atochem - Turco Products Division)

The Turco Products Division of Elf Atochem distributes a nonchrome conversion coating referred to as 2438-28D. The conversion coating process is listed below.

1. *Cleaning*
2. *Water Rinsing*
3. *Deoxidizing*
4. *Water Rinsing*
5. *Conversion Coating with 2438-28D:* The chemical mixture, which is inorganic, contains noncarcinogenic metals. The bath is maintained at ambient temperature.
6. *Drying:* Parts are allowed to drip dry for this process.

These coatings are not available commercially to date. However, the process is currently being patented by Elf Atochem.

B.10.5.1. Technical Considerations

NCMS issued a study that compared nonchromate conversion coatings to Alodine 600 and 1200 series coatings (chrome conversion coatings manufactured by Parker Amchem) on aluminum substrates. One alternative tested was referred to as 2438-28D. Below is a summary of the findings.

- *Corrosion Resistance:* 2438-28D coatings exceeded performance requirements for corrosion resistance tests on aluminum alloy 6061. However, they did not pass tests on alloy 2024 or alloy 7075. Tests followed MIL-C-5541 procedures.
- *Contact Electrical Resistance:* 2438-28D coatings passed contact electrical resistance tests on alloy 6061 before a salt spray. Tests followed MIL-C-81706 procedures. Substrates coated with 2438-28D were also tested until

failure after a salt spray. The coatings had a mean contact electrical resistance of 535 $m\Omega/in^2$.

- *Paint Adhesion:* 2438-28D coatings failed dry and wet paint adhesion tests on alloys 2024, 6061, and 7075. Tests followed MIL-C-5541 and MIL-C-81706 procedures.

Touch-up techniques have not been tested for 2438-28D. Elf Atochem expects that a traditional method, such as using a chrome-containing pen, will be feasible for repair.

B.10.5.2. Environmental Issues

Although the constituents of this conversion coating process are proprietary, the mixture contains no ODSs or HAPs. Under the CWA, wastewater may require neutralization depending on its pH level. In addition, the metals present in the process may require further treatment to remove from the wastewater. Sludge from the process baths may be considered to be a listed hazardous waste under RCRA Subtitle C.

B.10.5.3. Health and Safety Issues

Although the constituents of this conversion coating process are proprietary, the mixture contains no carcinogens. Turco recommends the use of gloves, respirators, rubber aprons, and goggles for personnel working with the cleaning and deoxidizing agents. The presence of human carcinogens, teratogens, genotoxins, or neurotoxins is unknown.

B.10.5.4. Additional Supporting Literature

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APPENDIX C

PRELIMINARY ESOH ANALYSIS OF VIABLE ALTERNATIVES

TABLE OF CONTENTS

Page

LIST OF TABLES

C.1. INTRODUCTION

As part of the selection of potential alternatives, each of the viable alternatives was qualitatively assessed for associated ESOH concerns. This initial assessment was conducted to determine whether there were any conspicuous ESOH issues that may need to be addressed when selecting alternatives for testing.

C.2. BACKGROUND TO ESOH SCREENING

C.2.1. Environmental Issues

The viable alternatives were also evaluated to determine the extent of their regulation under the major federal environmental laws. Using available resources, each alternative was evaluated based on the criteria listed below.

- *Air Emissions:* Each alternative was analyzed to determine if its constituents are regulated under the CAA as volatile organic compounds (VOCs) or HAPs.
- *Solid/Hazardous Waste Generation:* Each alternative was evaluated to determine whether its use generates solid waste, and, if so, whether that waste may be regulated as hazardous or otherwise, under Subtitle C of the RCRA.
- *Wastewater Discharges:* Each process was analyzed to determine whether its use would result in the discharge of any wastewaters regulated under the CWA. Currently, wastewater discharges from the conversion coating process are subject to regulation under the CWA's "Metal Finishing Point Source category." Wastewater from these operations may also be subject to the more stringent standards proposed under the new "Metal Products and Machinery (MP&M) category" (60 Fed. Reg. 28209, May 30, 1995).
- *Reporting Requirements*: The viable alternatives were examined to determine whether any of the constituents are required to be listed in Toxic Release Inventory (TRI) reports under Section 313 of the Emergency Planning and Community Right-to-Know Act (EPCRA).
- *CERCLA Hazardous Substances*: Each alternative was assessed to determine if its constituents are listed as hazardous substances under the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA).
- *EPA 17:* The constituents of each alternative were compared to the "EPA 17" list. Those substances on the EPA 17 list have been targeted by EPA because (1) they are released in large quantities each year, (2) they are generally identified as toxic or hazardous pollutants, and (3) pollution prevention practices have the potential to diminish releases of these chemicals. Substances on the EPA 17 list are likely to be targeted for more stringent regulation.

The regulatory impacts of process alternatives are not easily compared, since it is impossible to say that a process that emits a hazardous waste sludge is any more or less desirable than a process that emits a HAP. Therefore, it is not possible to categorize each of the alternatives based on some type of regulatory ranking system. However, an alternative that has few regulated constituents will clearly be preferable to one that has many regulated constituents, so the extent to which an alternative is regulated should be considered as an element of the down-selection process.

C.2.2. Health and Safety Issues

Toxicity Ranking: As part of the final ESOH analysis criteria, the viable alternatives were qualitatively assessed for evident hazards (i.e., toxicity and exposure). Toxicity was qualitatively reviewed, and each viable product given a final toxicity ranking of high, medium, or low based on the analysis of available product information. Parameters reviewed included median lethal concentration 50 (LC_{50}) and/or median oral lethal dose 50 (LD_{50}). The exposure criteria used in the screening and ranking are OSHA PELs and the ACGIH TLVs. The qualitative ranking scheme for alternative products is provided in Table C-1.

C-1. Toxicity Ranking (TR) for Alternative Products

TR	Descriptive Term	LC_{50} (ppm)	LD_{50} Single Dose, (per kg Body Mass)
H	Highly Toxic	< 50	< 50 mg
M	Moderately Toxic	50-50,000	50 mg - 5 g
L	Relatively Nontoxic	> 50,000	> 5 g

H = High
M = Medium
L = Low

Exposure Ranking: Because ESOH hazard down-selection is a function of toxicity and exposure, a qualitative exposure ranking scheme is also provided. The procedure for establishing the exposure ranking scheme is discussed briefly below.

Exposure can occur only when the potential exists for a receptor to directly contact released chemical constituents from the identified alternative to the chrome conversion coating, or if there is a mechanism for released constituents to be transported to a receptor. Each component (released constituents, mechanism of transport, point of contact, and presence of a receptor) must be present for a complete exposure pathway to exist. Without exposure, there is no risk; therefore, the exposure assessment is a key element when assessing potential risks associated with a technology alternative. A reliable method of calculating exposure is by conducting a state-of-the-art risk assessment for the potential alternative technologies replacing chrome conversion coating.

This report uses a screening and ranking method to account for the toxicity and potential exposure associated with the alternative technologies. The exposure criteria used in the screening and ranking are the OSHA promulgated PELs and the ACGIH TLVs. Three exposure ranking levels and associated TLV and PEL intervals were chosen based on the ACGIH recommendations. The three exposure ranking levels and the associated TLV and PEL interval levels are:

- *High Exposure Level (H):* When TLV and PEL values are less that 100 ppm
- *Moderate Exposure Level (M):* When TLV and PEL values are between 100 to 500 ppm
- *Relatively No Exposure Level (L):* When TLV and PEL values are more than 500 ppm.

Hazard Ranking: A final hazard ranking designation was given to the viable alternatives based on toxicity and exposure ranking as described above. The hazard ranking is determined by the matrix shown in Table C-2.

Table C-2. Hazard Ranking Matrix

	High TR	**Medium TR**	**Low TR**
High ER	H	M-H	M
Medium ER	M-H	M	L-M
Lower	M	L-M	L

TR = Toxicity Ranking
ER = Exposure Ranking

These judgments are based on available scientific information. Also note that this assessment is based on a limited scope, and *CTC* assumes no responsibility for the safe operation of alternative technologies based on these hazard rankings as outlined.

C.3. ESOH SCREENING

An ESOH screening was performed for each of the viable alternatives, including Alodine 2000, Alumicoat 6788, CFCC, and Sanchem FP. The results of the ESOH screening are compared with the baseline process in Table C-3. The hazard ranking for Alodine 2000 is based on the replacement of chromic acid with Deoxalume.

C.3.1. ALODINE 2000 (PARKER AMCHEM)

C.3.1.1. Environmental Issues

- *Air Emissions:* The Alodine 2000 process contains one substance that has a constituent listed as a HAP: cobalt nitrate (found in Parker Amchem PTD-2000-H). There are no VOCs present in this alternative process.
- *Solid/Hazardous Waste Generation:* Three substances used in the Alodine 2000 process may generate waste sludge that must be disposed of as characteristic hazardous wastes under RCRA. Deoxalume® 2200 (pH=1), Parker Amchem TD-3072-W (pH=13.1), and Alodine 2600 toner (pH=2-3) all contain constituents that exhibit the characteristic of corrosivity. All wastes exhibiting the characteristic of corrosivity are assigned the EPA hazardous waste ID number D002.
- *Wastewater Discharges:* The use of Alodine 2000 does not appear to result in the discharge of any regulated waste streams under the CWA.
- *Reporting Requirements:* The following constituents of substances used in the Alodine 2000 process are required to be listed in Toxic Release Inventory (TRI) reports under EPCRA Section 313: nitric acid (in Deoxalume® 2200) and cobalt nitrate (in Parker Amchem PTD-2000-H).
- *CERCLA Hazardous Substances:* This alternative process contains nitric acid (in Deoxalume® 2200) which is listed as a hazardous substance under CERCLA.
- *EPA 17:* There are no constituents included on the EPA 17 list of chemicals targeted for strict regulation.

Table C-3. Results of ESOH Screening of Viable Alternatives

Product	TR[a]	ER[a]	HR[a]	Waste-water	CERCLA HazSub	EPA 17	TRI Report	Air Emissions		Wastes	
								HAPs	VOCs	Solid	Hazardous
Baseline	H	H	H	Yes	4	2	4	3	U	Yes	Yes
Alodine 2000	M	H	M-H	No	1	0	2	1	0	Yes	Yes
Alumicoat 6788	M	M	M	Yes	0	0	2	0	0	Likely	No
CFCC[b]	M	M	M	U	4	0	1	0	0	Yes	Yes
Sanchem FP	M	H	M-H	Yes	1	0	1	1	U	Yes	U

[a] The toxicity ranking (TR), exposure ranking (ER), and hazard ranking (HR) are described in Appendix C.
[b] CFCC is a proprietary process; ESOH analysis is based on information on steps known at this time.

HazSub = Hazardous Substance
M = Medium
H = High
U = Unknown

C.3.1.2. Health and Safety Issues

An overall hazard ranking of medium to high is given to the alternative Alodine 2000. The medium to high ranking indicates that chemical toxicity and worker exposure are moderate-to-high ESOH concerns when using this alternative. Worker exposure controls should be reviewed and implemented to protect the health and safety of workers using Alodine 2000. Constituents of concern, exposure effects, and each specific ranking for Alodine 2000 are discussed below.

Constituents of concern used in the Alodine 2000 process include N-octyl-2-pyrrolidone, sodium metasilicate, nitric acid, hydrogen peroxide, cobalt nitrate, magnesium acetate, triethanolamine, sodium ammonium vanadate and surfactants. For information on exposure limits and product composition (percent weights) see Appendix B. Hydrogen peroxide, cobalt nitrate, and triethanolamine are suspected human carcinogens. Hydrogen peroxide is a confirmed human genotoxin. Sodium metasilicate, nitric acid, hydrogen peroxide and cobalt nitrate are experimental animal teratogens and/or reproductive toxicants. No other known or suspected carcinogens, teratogens, mutagens, or neurotoxins were noted in Alodine 2000.

Toxic effects for the constituents of concern may range from irritation, to liver and kidney damage. Identified oral LD_{50} and inhalation LC_{50} for the chemicals of concern also indicate a moderate level of toxicity. The lowest oral LD_{50} value identified for constituents of concern is an oral LD_{50} of 434 mg cobalt nitrate/kg of body weight. Ammonium vanadate, which was used as a surrogate for sodium ammonium vanadate, has an oral LD_{50} of 58 mg/kg and an inhalation LC_{50} or 7.8 mg/m^3 (four-hour exposure for rats). Additional toxicity data are discussed below.

- *Acute Effects:* Acute effects of exposure to products used in the Alodine 2000 process may include, but may not be limited to, the following: irritation of the nose, throat, and respiratory tract; severe skin irritation, allergic skin reactions, and aggravation of pre-existing skin disorders; gastrointestinal damage and burns of the digestive tract; blood, heart, thyroid, pancreas, and kidney damage; nausea, vomiting, and diarrhea; and aggravation of breathing or respiratory tract disease or disorders.
- *Chronic Effects:* Prolonged or repeated contact and/or inhalation may lead to dermatitis, obstructive lung disease, liver and kidney damage, and reproductive toxicity.

Comparison of individual constituents to published toxicity data indicates moderate toxicity; therefore Alodine 2000 was assigned a medium toxicity ranking.

Based on published exposure limits (PELs and TLVs), Alodine 2000 was given high exposure level ranking. The exposure ranking was estimated from the low level recommended for exposure limits.

Appropriate engineering controls (e.g., local ventilation) should be employed while using the Alodine 2000 process. Administrative controls may be appropriate as well (e.g., exposure time limits and job sharing). Also, all ignition sources should be removed from the area where Alodine 2000 is in use. Personal protective equipment is required for worker health protection throughout the process, and should include protective clothing (e.g., chemical goggles or face shield, aprons, boots and chemical-resistant gloves). Approved fitted respirators are recommended if exposure limits are to be exceeded. Approved emergency facilities should also be present (e.g., eye wash, shower, etc.).

The results of the ESOH analysis of the Alodine 2000 process are shown in Table C-4.

Table C-4. ESOH Analysis of Alodine 2000

Process:	**Alodine 2000**
Manufacturer:	**Parker Amchem**
Toxicity Ranking	M
Exposure Ranking	H
Hazard Ranking	M-H
Regulated Wastewaters	No
EPA 17 Constituents	0
Air Emissions – HAPs	1
Air Emissions – VOCs	0
Toxic Release Inventory (TRI) Reporting	2
CERCLA Hazardous Substance	1
Wastes Generated – Solid	Yes
Wastes Generated – Hazardous	Yes

M =Medium
H = High

C.3.2. ALUMICOAT 6788 (ELF ATOCHEM - TURCO PRODUCTS DIVISION)

C.3.2.1. Environmental Issues

- *Air Emissions:* Alumicoat 6788 does not contain any constituents that are listed as HAPs or VOCs.
- *Solid/Hazardous Waste Generation:* While use of Alumicoat 6788 does not appear to result in the generation of any hazardous wastes, solid waste sludges may result and must be disposed of properly.
- *Wastewater Discharges:* The use of Alumicoat 6788 may result in the discharge of one regulated waste stream. Under the CWA, n-methyl-2-pyrrolidone is listed as a pretreatment pollutant. Pretreatment pollutants must undergo pretreatment to ensure that their discharge to a publicly-owned treatment works (POTW) is compatible with the capabilities of that POTW.
- *Reporting Requirements:* The following constituents of substances used in the Alumicoat 6788 process are required to be listed in TRI reports under EPCRA Section 313: n-methyl-2-pyrrolidone and isopropanol.
- *CERCLA Hazardous Substances:* This alternative does not contain any constituents which are listed as hazardous substances under CERCLA.
- *EPA 17:* There are no constituents included on the EPA 17 list of chemicals targeted for strict regulation.

C.3.2.2. Health and Safety Issues

An overall medium hazard ranking is given to the alternative Alumicoat 6788. A medium hazard ranking indicates that chemical toxicity and worker exposure are moderate ESOH concerns when using this alternative. Worker exposure controls should be reviewed and implemented to protect the health and safety of workers using Alumicoat 6788. Constituents of concern, exposure effects, and each specific ranking for Alumicoat 6788 are discussed below.

Constituents of concern in Alumicoat 6788 include n-methyl pyrrolidone and isopropyl alcohol. For information on exposure limits and product composition (percent weights) see Appendix B. Isopropyl alcohol is a suspected human carcinogen and a known human neurotoxin. Mutation data exists for n-methyl pyrrolidone and isopropyl alcohol and they are also experimental animal teratogens and/or reproductive toxicants. No other known or suspected carcinogens, teratogens, mutagens or neurotoxins were noted in Alumicoat 6788.

Toxic effects for the constituents of concern may range from irritation to reproductive toxicity. Identified oral LD_{50} and inhalation LC_{50} for the chemicals of concern also indicate a moderate level of toxicity. The lowest oral LD_{50} value identified for constituents of concern is an oral LD_{50} of 3,600 mg isopropyl alcohol/kg of body weight. Additional toxicity data are discussed below.

- *Acute Effects:* Acute effects of exposure to Alumicoat 6788 may include, but may not be limited to, the irritation of the eyes, skin, respiratory tract, and gastrointestinal tract.
- *Chronic Effects:* Prolonged or repeated contact and/or inhalation may lead to reproductive toxicity.

Comparison of individual constituents to published toxicity data indicates moderate toxicity; therefore Alumicoat 6788 was assigned a medium toxicity ranking.

Based on published exposure limits (PELs and TLVs), Alumicoat 6788 was given a medium exposure level ranking. The exposure ranking was estimated from the moderate level recommended for exposure limits.

Appropriate engineering controls (e.g., local ventilation) should be employed while using Alumicoat 6788. Administrative controls may be appropriate as well (e.g., exposure time limits and job sharing). Also, all ignition sources should be removed from the area where Alumicoat 6788 is in use. Personal protective equipment is required for worker health protection throughout the process, and should include protective clothing (e.g., face shield or goggles, gloves, boots and apron made of neoprene or other impervious material). Approved fitted respirators are recommended if exposure limits are to be exceeded. Approved emergency facilities should also be present (e.g., eye wash, shower, etc.).

The results of the ESOH analysis of the Alumicoat 6788 process are shown in Table C-5.

Table C-5. ESOH Analysis of Alumicoat 6788

Product:	Alumicoat 6788
Manufacturer:	Elf Atochem - Turco Products Division
Toxicity Ranking	M
Exposure Ranking	M
Hazard Ranking	M
Regulated Wastewaters	Yes
EPA 17 Constituents	0
Air Emissions - HAPs	0
Air Emissions - VOCs	0
TRI Reporting	2
CERCLA Hazardous Substance	0
Wastes Generated - Solid	Likely
Wastes Generated - Hazardous	No

M = Medium

C.3.3. CHROME-FREE CONVERSION COATING (CFCC) (HUGHES AIRCRAFT COMPANY)

C.3.3.1. Environmental Issues

- *Air Emissions:* Chrome-Free Conversion Coating (CFCC) does not contain any constituents that are listed as HAPs or VOCs.
- *Solid/Hazardous Waste Generation:* One substance used in the CFCC process may generate waste sludge that must be disposed of as a characteristic hazardous waste under RCRA. Turco Liquid Smut-Go NC contains at least one constituent that exhibits the characteristic of corrosivity. All wastes exhibiting the characteristic of corrosivity are assigned the EPA hazardous waste ID number D002.
- *Wastewater Discharges:* The use of CFCC may result in the discharge of one type of regulated wastestream. Under the CWA, ferric sulfate, sodium bifluoride, nitric acid, and ferrous sulfate (all found in Turco Liquid Smut-Go NC) are designated as hazardous substances under CWA Section 311. Spills or other discharges of CWA hazardous substances into navigable waters must be reported when the amount meets or exceeds the substance’s reportable quantity.

- *Reporting Requirements:* Nitric acid (in Turco Liquid Smut-Go NC) used in the CFCC process is required to be listed TRI reports under EPCRA Section 313.
- *CERCLA Hazardous Substances:* This alternative process contains ferric sulfate, sodium bifluoride, nitric acid, and ferrous sulfate (all found in Turco Liquid Smut-Go NC) which are listed as hazardous substances under CERCLA.
- *EPA 17:* There are no constituents included on the EPA 17 list of chemicals targeted for strict regulation.

C.3.3.2. Health and Safety Issues

An overall medium hazard ranking is given to the CFCC process. This ranking is based on the determination that products used in the CFCC process have a medium toxicity ranking and a medium exposure ranking. A medium hazard ranking indicates that chemical toxicity and worker exposure are moderate ESOH concerns when using this alternative. Worker exposure controls should be reviewed and implemented to protect the health and safety of workers using CFCC. Constituents of concern, exposure effects, and each specific ranking for CFCC are discussed below.

Constituents of concern used in the CFCC process include borax, 2-butoxyethanol, monoethanolamine, trisodium phosphate, calcium silicate, ferric sulfate, ferrous sulfate, sodium bifluoride, and nitric acid. For information on exposure limits and product composition (percent weights) see Appendix B. Ferrous sulfate is a suspected human carcinogen. 2-Butoxyethanol, monoethanolamine, and ferrous sulfate are known human neurotoxins. Mutation data exists for borax, trisodium phosphate, and ferrous sulfate; monoethanolamine is a known human genotoxin. Borax, 2-butoxyethanol, monoethanolamine, nitric acid, and ferrous sulfate are experimental animal teratogens and/or reproductive toxicants. No other known or suspected carcinogens, teratogens, mutagens, or neurotoxins were noted in CFCC.

Toxic effects for the constituents of concern may range from irritation to nose tumors. Identified oral LD_{50} and inhalation LC_{50} for the chemicals of concern also indicate a moderate level of toxicity. The lowest oral LD_{50} and inhalation LC_{50} values identified for constituents of concern are an oral LD_{50} of 319 mg ferrous sulfate/kg of body weight and LC_{50} of 700 mg/m^3 for 2-butoxyethanol (seven-hour exposure). Additional toxicity data are discussed below.

- *Acute Effects:* Acute effects of exposure to products used in the CFCC process may include, but may not be limited to, the following: irritation of the mouth, throat, and respiratory tract; eye irritation, burns, and possible blindness; skin irritation and damage; gastrointestinal tract damage, nausea, diarrhea, and vomiting; hemolysis; aggression, somnolence and brain recording changes.

- *Chronic Effects:* Prolonged or repeated contact and/or inhalation may lead to blood, kidney, lung and liver effects, reproductive toxicity, and nose tumors.

Comparison of individual constituents to published toxicity data indicates moderate toxicity; therefore CFCC was assigned a medium toxicity ranking.

Based on published exposure limits (PELs and TLVs), CFCC was given a medium exposure ranking. The exposure ranking was estimated from the moderate level recommended for exposure limits.

Appropriate engineering controls (e.g., local ventilation) should be employed while using CFCC. Administrative controls may be appropriate as well (e.g., exposure time limits and job sharing). Personal protective equipment is required for worker health protection throughout the process, and should include protective clothing (e.g., safety glasses with nonperforated sideshields and impervious gloves). Approved fitted respirators are recommended if exposure limits are to be exceeded. Approved emergency facilities should also be present (e.g., eye wash, shower, etc.).

The results of the ESOH analysis of the CFCC process are shown in Table C-6.

Table C-6. ESOH Analysis of CFCC

Process:	**CFCC**
Manufacturer:	**Hughes Aircraft Company**
Toxicity Ranking	M
Exposure Ranking	M
Hazard Ranking	M
Regulated Wastewaters	Unknown
EPA 17 Constituents	0
Air Emissions - HAPs	0
Air Emissions - VOCs	0

(Table C-6 continued on next page)

Table C-6. ESOH Analysis of CFCC (Continued)

Process:	**CFCC**

Manufacturer:	Hughes Aircraft Company
TRI Reporting	1
CERCLA Hazardous Substance	4
Wastes Generated - Solid	Yes
Wastes Generated - Hazardous	Yes

M = Medium

C.3.4. SANCHEM FP (SANCHEM)

C.3.4.1. Environmental Issues

- *Air Emissions:* Sanchem FP uses potassium permanganate (found in Safeguard 3000) which is listed as a HAP under the general category of manganese compounds. It is unknown if any VOCs are involved in the Sanchem FP process.
- *Solid/Hazardous Waste Generation:* The Sanchem FP process utilizes Safeguard 3000, which contains potassium permanganate, a regulated manganese compound. Use of this substance may generate waste sludge that must be disposed of as a hazardous waste under RCRA.
- *Wastewater Discharges:* The use of Sanchem FP may result in the discharge of one type of regulated wastestream. Under the CWA, potassium permanganate (in Safeguard 3000) is designated as a hazardous substance under CWA Section 311. Spills or other discharges of CWA hazardous substances into navigable waters must be reported when the amount meets or exceeds the substance's reportable quantity.
- *Reporting Requirements:* The following constituent of a substance used in the Sanchem FP process is required to be listed in TRI reports under EPCRA Section 313: potassium permanganate (in Safeguard 3000).
- *CERCLA Hazardous Substances:* This alternative process contains potassium permanganate (in Safeguard 3000) which is listed as a hazardous substance under CERCLA.
- *EPA 17:* There are no constituents included on the EPA 17 list of chemicals targeted for strict regulation.

C.3.4.2. Health and Safety Issues

An overall medium-to-high hazard ranking is given to the alternative Sanchem FP. A medium-to-high hazard ranking indicates that chemical toxicity and worker exposure are moderate to high ESOH concerns when using this alternative. Worker exposure controls should be reviewed and implemented to protect the health and safety of workers using Sanchem FP. Constituents of concern, exposure effects, and each specific ranking for Sanchem FP are discussed below.

Constituents of concern in Sanchem FP include sodium bromate, aluminum nitrate, lithium nitrate, and potassium permanganate. For information on exposure limits and product composition (percent weights), see Appendix B. Mutation data exists for potassium permanganate and it is also an experimental animal teratogen/reproductive toxicant. No other known or suspected carcinogens, teratogens, mutagens, or neurotoxins were noted in Sanchem FP.

Toxic effects for the constituents of concern may range from irritation to reproductive toxicity. Identified oral LD_{50} for the chemicals of concern also indicate a moderate level of toxicity. The lowest LD_{50} value identified for constituents of concern is an LD_{50} of 140 mg sodium bromate/kg of body weight. Additional toxicity data are discussed below.

- *Acute Effects:* Acute effects of exposure to Sanchem FP may include, but may not be limited to, the irritation of the eyes and skin, dyspnea, nausea, and other gastrointestinal effects.
- *Chronic Effects:* Prolonged or repeated contact and/or inhalation may lead to reproductive toxicity.

Comparison of individual constituents to published toxicity data indicates moderate toxicity; therefore Sanchem FP was assigned a medium toxicity ranking.

Based on published exposure limits (PELs and TLVs), Sanchem FP was given a high exposure level ranking. The exposure ranking was estimated from the low level recommended for exposure limits.

Appropriate engineering controls (e.g., local ventilation) should be employed while using Sanchem FP. Administrative controls may be appropriate as well (e.g., exposure time limits and job sharing). Also, all ignition sources should be removed from the area where Sanchem FP is in use. Personal protective equipment is required for worker health protection throughout the process, and should include protective clothing (e.g., goggles and rubber gloves). Approved fitted respirators are recommended if exposure limits are to be exceeded. Approved emergency facilities should also be present (e.g., eye wash, shower, etc.).

The results of the ESOH analysis of the Sanchem FP process are shown in Table C-7.

Table C-7. ESOH Analysis of Sanchem FP

Product:	**Sanchem FP**
Manufacturer:	**Sanchem**
Toxicity Ranking	M
Exposure Ranking	H
Hazard Ranking	M-H
Regulated Wastewaters	Yes
EPA 17 Constituents	0
Air Emissions – HAPs	1
Air Emissions – VOCs	Unknown
TRI Reporting	1
CERCLA Hazardous Substance	1
Wastes Generated – Solid	Yes
Wastes Generated – Hazardous	Unknown

M = Medium
H = High

C.4. POTENTIAL IMPACT OF ESOH ISSUES OF VIABLE ALTERNATIVES

The reason for finding an alternative to chrome conversion coatings is to eliminate the use of hexavalent chrome which is known to cause cancer in humans. Care must be taken, however, not to replace one hazard with another. Alternatives that received a high hazard ranking should only be considered if no other technically acceptable alternative is found, and then only after a detailed ESOH review to verify improved ESOH performance over the present baseline process. Though the viable alternatives screened contain fewer regulated substances, all alternatives will require changes in engineering controls to insure the safety of the workers using the chemicals.

APPENDIX D

REFERENCES

REFERENCES

- 40 CFR part 261 *et seq*.
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- 40 CFR part 129 *et seq*.
- 40 CFR part 302 *et seq*.
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