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The MONITOR

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The MONITOR is a quarterly publication of the Headquarters Air Force Materiel Command (AFMC) Pollution Prevention Integrated Product Team (P2IPT) dedicated to integrating environment, safety, and health related issues across the entire life cycle of Air Force Weapon Systems. AFMC does not endorse the products featured in this magazine. The views and opinions expressed in this publication are not necessarily those of AFMC. All inquiries or submissions to the MONITOR may be addressed to the Program Manager, Mr. Frank Brown.

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The C-17 Program Wins Award

In November 2001, the C-17 Program was awarded the California's Governor's Award for the accomplishment of its pollution prevention (P2) program. This award was given as a reflection of the successful government/private partnership established between the Air Force and Boeing in the C-17 Program. This article provides an overview of the C-17 Program and summarizes its successes that led to winning this prestigious award.

The C-17 P2 Program has achieved the goal of environmental stewardship by meeting Air Force Major Command requirements and C-17 aircraft maintainer needs with The Boeing Company's technical support. This diverse team is capable of responding to environmental, safety and occupational health (ESOH) issues effectively in the field, and at various stages of engineering design and support. The C-17 Program uses the Integrated Product Team (IPT) approach to address systemic environmental problems and allows for multi-functional team problem solving. The C-17 P2 IPT multi-functional team integrates design, production, sustainment, and environmental representatives while encouraging transfer of solutions and lessons learned across all Air Force aircraft and weapon systems.

Background

Manufacture, operation and maintenance of the C-17 Weapon System at Air Force and Boeing sites across the country and internationally can have significant impacts on the environment as well as human health and safety. Since 1995, the C-17 Program strategy has been to minimize ESOH impacts by integrating pollution prevention into the product design process and eliminating the use of hazardous materials during the earliest phases of the program, with minimum cost and risk to weapon system performance.

In order to maximize the efficiency of the government/private industry relationship, a core IPT was formed comprised of United States Air Force (USAF) and Boeing Airlift and Tanker personnel. The IPT's goals include the following:

- Eliminate or reduce the use of hazardous materials on the C-17 Weapon System;
- Control the use of hazardous materials required for safe and effective operation and maintenance of the C-17 Weapon System;
- Protect employees, public health, and the environment.

The C-17 P2 IPT is co-led by the USAF C-17 System Program Office ESOH Manager and the Boeing A&T C-17 Pollution Prevention Program Manager. The primary method used by the C-17 P2 IPT to achieve hazardous material reduction goals has been to select, evaluate, and implement environmentally-friendly alternative materials. It is important to note that the Boeing A&T C-17 Pollution Prevention group is functionally aligned with Materials and Process Engineering and is part of the C-17 Air Vehicle Integration organization. This organizational alignment with engineering, instead of Environmental Assurance, facilitates technology transfer and reduces the risks associated with the implementation of hazardous material alternatives.

The organizational alignment of the Pollution Prevention group also incorporates the ideals of "Sustainable Practices", by including representatives from the C-17 Support Systems IPT. The Support Systems representatives take the engineering solutions and hazardous material alternatives and incorporate them into the C-17 support and sustainment documentation. In addition to the Boeing A&T C-17 manufacturing presence, the C-17 P2 IPT holds regular meetings which include USAF personnel from each Air Base operating C-17 Aircraft, Air Mobility Command, Air Education and Training Command, Air Staff, USAF Air Logistics Centers, Air Force Research Laboratories, and Jackson Air National Guard. This "expanded" IPT is empowered to select viable P2 projects, shares information on pending Federal, State, and local environmental regulations, and discuss successes and failures of ESOH activities at each location.

Program Summary

The strength of the C-17 P2 Program is coordination. The C-17 P2 Program is able to ensure ESOH considerations are incorporated into the decision making process at the earliest possible instance by capitalizing on the benefits provided by its organizational structure. C-17 Materials and Process engineers provide direction to design engineers regarding the use of various aircraft materials and processes in their designs. The design engineers work closely with Support Systems personnel to identify design upgrades to improve aircraft sustainability and performance. The Systems Engineering approach is used to facilitate and track aircraft changes.

The C-17 P2 Program has been successfully integrated into each of these critical areas. This successful integration translates into the following: Materials and Process engineers knowledgeable of the latest "green technologies"; designs engineered to reduce hazardous material use and occupational exposure; logistics data that reduces the amount of hazardous material required to operate and maintain the Weapon System; and engineering processes that track the effectiveness of the hazardous material substitutions and ensure that airworthiness and mission readiness are not compromised.

Accomplishments

The C-17 P2 Program has achieved a 43% reduction in the use of EPA 17 Chemicals per aircraft for the year 2000 at the Long Beach production facility.

Material substitution has been recognized as one of the best methods to minimize the use of hazardous materials. Material substitution on the C-17 Program is controlled by the Materials and Process engineering group and successful completion of all qualification test requirements is required. In addition, logistics requirements are evaluated and incorporated into the decision making process. The result is reduced hazardous waste storage and generation, and reduced worker exposure. The results of the C-17 P2 Program material substitution efforts have been dramatic.

Using an IPT approach, product substitutions for cleaning solvents, aircraft sealants, and paint strippers have resulted in the continued reduction of the use of hazardous materials at the Boeing C-17 Assembly Facility in Long Beach, California. The use of EPA 17 chemicals per aircraft was reduced by 43% from the previous year (1999) while the aircraft production rate increased by 15%. Figure 1 summarizes the historical reduction in ODCs and EPA-17 chemicals for the C-17 Program.

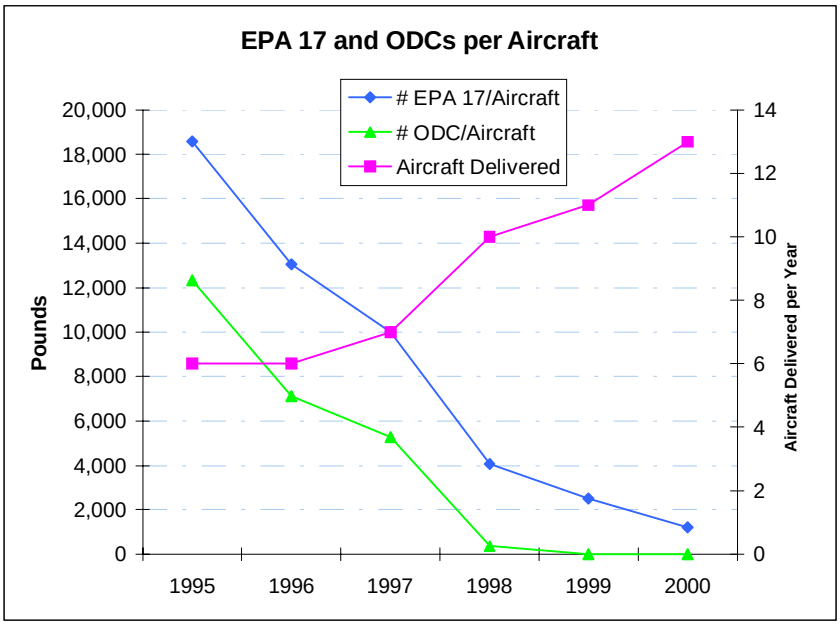

Figure 1. Historical Reduction in ODCs and EPA-17 Chemicals

Technology Transition

Technology transition is the key to successful implementation of P2 in Weapon System acquisition. The C-17 P2 Program has transitioned technology that benefits the entire Air Force. Some of these successes are presented on the next page.

Extended Life Camouflage Aircraft Coating: In 1997, the C-17 P2 Program was tasked by the USAF to develop an extended life camouflage topcoat paint for C-17 aircraft. In 1998, after successful laboratory trials, The Boeing Company and the USAF began flight testing of the "Advanced Performance Coating" (APC) (see related article below). The APC, developed in Deft Laboratories and transitioned into production by Deft and The Boeing Company, is a fluoro-modified polyurethane paint that has excellent weathering and cleaning properties. In 2000, APC was selected as the preferred C-17 topcoat paint and demonstrated a 15-fold improvement in color stability during the 2-year flight test evaluation. This improvement in color stability is extremely important for military aircraft and is expected to save the USAF millions of dollars in aircraft repaint costs while avoiding the release of hazardous air pollutants released during the repaint process. The C-17 Materials & Process Engineering group developed an aircraft coating specification and qualified the APC to the new specification, allowing the C-17 to become the first aircraft to use the APC in production as well as aircraft repaints.

Implementation of the Thermal-Electric Refrigerator: Newer C-17 aircraft are now equipped with a Thermal-Electric refrigerator instead of the vapor cycle refrigerator. The refrigerator was redesigned based on the primary need to eliminate the use of R-12 refrigerant, an Ozone Depleting Substance. The Thermal-Electric refrigerator is not only more environmentally sound, it is better designed, requires less maintenance, and will have a longer service life.

Non-Chrome Primer Evaluation: The C-17 P2 Program has been a major participant to joint technology demonstrations such as the Non-Chrome Primer Evaluation being conducted by the Joint Group on Pollution Prevention (JG-PP). Although initial contributions were confined to participation in the laboratory evaluations of various primers, recent activity has included application of non-chrome primer to C-17 aircraft for evaluation of application methods and topcoat compatibility. The C-17 non-chrome primer aircraft evaluation team is a reflection of the C-17 P2 expanded IPT and includes participants from C-17 SPO, Air Force Corrosion Program Office (AFCPO), Air Force Research Laboratories (AFRL), Coatings Technology Integration Office (CTIO), Charleston Air Force Base, Boeing Aircraft and Missile Division, and Boeing Aerospace Support Center.

Promoting Awareness

The C-17 P2 Program developed a web site and CD-ROM to distribute all of the information developed since 1995. Over 60 pollution prevention project reports are available as well as reviews of pending environmental regulations, minutes and presentations from expanded IPT meetings, and lists of contacts.

Conclusion

The C-17 P2 Program continues to provide leadership in the form of program management while promoting technical excellence in the execution of P2 projects. Strong program planning, and an infrastructure flexible enough to adapt to changing needs as identified by strategic planning, allows the C-17 P2 Program to serve as model for other Government/Private Industry partnerships.

For additional information about the C-17 P2 Program, please contact Major Joel Almosara at DSN 986-9311.

C-17 Program Implements an Advance Performance Coating (APC) to Improve the Cleanability and Durability of the Weapon System

Background

Early C-17 aircraft painted with low gloss high solids polyurethane topcoat have experienced premature oxidation or chalking of the topcoat. The chalking phenomenon results from sunlight induced ultraviolet (UV) oxidation of the resin. Chalking is manifested as a severe lightening of the color usually accompanied with a chalky appearance. A marked decrease in cleanability is associated with topcoat chalking.

An integrated product team was formed to develop the advanced performance coating (APC). Members of the team included Boeing A&M (Long Beach & St. Louis), Air Force Research Laboratory (AFRL), University of Southern Mississippi (USM), BM Technologies, Inc. and Battelle Memorial Institute.

Project Description

Boeing and the AFRL prepared the C-17 APC requirements document for the C-17 Program Office. The document provided target threshold values for 36 critical coating properties. USM provided state-of-the-art accelerated test methods to expedite the downselection phase. Battelle performed additional screening tests.

Nine different coating technologies were evaluated during the APC downselect phase. A total of 24 coatings were screened. BBM Technologies, Inc. was the main formulator. Battelle and USM also provided formulations for evaluation. Commercial paint vendors were solicited to submit an advanced technology coating specifically designed for superior UV stability and cleanability.

A statistical desirability program was developed to downselect an APC candidate. Thirteen tests were selected, with each having a weighting factor associated with its importance to the program. Three materials were down selected for continued development. Two of the materials were fluorine-modified polyurethanes, while the other was a highly branched polyurethane. All three materials showed a 2-3-fold improvement over the baseline coating. A candidate coating from Deft Incorporated was selected as the APC with a composite score of 67%. The baseline control coating had a composite score of 18%.

Deft submitted a fluoro-modified high solids polyurethane topcoat. The material is a chemically cured two component fluoro polyurethane. Fluropolymers have been used since the late 1960s as architectural coatings. They offer superior weatherability, chemical resistance and colorfastness. Recent advances in polymer technology have improved the workability of the polymers allowing them to be spray applied. The new coating shows a 5-fold improvement over the current C-17 topcoat with respect to color stability, and a 3-fold increase with respect to gloss retention in accelerated weathering tests. Lab testing of the coating shows it to have improved cleanability over the current topcoat.

Results

On 25 February 1998, C-17 aircraft P-39 was painted with the Deft APC topcoat. It took 2 hours for twenty-two painters to paint the 20,000 square foot aircraft. One hundred gallons of paint was used.

The aircraft passed customer inspection and was delivered to Charleston AFB, South Carolina on 15 April 1998. The aircraft was field evaluated on 13 July 1998 at Charleston AFB. Color and gloss measurements taken on P-39 showed the APC to be a 5-fold improvement over the current C-17 topcoat with respect to color retention, and a 58% improvement with respect to gloss retention.

For further information, please contact Major Joel Almosara at DSN 986-9311.

C-17 Program Conducts a Project to Eliminate Hazardous Materials from Local and Spot Paint Removal

Project Description

The goal of this project was to implement a chemical stripper that did not contain methylene chloride and mechanical stripping method capable of capturing sanding dust that contains hexavalent chrome. The methods selected would be able to meet the Expanded Workplace Occupational Safety and Health Administration (OSHA) Standards and Environmental Protection Agency (EPA) National Emission Standards for Hazardous Air Pollutants (NESHAP) for source Categories: Aerospace Manufacturing and Rework Facilities.

Results

Both the chemical and vacuum controlled sanding technologies offered the ability to reduce/control of hazardous materials associated with local and spot paint removal for C-17 paint systems and both were recommended by C-17 Pollution Prevention Program. Chemical strippers selected were: McGean Rohco #Cee Bee E-2002A, Eldorado Chemical #PR-3133, Turco Products #6840S, and Turco Products #6813. Mechanical stripping method/equipment selected was: Dynabrade Model 57804 “jitterbug type” orbital sander attached to a DCM Model 50120 or 50125 HEPA-filter vacuum system. In order to implement the paint removal technologies selected, 579 Logistic Support Analysis Record (LSAR) task, one item in the Consumable Bulk Item Listing (CBIL), and 5 pages in Technical Order 1C-17A-23 were revised.

For further information, contact Major Joel Almosara at DSN 986-9311.

C-17 Program Implements Installation and Maintenance Instructions for Polyurethane Erosion Protection Sheet Used on Leading Edges

Project Description

This project evaluated and implemented installation and maintenance instructions for polyurethane erosion protection sheet used on leading edges of the C-17 Weapon System. Procedures were coordinated with C-17 Modification Center Liaison Engineering MRB, Charleston Air Force Base EMS/LGMFC and Boeing on-site engineering. C-17 System Program Office, C-17 Materials and Process Engineering, Mass Properties, Aero Design/Loads, Liaison Engineering, Environmental Services, and Pollution Prevention.

Results

Instructions included adhesion promoter, edge sealer, cure or dwell times, logistics of applying large pieces, surface preparation, fasteners, and pre-molded boots. Damage scenarios included damage areas from less than two inches to complete sections, edge peeling, fastener coverage, patching, and varying substrates. The goal was to cover many details as possible while at the same time giving the operator as much freedom with as many options as possible. This goal was to provide the operator with guidelines to meet the widely varying conditions found in the field. Standard Repair Process (SRP) Number 017 Repair of Polyurethane Sheet Leading Edge Erosion Protection was written as a baseline for other documentation. SRP #017 procedures were then added to C-17 Technical Order (T.O.) 1C-17A-23 and the Logistic Support Analysis Record (LSAR) and record narratives.

For further information regarding this project, please contact Major Joel Almosara at DSN 986-9311.

C-17 Program Evaluates Non-Chromated Tie Coat for Leading Edge Erosion Tape on Wing Tips, Vertical and Horizontal Stabilizers

Project Description

The goal of this project was to qualify a non-chromated primer and/or adhesion promoter for use during the installation of leading edge erosion tape on the wing tips, vertical stabilizer, and horizontal stabilizer of the C-17 Globemaster III. Site visits to Northrop Grumman, Dallas, Texas, and McDonnell Tactical Aircraft in Long Beach, California provided input from the manufacturers' standpoint. A site visit to Charleston Air Force Base provided input from an operational perspective.

The following project decisions were validated during the C-17 Expanded Pollution Prevention Integrated Product Team meeting:

- Use of DMS 2144 impact resistant primer as the baseline primer on the composite laminate.
- Change from emphasis on evaluation of multiple non-chromated primers to tie coats, wetting solution, and no treatment in evaluation.
- Use of three test configurations.
- Recommendation that the final procedures be incorporated in the IC-17A-23 Corrosion Manual.

The leading non-chromated primer candidate, two adhesion promoter tie coats, a wetting solution, and no treatment were the conditions evaluated in three configurations. The configurations include over primed composite substrate, over clear glossy 8671 protective tape, and over topcoat. Peel testing was conducted over a range of temperatures and after exposure to various fluids.

Results

Test results indicate that the tie coat materials, 3M Adhesion Promoter 86 and 3M Adhesion Promoter 86A (toluene free), facilitate better adhesion than the non-chromated primer or no treatment. In addition, a wetting solution of isopropyl alcohol/water/detergent is tailorable for the aggressiveness of the adhesion to balance between time/flexibility of movement for large area repair/installation versus quick adhesion because of short turnaround for operations. It was recommended that processing studies and a field test be conducted to provide the best operational procedures for installation and repair to the Air Force.

For further information, please contact Major Joel Almosara at DSN 986-9311.

SERDP/ESTCP Hosts Annual Meeting to Build on Past Successes to Address Emerging Issues

The Strategic Environmental Research Development Program (SERDP) and the Environmental Security Technology Certification Program (ESTCP) hosted their annual environmental symposium in Washington, DC from November 27 – 29, 2001.

Mr. Bradley Smith, the Executive Director of SERDP opened the Plenary session and stressed that this year's theme focused on "building on past successes to address emerging issues." Ms. Madelyne Creedon Council for the Committee on Armed Services gave a historical perspective on the challenges and the players involved in establishing SERDP ten years earlier. Mr. Raymond DuBois, the Deputy Under Secretary of Defense for Installation & Environment summarized some of the current defense environmental challenges. Dr. Robert Foster, Director, Biological Systems discussed how technology has and continues to respond to defense environmental challenges.

Dr. James Decker, Acting Director of Department of Energy's Office of Science presented the annual SERDP Project Awards. Within Pollution Prevention, Dr. Mel Roquemore, Air Force Research Laboratory (AFRL) won the Award for the Trapped Vortex Combustor (TVC) Project. AFRL is working with General Electric on this project to develop a TVC design for potential application in gas turbine engines. The environmental objective is to reduce nitrogen oxides (NOx), volatile organic compounds (VOC), carbon monoxide, and particulate emissions to 50 percent of the 1996 International Civil Aviation Organization (ICAO) standards. Dr. Jeffrey Marqusee closed the plenary session and encouraged all participants to attend the poster and technical sessions for the rest of the conference.

Air Force Material Command's (AFMC's) Portable Laser Coating Removal Systems were among the poster sessions at the Conference. Ms. Debora Meredith, AFMC hosted the Cleaning and Inspection of Weapon Systems Technical Session. The keynote speaker for the session was Ms. Olga Dominguez, National Aeronautics and Space Administration (NASA). Other session related to pollution prevention initiatives included topics such as environmentally friendly corrosion protection and environmental design for maintainability.

For more information about SERDP and ESTCP and their programs, please visit their web sites at http://www.serdp.org and http://www.estcp.org.

AFRL Team Wins SERDP Pollution Prevention Award

A multi-agency team led by Dr. Mel Roquemore of the Air Force Research Laboratory's Propulsion Directorate won the Pollution Prevention Program of the Year Award from The Strategic Environmental Research and Development Program office. A joint DoD, DOE and EPA program, the SERDP recognized the Trapped Vortex Combustor (TVC) program as the best for 2001.

The TVC concept grew from fundamental studies of flame stabilization conducted by Dr. Roquemore. AFRL conducted these studies to better understand how jet engines sometimes "blew out" while in flight. Not only does the TVC significantly reduce this problem but also produces impressive numbers from a pollution control perspective.

Using the TVC produces a three-way performance improvement which includes a 40% expansion of the operating envelope, a 50% decrease in engine blow-out occurrence, and a 50% improvement in re-light if blow-out occurs.

The pollution prevention numbers are equally impressive. Use of the TVC in turbine engines could reduce aircraft emissions to 50% below the ICAO standard for Nitrogen Oxides (NOx) and a comparable amount for Volatile Organic Compounds (VOCs). Compared to conventional combustors used in marine gas turbine engines, a TVC-equipped turbine engine will reduce yearly emissions of NOx and VOCs from Navy ships by 52% and 60%, respectively. When applied to various fleets of aircraft, turbine powered ships and stationary power plant turbines, the TVC use will reduce NOx emissions by 95 million pounds per year and VOCs by 300 million pounds per year.

The TVC is an innovative design that departs from the traditional swirl stabilized combustor designs used in gas turbine engines for the past 40 years. It consists of a pilot combustor for stability and a main combustor for power. The pilot contains cavities sized to trap a vortex, thus the name TVC. It is a simple design that provides low NOx because it operates with high flow-through velocities (low residence time), low fuel to air ratios, and good mixing in the main and trapped vortex pilot com-

bustors. The Air Force Research Laboratory, General Electric Aircraft Engines, Naval Sea and Air Systems Commands, and National Energy Technology Laboratory (NITL) have been developing the TVC with funding from SERDP and other sources.

The 25 member award winning team was made up of representatives from AFRL's Propulsion Directorate, Wright-Patterson AFB, Ohio; Naval Sea Systems Command, Washington, D.C.; Naval Air Systems Command, Patuxent River, Maryland; the National Energy Technology Laboratory, Morgantown, West Virginia; General Electric Aircraft Engines, Cincinnati, Ohio; and Innovative Scientific Solutions Incorporated, Dayton, Ohio.

This article was written by Adrian Denardo, AFRL Propulsion Directorate.

Air Force Research Laboratory (AFRL) Conducts a Research and Development Requirements Survey for Space and Missile Operations

In 1999-2000, Air Force Research Laboratory, Weapon Systems Logistics Branch (AFRL/MLQL) conducted a research and development (R&D) requirements survey for Air Force Space Command. The objective of the survey was to identify pollution prevention (P2) RDT&E requirements to reduce the types and amounts of hazardous materials and processes associated with Air Force space and missile systems. This article summarizes the methodology uses to conduct the survey and the results of this effort.

Overview of Survey Methodology

The survey methodology included the following components:

- Review current FY97 space and missile related ESOH Pollution Prevention Technology Needs (see information on page 10).
- Identify current and planned space and missile systems.
- Identify and contact program management offices, ALC/depot/field level personnel and OEM production and environmental POCs for identified systems.
- Perform data collection site visits to operational launch locations.

Major Findings and Recommendations

The major findings from the survey are summarized in Table 1.

Table 1. R&D Requirements Survey's Major Findings

Description of Findings	Recommendations
Ammonia perchlorate based solid rocket propellants generate large quantities of chlorinated compounds and particulate matter during the launch.	Provide continued support of scale up and flight test of non-ammonium perchlorate propellants.
Potential use of up to 26,000 pounds of Freon 113 and 18,000 pounds of 1,1,1-Trichloroethane per year is used for precision/specialty cleaning applications.	Identify and qualify non-ODC/HAP alternatives.
Current method of neutralizing nitrogen tetroxide and hydrazine vapors generates over 300,000 pounds of hazardous waste depending on the launch schedule.	Develop process to decompose vapors into harmless products.
Corrosion control processes on infrastructure and support equipment account for the most widespread use of hazardous materials.	Qualify and implement low no-VOC/HAP/EPA-17 coating system.
Hydrazine poses a significant environment, safety and occupational health hazard.	Develop and qualify hydrazine replacements.
HCFC-141b is used as a blowing agent for cryogenic spray on foam insulation used on the Delta IV and Titan Launch Vehicles	Develop and qualify non ODC/HAP replacements.

Recommended Projects

Based on the recommendation, the following projects were funded in FY01 and proposed for funding in FY02 (see Table 2).

Table 2. Recommended Projects

FY	Status	Project Name	Description
01	Funded	Alternative Cleaners for Aerospace Systems	Investigate, identify, laboratory test and field test effective alternatives to Freon 113 and 1,1,1-Trichloroethane used for precision cleaning.
01	Funded	Oxidizer Vapor Recovery System	Investigate potential alternatives to packed bed scrubbers used to neutralize nitrogen tetroxide oxidizer and hydrazine fuel vapors.
01	Funded	Alternative Blowing Agent for Insulation Foams	Replace HCFC-141b used as a blowing agent for cryogenic spray on foam insulation on Delta and Titan Launch Vehicles.
02	Funded	Low/No VOC Corrosion Prevention Coatings for Space and Missile Facilities	Replace VOC/HAP/EPA-17 containing coating systems currently applied to space launch complex fixed and mobile service towers.
02	Funded	Low/No VOC Corrosion Prevention Coatings for CBM Missile Support Equipment	Replace VOC/HAP/EPA-17 containing coating systems currently applied to Minuteman and Peacekeeper shipping/storage containers transport trailers and vehicles.

For further information regarding this survey, please contact Mr. Randall Straw at DSN 785-5598.

Summary of High, Medium and Low Ranked Needs From FY97 Survey for Air Force Space Command

The FY97 Needs survey identified the high, medium, and low needs summarized below for Air Force Space Command (AFSPC).

High Ranked Needs:

- Need # 426: Environmentally Enhanced Solid Rocket Propellants

Medium Ranked Needs:

- Need #418: Development of a Hydrazine Propellant Fuel Production Process.
- Need #430: Alternative Thinners for Silicone Based Ablative Systems that Require the use of CFCs.

Low Ranked Needs:

- Need #406: Hazardous Waste Reduction in Chemical Vapor Deposition Process.
- Need # 429: A replacement Cleaner/Drying Agent is Required for Applications Where Parts Could be Exposed to Nitrogen Tetroxide.
- Need #431: No-Clean Alternative for Hand Touchup of Printed wiring Assemblies to Eliminate ODCs and VOCs.
- Need # 432: Replacement for Lead Based Solder in Surface Mount Technology and Other PWB Populating Applications to Reduce Lead, and EPA Targeted Toxic.
- Need # 433: Environmentally Friendly and Reliable Replacement for Urethane Conformal Coatings that Use Solvents such as Toluene and Xylene.
- Need #434: Need for Objective Analysis of Alcohol Cleaning Technologies for Cleaning of Printing Wiring Boards.
- Need #465: Non-EPA-17 Replacement for Conformal Coatings Application for GPS User Equipment.

For more information about these needs, please visit the Needs web site at http://xre22.brooks.af.mil.

AFRL/ASC Implement Environmentally Advantaged Radar Absorbing Material Coating (EARC) Project

In 1999, the Air Force Research Laboratory, Materials and Manufacturing Directorate, Airbase and Environmental Technology Division (AFRL/MLQ) initiated a project to develop Environmentally - Advantaged Radar Absorbing Material (RAM) Coating (EARC). As shown in Figure 2, this project was initially implemented by the Weapon System Logistics Branch (AFRL/MLQL, with Mr. Tom Naguy as the team lead.). Based on the successful results from the AFRL/MLQL effort, a follow-on demonstration/validation program is currently being implemented by the Aeronautical Systems Center, Engineering and Environmental Science Division (ASC/ENV). Details related to the EARC project are provided below.

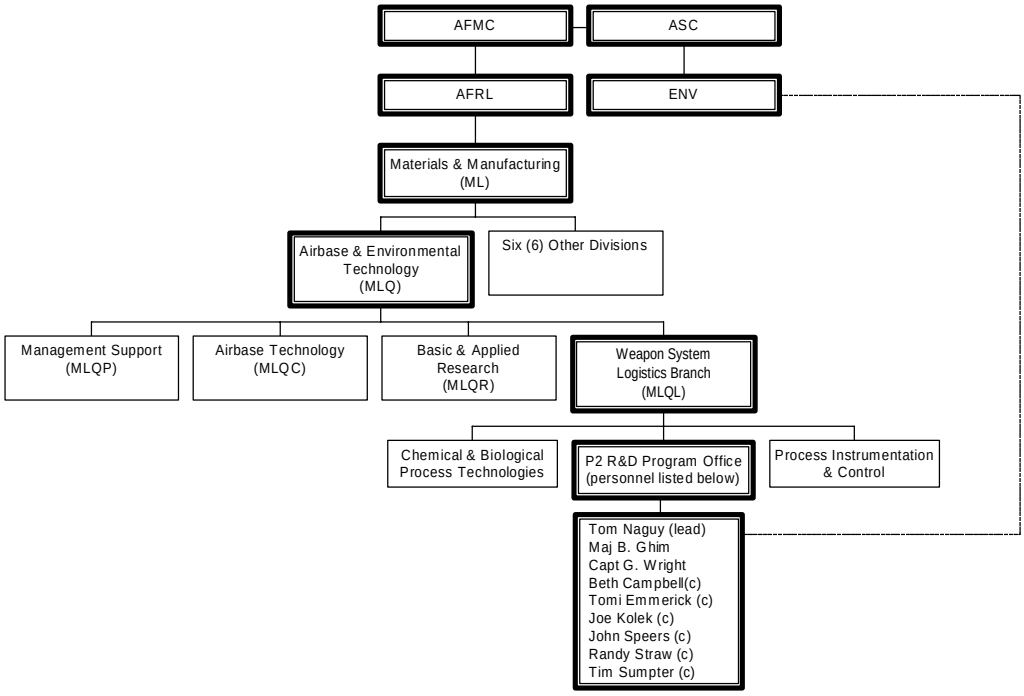

Figure 2. Organizational Chart

Background/Description of Need

Conventional RAM coating is used on aircraft, missiles, radar towers, and ships. RAM coatings are applied as paints to provide low observability (LO) characteristics. Environmental issues associated with the current technology lie in the high volatile organic compound (VOC) and hazardous air pollutant (HAP) content (up to 600 grams per liter (g/l)). Though currently exempt from the National Emission Standards for Hazardous Air Pollutants (NESHAP) for Aerospace Repair and Rework Facilities, RAM applications may comprise a significant portion of a facility's overall emissions of VOCs and HAPs. Failure to reduce these emissions can lead to significant cost and time expenditures to comply with SARA 313 and Title V requirements for record-keeping and permitting.

Building RAM coatings to the required thickness (up to .001 inch) is labor and time consuming, generally requiring many application cycles and significant time between each cycle for solvent evaporation. Typically, RAM coating application requires several passes while allowing time for solvent flash between each pass. A typical RAM application to an aircraft or missile requires many hours and multiple working shifts to complete.

Overview of the AFRL Effort

In 1999, AFRL/MLQL established a project to develop "low" VOC/HAP RAM coatings with quick deposition and cure rates. AFRL/MLQL placed Science Applications International Corporation (SAIC) under contract to manage the project and work with The Boeing Company to select, test and recommend an environmentally friendly as well as economically viable alternative to manufacture and apply RAM and LO coatings.

Initially, a total of nine candidate coatings were pre-screened and four were downselected for full screening tests. After several reformulation efforts and further down-selection, two final coatings were subjected to full physical property characterization testing. These two RAM coatings have been developed to a set of physical and electromagnetic requirements for a generic RAM coating. Both coatings met or exceeded the project's goals which included: less than 150 g/l VOC; reduced worker exposure; 75% reduction in material build rate; 75% reduction in labor hours to apply coating; and meeting typical electrical and mechanical performance requirements. The two developed coatings, CAAP Co FP-212-R and Boeing RDR-20, have a 75 percent reduction in VOC level as well as a 75 percent reduction in application time as compared to baseline coatings.

Dem/Val Project Transitioned to ASC/ENVV

The AFRL project originally included a demonstration and validation (dem/val) phase at an Air Logistics Center (ALC) or other Air Force site. However, the B-2 program was briefed on the results of this program, and they demonstrated genuine interest in trying to tailor the coatings to meet the requirements for their program specification. A follow-on dem/val program was subsequently initiated by ASC/ENV to tailor the coatings and perform limited modifications to the existing coating to meet the B-2 specific platform requirements. Once the specific coatings have been tailored to meet the goals, the program will progress into a scale-up and dem/val phase. Thus, the original dem/val phase was cancelled and will be expanded and coordinated as part of the B-2 dem/val follow-on program.

The goal of the ASC/ENVV dem/val is to extend AFRL's project achievements to identify, test and optimized a low VOC/HAP RAM coating systems. The demonstration will be conducted on suitable LO program components at test facilities and at an Air Force base employing Original Equipment Manufacturer (OEM) and repair applications. If this is successful, the technology will be transitioned to the LO Program and the spray system will be optimized.

For further information regarding this project, please contact Mr. Tom Naguy, AFRL/MLQL at DSN 986-5709 or 937-656-5709 or Lt Lowell Usrey at DSN 785-3059 ext. 317 or 937-255-3059 ext. 317.

Environmentally Friendly Topcoat Successful During Flight Test

Aeronautical Systems Center engineers recently completed a three-year flight test of an environmentally friendly, topcoat product for use on aircraft.

The product, successfully flown on two supersonic aircraft, is applied as a thin film over primer painted on the aircraft body. According to environmental scientist Charles Valley, ASC Engineering Directorate, Acquisition Environmental, Safety and Health Division, the thin film "appliqué" is a zero volatile organic compound (VOC) material, which has no waste stream and can be recycled. Similar to contact paper, the covering replaces the traditional sprayed-on, high-VOC topcoat paint. The film is a fluorinated polymer material with design characteristics similar to those of traditional paint topcoats, but without the hazardous materials. "This process reduces the use of volatile organic compounds and, as a result, fosters Air Force pollution prevention goals," Valley said.

Current aircraft paint systems depend heavily on large volumes of VOCs and heavy metals, such as methylene chloride, methyl-ethyl ketone and chromium. "These chemical compounds are a threat to the environment and to

the health of workers at manufacturing facilities and aircraft maintenance depots, so we are seeking environmentally friendly replacements for them," explained Valley.

The ASC team began testing the topcoat in October 1996 – and has continued testing the material as it has evolved. Engineers initially applied "applique" to an F-15B chase and target aircraft at Boeing Aerospace in St. Louis, MO. During those tests the aircraft logged more than 50 hours of flight time, including about a half-hour of supersonic time at 48,000 feet.

"Initial tests on the F-15 demonstrated how thin film 'applique' topcoat performed in a typical flight environment, including flight at supersonic speeds," said Valley. "We also gained valuable data by applying the material to various regions on the aircraft to evaluate its reaction to common hydraulic and de-icing fluids. Additionally, we tested for resistance to infrared and ultraviolet light. The topcoat held up well under exposure to nearly every element of the real world flight environment."

In June 2000, maintenance technicians applied the topcoat to an F-16, flown by the Air National Guard (ANG) at Duluth, Minn. Pilots there logged about 250 hours in hot and cold climactic conditions – and continue to fly the aircraft so that ASC is able to monitor the material for aging, ultraviolet degradation and potential corrosion issues.

"Our function for the project has been to get the maximum hours of flight time with the 'applique'," said Col. William Bordson, maintenance squadron commander, Duluth ANG. "So far, it has had little, if any, impact on our mission. Most of our pilots are not even aware that the 'applique' has been applied to the aircraft."

While these early flights were highly encouraging, Valley said a few hurdles remain. "Before the Air Force can fully accept this material as an alternative topcoat, we need to examine it further to determine the degree of resiliency it offers for long-term corrosion protection of aircraft skins," he said. "We'd like to have the ultimate, environmentally friendly topcoat with corrosion resistance properties of an aircraft primer."

Valley also noted that during early flight tests with the F-16, adhesion of the material was a problem on areas of the aircraft where JP8 fuel had leaked. A new adhesive formulation was developed to correct this weakness.

The ultimate goal for applique, Valley stressed, is to completely eliminate dependence on using chrome in aircraft topcoats. To that end, the Air Force – and ASC – now are evaluating a primerless thin film topcoat product that would completely eliminate chrome in the entire aircraft topcoat primer system.

Engineers at ASC continue to assess the effectiveness of applique for future Air Force use. The Joint Strike Fighter office at Wright-Patterson Air Force Base has shown an interest in the thin film topcoat and is monitoring the current F-16 applique flight tests. "The JSF SPO is supportive of the project's goal to qualify applique for use on a supersonic aircraft," Valley said.

Environmental projects similar to the topcoat work at ASC are helping the Air Force identify ways to reduce its reliance on hazardous materials – and eliminate the resultant waste in the weapon system life cycle.

"We have a unique opportunity here to support the Air Force in 'greening up' our military aircraft operation and maintenance processes," Valley said. "This saves the government millions in hazardous material permitting fees and cost avoidance, while developing smarter technology for our weapon systems."

This article was submitted by Ms. Larrine Barr, ASC/ENV.

Overview of Historical and Current Environmental Trends in Air Force Materiel Command (AFMC)

Over the last decade, the Air Force has decreased its notices of violations (NOVs) from 257 to 7. All the trends in environmental management indicate that the Air Force is moving towards a greener Force. HQ AFMC has far exceeded it Ozone Depleting Substance (ODS), EPA-17, and toxic release inventory (TRI) reduction goals.

Despite this achievement, the command is still using a significant amount of EPA-17 materials, such as methylene chloride, methyl ethyl ketone (MEK), perchloroethylene, and chromium. The current trend of select EPA-17 chemical usage in AFMC is shown in Figure 3.

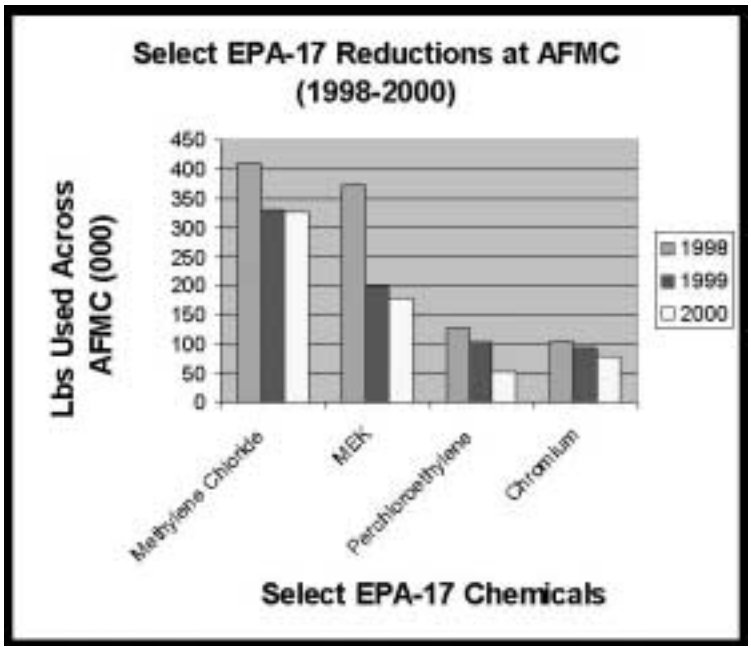

Figure 3. Chemical Usage in AFMC

AFMC is the largest Air Force generator of hazardous waste. Historically, AFMC generates 42% of the annual USAF volume, with generation rates of 6657 tons in FY99. The annual cost to AFMC for hazardous waste management and disposal is $8.2 Million. The major sources of hazardous waste generation in AFMC currently include industrial wastewater treatment plant (IWTP) sludge, paint operations media/sludge, contaminated fuels, and electroplating baths.

Overview of Historical Regulatory Drivers

In 1960, there were only six environmental laws. Forty years later, there are over sixty and the list is continually growing. The cost of compliance and risk of civil fines has steadily grown. Historically, federal agencies received immunity from environmental laws. Today, the same agencies are required to comply with most federal, state, and local laws under the Federal Facilities Compliance Act (FFCA) of 1992. This Act amended the waiver of sovereign immunity granted to federal facilities under the Resource Conservation and Recovery Act (RCRA). Under the FFCA, United States Environmental Protection Agency (US EPA) inspectors can levy fines for uncorrected violations found after October 6, 1992. Fines levied through the FFCA and RCRA can be as high as $25,000 per day, until the violation is corrected.

Some of the key drivers that have been directing AFMC's pollution prevention program are summarized in Figure 4 (see page 15).

Future Challenge to AFMC

The future challenge to AFMC, who owns approximately 80% of the AF's environmentally regulated processes and generates approximately 45% of the annual USAF hazardous waste volume, is to comply with future regulations in a cost effective manner. AFMC is faced with complying with increasing stringent regulatory requirements, identifying and targeting current and future DMAG cost drivers, and updating DMAG practices to lessen impact to facilities, logistical footprint, and the warfighter.

For further information on current and historical trends in AFMC, please contact Mr. Warren Assink at DSN 674-0151.

- **Pollution Prevention Act of 1990** – encouraged source reduction strategies over waste management or pollution control
- **Clean Air Act Amendments of 1990** – directed federal agencies engaged in the release of air pollutants to comply with all federal, state, and local regulations regarding the control of these pollutants. The ban on Class I ODS was implemented in the United States through Title VI of the CAA Amendments. There are 189 hazardous air pollutants (HAP) controlled under the CAA.
- **EPA 33/50 Program** – required the reduction of 17 chemicals (known as EPA-17) by 33% in 1992 and 50% by 1995.
- **Resource Conservation and Recovery Act (RCRA)** – has established a comprehensive law for "cradle-to-grave" control of the treatment, storage, and disposal of hazardous waste.
- **Emergency Planning and Community Right to Know Act (EPCRA)** – this Act is a freestanding provision of the Superfund Amendments and Reauthorization Act (SARA) of 1986. Previously, AFMC voluntarily agreed to comply with this statue and provide hazardous material information to state and local emergency planning bodies. This information is no longer voluntary and is required by EO 12856 and mandated by FFCA. EO 12856 also required each DoD service to achieve a 50 % reduction by 1999 of its TRI, from a 1994 baseline.

Figure 4. Historical Drivers for AFMC's P2 Program

Summary of Pending Environmental Issues Impacting Air Force Materiel Command (AFMC)

HQ AFMC/LGP-EV is tracking the several environmental issues and evaluating their potential impact to AFMC bases. A summary of some of these issues is provided below.

Deicing: Aircraft deicing operations represent a significant financial and compliance burden in the Air Force and DoD. Propylene glycol aircraft deicing fluids are aquatic toxins, and exert a high chemical and biochemical oxygen demand on receiving waters. (There are no non-glycol aircraft deicing fluids approved for use in the USAF.) The Government Accounting Office (GAO) reports the control of spent deicing fluids is second only to aircraft noise abatement at airports today.

The Air Force is addressing deicing problems through integrated approach that includes evaluating infrared technology to minimize fluid consumption, improving glycol recovery techniques, and evaluating/testing of less harmful fluids. Within the Air Force *TO 42C-1-2, Anti-Icing, Deicing, and Defrosting of Parked Aircraft* drives deicing procedures.

Halon: Halon fire suppression agents have been used in the Air Force weapon system for decades for their effectiveness and low costs. Scientific discoveries in the 1980's showed that these substances cause damage to the earth's ozone layer and led to a U.S Government ban on the production of all Class I Ozone Depleting Substances (ODS) effective 1 January 1996. In the years, prior to the production ban, the Department of Defense (DoD) issued a policy letter requiring conservation and "banking" of Class I ODSs.

Today, there are non-ODS fire suppressants available, but they pose a few problems. First, more agent is required for the same effect, so there is no "drop in" replacement. Distribution systems require re-engineering before today's Halon substitutes can be used on existing aircraft. Second, the new agents are more toxic to humans than the Class I Halons. There is no compelling reason to convert from Halon at this time. The Air Force can continue to use Halons on legacy aircraft until retire.

HCFC-141b: The Air Force and support contractors are using HCFC-141b solvents throughout the Air Logistics Centers (ALCs) for both general purpose and precision cleaning. Under Section 606 of the Clean Air Act, the production and consumption of HCFCs is required to be phased out by 2030. To meet this limit the production and consumption of HCFC-141b is set to cease on January 1, 2003, except for specified exemptions.

A recent survey of Pharmacy purchases at Robins AFB, Tinker AFB, and Hill AFB showed issues of cleaners under approximately 20 different NSN/local stock numbers containing over 27,000 lbs of HCFC-141b. In the past year, these chemicals were used in approximately 170 different work centers. Quantities used per individual work center ranged from ounces per year to over 7000 lbs per year.

AFMC is in the process of identifying the technical performance requirements for the use of HCFC-141b, identifying potential alternatives, testing alternatives against requirements, and demonstrating/validating and transitioning suitable alternatives to the ALCs. If needed, a new performance specification will be written for qualified alternatives.

For further information about these or other pending environmental issues, please contact Mr. Warren Assink at DSN 674-0151.

Overview of HQ AFMC/LGP-EV's Weapon System Pollution Prevention Projects

HQ AFMC/LGP-EV is involved in the Air Force lead on several Joint Group on Pollution Project (JG-PP) projects and others that are AFMC funded. This article summarizes the current projects being executed within AFMC and through the JG-PP by HQ AFMC/LGP-EV.

Chromium Electroplating Alternatives Partnering with HCAT – consists of four active JG-PP projects to replace hexavalent chromium electroplating with High Velocity Oxygen Fuel (HVOF) on actuators, helicopter dynamic components, landing gear, and propeller hubs. The replacement of hexavalent chromium plating with less hazardous materials and regulated processes is a high priority within DoD. USEPA regulates air emissions and solid and liquid waste and OSHA regulates personnel safety from chromium plating operations. HVOF coatings would eliminate these environmental hazards. Additionally, preliminary testing has shown that the performance of HVOF coatings is superior to chrome in wear, fatigue, and impact resistance and is at least equal in corrosion resistance.

Demonstrate Powder Coating Technology – the objective of this AFMC wide project is to transition powder coating technology across the command. The purpose of this project is to use powder coatings on non-critical components such as F-100 exciter box, air scoops, segments and forgings, liquid oxygen bottles, and missile bodies. Compared to traditional painting operations, powder painting reduces volatile organic compound (VOC) and Hazardous Air Pollutant (HAP) emissions to near zero, and thereby reduces the associated compliance burden, while producing a high quality coating. Additionally, the use of hazardous waste stream generated from painting operations is eliminate through powder coatings.

Diode Laser – the goal of this AFMC/AFRL project is to demonstrate/validate the potential of a diode based laser coating removal system. The objectives of the project include the following:

- Develop, demonstrate, and validate a "glove box" cabinet containing a hand held diode laser stripping system capable of removing conventional/specialty coatings and carbon build-up from small off-equipment components.
- Demonstrate/validate the capability of the diode laser to remove specialty coatings sealants/adhesives, and carbon build-up from on-and off-equipment components.

Low/No-VOC and Nonchromate Coating System for Support Equipment – this JG-PP project identifies and qualifies environmentally acceptable alternatives to conventional primers and topcoats used for coating support equipment. The new coating would eliminate hexavalent chromium, lead, VOCs and HAPs found in current primer and topcoat formulations. Eleven advanced film technology, high-solid coatings, metal wire arc spraying, powder coating, and waterborne coating primer/topcoat systems have been chosen for testing.

Nonchromate Conversion Coating – The Air Force has participated in The JG-PP Non-Chrome Primer for Aircraft Outer Moldline project from the time it started in 1995. The field-testing completed under the JGPP Non-chrome primer project was conducted on aircraft with a history of good corrosion resistance. With the concept of flying many of the weapons systems out as far as 2027 the need for further testing on legacy aircraft is realized. HQ AFMC/LGP-EV with the support of Boeing St. Louis is planning to further field test the non-chrome primers on large aircraft. The platform being considered for this testing is the KC-135.

Non-ODC Oxygen Line Cleaning – this JG-PP project identifies and validates one or more technologies that use non-ODCs to clean oxygen lines. Technologies being demonstrated include a portable unit for onboard cleaning oxygen systems and one or more technologies for off-aircraft cleaning. Successful completion of this project will result in removing dependence of chlorofluorocarbons and other ozone depleters to clean oxygen lines and components. Significant savings will be realized in manpower, avoided aircraft downtime and chemical purchase/volume disposal.

Portable Laser Coating Removal System – this JG-PP project demonstrates the feasibility of using a compact, low powered, handheld laser system for small area paint removal. Currently, removing these coatings requires using hazardous materials that generate large amounts of hazardous waste and pose as significant occupational health risk for the workers performing this task. An annual estimated cost savings documented from one Air Logistics Center is $295K just from eliminating or minimizing methyl ethyl ketone (MEK) and methylene chloride purchases, their use, and associated waste streams.

Titanium Wipe Solvent – the goal for this AFMC project is to validate the use of an environmentally safe wipe solvent by proving its ability to increase the bond ability of paints to titanium surface. This product combines environmentally safe volatile organic solvents with adhesion promoter. The solvent is exempt from current state and federal regulations.

For further information regarding these projects, please contact Mr. Jerry Mongelli at DSN 787-7693.

Overview of the Capital Purchase Program

The Capital Purchases Program (CPP) is the Depot Maintenance Activity Group's (DMAG's) capital investment program. It sustains existing equipment infrastructure capability by replacing worn out equipment and obsolete technology supporting current workloads. CPP is financed through depreciation (a DMAG operating expense) and is factored into the customer sales rates. It generates funds (cash) for reinvestment. When capital requirements exceed annual depreciation, a surcharge is applied.

The four categories that make up the CPP include: equipment (replacement, productivity, and environmental compliance), automated data processing equipment (ADPE), software development (software/management information systems), and minor construction (MC). Acquisitions must have a value greater than $100,000 and have a useful life of two years or more. Minor construction must cost $500,000 or less.

Acquisitions purchased with CPP funds include: industrial plant equipment (IPE), Rehabilitation and Modification of Depot Equipment (DPE), initial lay-in of weapon system support equipment (peculiar and common) required for existing weapon systems, special purpose non-passenger vehicles, computer hardware, software/management systems (such as the Depot Maintenance Accounting and Production System (DMAPS)), and environmental compliance equipment (wash/paint/strip (media blast)).

Acquisitions not available for CPP include new mission, modifications, or other program driven requirements, and unspecified minor/emergency construction costing more than $500,000 and up to $1,500,000.

To submit a requirement for CPP, the requirement must be identified and be in support a non-production weapon system, DMAG owned, have a cost of at least $100,000, and a two-year useful life. A fact sheet with a description and justification accompanies the requirement and includes a vital mission statement; base civil engineering work request (AF 332) and military construction project data (DD 1392) for MC; computer systems requirements document (CSRD) for ADPE hardware/software; economic/cost analysis for acquisitions costing at least $100,000; simulation model for acquisitions costing at least $500,000; and other pertinent documentation such as a workload review and sales rate analysis.

For further information, please contact Ms. Susan Misra, HQ AFMC/LGP-EV at DSN 787-3498.

Trends in Cadmium Use and Cadmium Electroplating

Over the last 25 years, cadmium use in the plating industry has declined. Today, this trend is further accelerating due to tightening regulations governing the use and emissions of cadmium (see related article on page 21). A recent Occupational Safety and Health Administration (OSHA) survey indicates that there are about 1,166 plating facilities in the United States (US) that still use cadmium.

The aerospace and defense industries account for the largest cadmium use in the US. A survey conducted by the Defense Logistics Agency (DLA) indicates there are over 230,000 cadmium plated parts purchased through this agency. A breakdown of these parts by hardware, show that a majority of cadmium plated parts are fasteners (38%), followed by hardware (e.g., bushing) (22%), electrical connectors (17%), and springs (7%).

Cadmium Plating at Air Logistics Centers

Figure 5 provides a summary of cadmium plating and alternative technologies used at the Air Logistics Centers (ALCs). Within the Air Force, a majority of the re-work associated with cadmium plating for weapon system components at the ALCs has been supplemented through the use of Ion Vapor Deposited (IVD) aluminum (see related article on page 23) and Zinc-Nickel Plating technology. In the early 1990's, the Air Force identified cadmium plated components, and where feasible, substituted IVD aluminum.

Warner Robins Air Logistics Center (WR-ALC):
- Eliminated Cadmium Plating in the 90's
- Currently uses IVD Aluminum to coat parts for the C-130, C-5, and C-141
- Uses cadmium brush plating

Oklahoma City Air Logistics Center (OC-ALC):
- Eliminated Cadmium Plating in the 90's
- Engine and other parts are coated using Electroless Nickel Plating and IVD Aluminum
- Uses cadmium brush plating

Ogden Air Logistics Center (OO-ALC):
- Uses Cadmium Plating and IVD Aluminum to coat approximately 100,000
  - 500,000 parts annually
- Uses cadmium brush plating

Figure 5. Cadmium Plating and Alternative Technologies Used at the ALCs

In 1990, Warner Robins Air Logistics Center (WR-ALC) replaced its cadmium plating with IVD aluminum. Currently, the two IVD chambers at WR-ALC handle parts primarily for the C-130 that include hubs, crank drives, and struts. Some brush plating is also conducted at WR-ALC. The two IVD chambers are being upgraded this year and a service contract is being established for their maintenance.

In 1987, Tinker AFB installed two IVD aluminum chambers. In 1992, the facility eliminated it cadmium plating by going to Zinc Nickel plating and Electroless Nickel. Today 5% of all parts that were historically cadmium plated are

managed through the Electroless Nickel process. The remaining throughput is handled by the zinc-nickel plating and the IVD aluminum chambers. Engine and aircraft parts are the main parts that go through these processes.

On an annual basis, Ogden Air Logistics Center (OO-ALC) manages 100,000 – 500,000 different parts associated with landing gears. There are approximately 5,000 gear assemblies, 25,000 wheel and brake assemblies (steel), each of about 100-1000 components. IVD Aluminum has been qualified for 80% of Air Force landing gear parts that do not involve coating internal diameters. Although 80% of all landing gears parts are qualified of IVD Aluminum coating, only 50% currently run through the IVD chambers . Landing gear for the C-5 and B-2 require cadmium plating because these parts will not fit into an IVD Chamber.

Overview of the Cadmium Electroplating Process

Electroplating is the process of applying a metallic coating through an electrolyte containing a salt of the metal. In electroplating, the part to be plated is made the cathode where the reduction reaction occurs and a second electrode (the anode) is present to complete the circuit. Figure 6 presents a process flow diagram of a typical cadmium electroplating process. The basic steps in this process include: surface preparation, surface treatment, and post treatment, which are further discussed below.

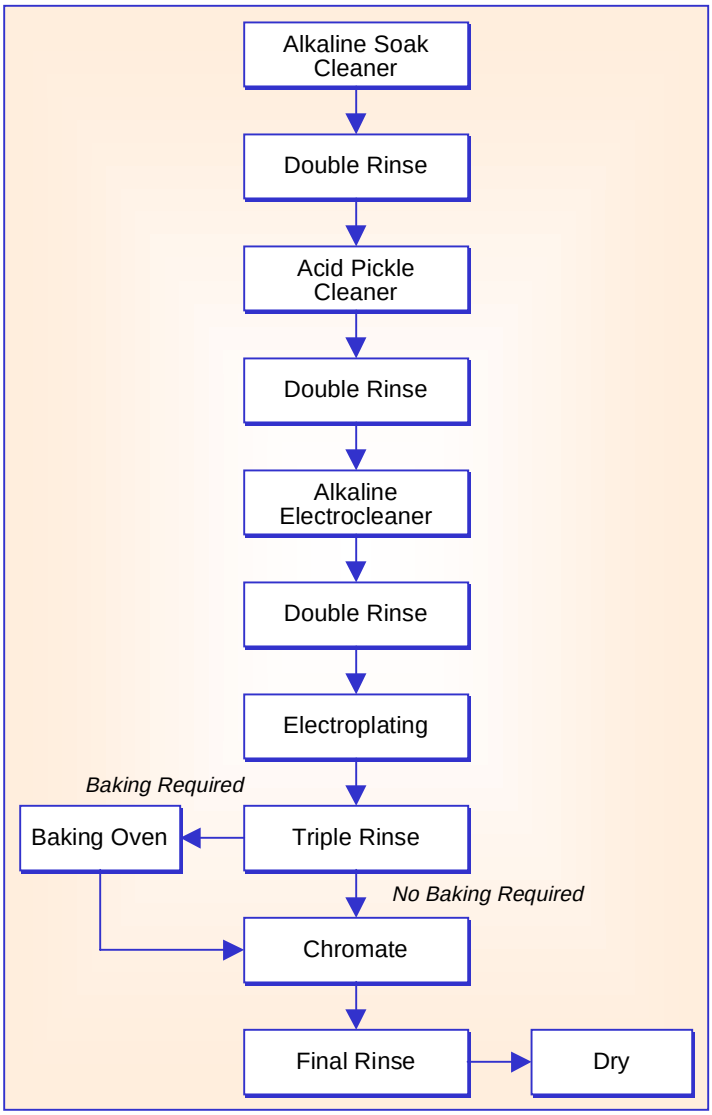

Figure 6. Overview of a Typical Cadmium Electroplating Process

Surface Preparation

Surface preparation involves a series of steps to remove greases, soils, oxides and other materials to prepare the part for surface treatment. Historically, this step has involved the use of alkaline detergents and solvents for parts cleaning followed by rinsing the workpiece. Next, an acid and an alkaline dip are used to remove oxides and clean the surface for treatment. These steps are followed with rinsing the work pieces. The cadmium plating process at OO-ALC uses Calla-296, an aqueous cleaner followed by dry blasting using 80-180 grit aluminum oxide (Al_2O_3), silicon dioxide (SiO_2), or garnet per MIL-STD-1504. This process takes approximately one hour. The parts are then rinsed with cold water.

Surface Treatment

Surface treatment involves electroplating the cadmium coating on the part. Cadmium electroplating operations are typically batch operations in which the metal objects are dipped into a series of baths containing cyanide or acid solution for achieving the required surface characteristics. The process is controlled by a variety of parameters including voltage and current, temperature, residence times, and purity of the bath solutions. After plating, parts are typically triple rinsed prior to post treatment.

Continued on Page 21

C-17 - Evaluation of IVD & Non IVD Aluminum Replacement of C-17 Parts *(Completed)*

- Since 1995, C-17 has conducted 4 projects to replace cadmium for various aircraft parts:
  - First project evaluated applicability of Ion Vapor Deposited (IVD) aluminum coating as a "drop-in" replacement for cadmium plating on OEM controlled, non-standard C-17 parts. Laboratory testing indicated that 85% of the parts could be easily converted to IVD Aluminum.
  - Two additional projects were implemented to: 1) investigate methods for improving the applicability and functionality of IVD aluminum; 2) evaluate non-IVD aluminum finishes for existing C-17 cadmium parts that involved oversized parts, parts with plated internal surfaces, and standard parts. Laboratory testing showed IVD aluminum plus supplemental processing (zinc-nickel) is functionally similar to cadmium for internal surfaces.
  - A final project was implemented to evaluate the applicability of compliant IVD aluminum coating as a replacement for cadmium plating to threaded portions of fasteners for non-critical applications on the C-17 aircraft. Based on results, Boeing could not recommend IVD coating on threaded fasteners.

F-22 - Cadmium Replacement on Landing Gear *(Completed)*

- OO-ALC and the F-22 WS HAZMAT Team advocated the SPO to fund an evaluation study for alternative finishes and associated replacement costs for cadmium plating. The study identified IVD Aluminum to replace cadmium plating on external surfaces and a metallic-ceramic coating for parts with deep internal diameters or threaded parts.

AFRL/MLSA - Replacement of Cd and Ni Plating on Connectors *(Completed)*

- The purpose of this project was to identify and test replacements for existing cadmium plated electronic connectors. A final report is available on this project that identified potential candidates.

F-16 - Cadmium Replacement on Inlet Fasteners and Electrical Connectors *(Ongoing)*

- This project is evaluating new processes to replace cadmium plating on inlet fasteners, threaded fasteners, and electric connectors. Candidate solutions include IVD aluminum, aluminum plating, zinc nickel, and tin zinc.

JG-PP - Alternatives to Electrodeposited Cadmium for Corrosion Protection and Threaded Part Lubricity Application *(Ongoing)*

- The objective of this project is to eliminate cadmium in metal plating on threaded fasteners, gears and cabinets. Electrodeposited tin-zinc and electrodeposited zinc-nickel are being considered as potential alternatives.

ASC/ENVV - Replacement of Cadmium for Landing Gear Internal Surface Coverage *(Ongoing)*

- The objective of this project is to develop and implement a technology transfer plan which entails coordinating with an ALC demonstration site, equipment acquisition, installation, demonstration, validation, and training. The work done under this project has proved that IVD Aluminum and Sputtered Aluminum processes are viable alternatives to cadmium plating for high strength alloy steels used on landing gear parts.

PEWG - Environmentally Acceptable Alternative to Cadmium Plating in 2J-T56-53 Maintenance TO *(Ongoing)*

- The objective of this project is to find an environmentally acceptable alternative to cadmium plating called out in various places of the 2J-T56-53 depot maintenance TO. Priority parts considered for cadmium coating replacement include the following: parts without splines or thread, parts with inactive (clamped) spines; parts with positioning threads; and parts with threads for clamping. Alkaline zinc-nickel was selected as the most liked candidate based on available test data.

US Army Tank Automotive Armament Command - Long Term Performance of Cadmium Alternatives *(Completed)*

- The study provides fastener specific data on seven commercially available cadmium substitutes and four lubricants. An organic alternative was found to have performance comparable to cadmium in all respects except for electrical conductivity.

NAWCAD - Evaluation of Aluminum-Manganese as a Cadmium Replacement *(Ongoing)*

- Testing aluminum-manganese as a replacement for cadmium plating. Aluminum-manganese is applied by electroplating in molten salt and can plate internal diameters, complex geometries, and threaded applications. Aluminum-manganese has the potential for use in high strength steel application where electroplated cadmium alternatives such as tin-zinc and zinc-nickel have concerns with environmentally assisted cracking.

NAVSEA - Alternative Surface Coating and Surface Treatment for Hazardous Cadmium Plating of Small Parts *(Completed)*

- This was a program to evaluate environmentally acceptable alternatives to cadmium plating in U.S. Navy applications. Several coatings appear to provide corrosion resistance compared to cadmium plating on non-complex shapes. In the area of complex shapes, none of the alternatives assessed performed as well as cadmium.

Army Research Laboratory - The Performance of Three Alternative Coatings to Electroplated Cadmium for Corrosion Protection in Fastener Applications *(Completed)*

- ARL examined three alternatives to cadmium for corrosion protection in AH-64 fastener applications, including IVD aluminum, a MIL-T-83483 anti-seize compound, and a MIL-C-16173 corrosion preventative compound. The results of the research indicated that the anti-seize compound and the corrosion preventative compound were not adequate replacements for cadmium based upon unacceptable fastener and aluminum block corrosion. IVD was deemed comparable to cadmium based upon torque values, fastener corrosion, and block corrosion results.

Summary of Cadmium Funded Projects

Continued from Page 19

OO-ALC has two large cadmium cyanide plating baths that contain a total of 3,200 gallons of plating solution. A current density of 50 – 70 amperes/ft^2 is applied to ensure a uniform coating. After electroplating, the parts are rinsed, first with cold water, and then in hot water, and dried with compressed air. Surface treatment typically takes up to four hours.

Post Treatment

Post treatment processes are used to enhance the appearance or add to the properties of the coated parts. For example, parts are heat-treated to bake out hydrogen that can cause embrittlement of steel, and a chromate conversion is applied to increase corrosion resistance and paint adhesion.

At OO-ALC, all high strength steel parts that have been heat-treated over 180,000 psi are baked for 24 hours minimum at 374ºF. All the parts at OO-ALC are then immersed in the Type II chromated solution (Iridite No 8P or equivalent) for 15-30 seconds and rinsed with cold water and then with warm water to facilitate drying.

Waste and Emissions Generation From Cadmium Electroplating

In-service costs of cadmium coatings are significant and are attributed to the required maintenance procedures on cadmium coated parts that yield cadmium containing wastes or cadmium contamination. Cadmium electroplating produces air emissions, hazardous wastes, and solid wastes. Air emissions are generated during the cleaning (pretreatment) and electroplating process. Mists arising from electroplating fluids and processes gases include metal ion bearing mists and acid mists. Additionally, maintenance procedures, such as cutting or grinding of cadmium coated nuts and bolts generate cadmium fume or dust. Mechanical stripping of cadmium coating also generates cadmium dust.

Solid and hazardous wastes are generated during the cleaning (pretreatment and pre/post plating) and electroplating process. Additionally, chemical stripping of cadmium coatings generates large amounts of hazardous wastes. Compliance with hazardous waste regulations requires strict handling, storage, and disposal procedures.

Cadmium contamination has been observed in rinse waters from equipment containing cadmium-coated parts. Contaminated wastewater results from work-piece rinsing and process cleanup waters and contains metal salts, acid, and base wastes. Wastewater treatment techniques generate sludge that needs to be disposed. Other wastes include spent bath solutions and wastes generated from the chromate post treatment processes.

The primary contributing factors to the lifecycle cost of cadmium use in the electroplating process are related to personnel exposure, waste management, reporting requirements and the long-term legal liabilities associated with the use of cadmium. Exposure to small amounts of cadmium dust or fume can easily exceed the action levels and personnel exposure limit of cadmium that may result in significant medical and legal costs.

Environmental, Safety, and Occupational Health (ESOH) Concerns Associated with Cadmium Use

The United States Environmental Protection Agency (EPA) lists cadmium as a probable human carcinogen (class B1). In 1992, the U.S. OSHA revised its Permissible Exposure Limit (PEL) for cadmium in the workplace. The new OSHA PEL is 95% lower than the previously acceptable value. Today, under OSHA, the amount of cadmium to which workers can be exposed to is at 5 micrograms per cubic meter (5 µg/m^3) and an action level (AL) of 2.5 µg/m^3. Compliance with the OSHA Cadmium Standard was expected to cost domestic industries $159 million/year.

Serious impacts can result from cadmium particles that are too large to be drawn deep into the lungs but small enough to enter the tracheobronchial region of the lung. This can lead to bronchoconstriction, chronic pulmonary disease, and cancer of that portion of the lung. Particles that remain

in the nose of mucous membranes because of their size can be absorbed into the blood. This is a concern when grinding off cadmium plating.

OSHA's cadmium standard is contained in 29 CFR 1910.1027, which can be found at http://www.osha-slc.gov/OshStd_data/1910_1027.html. The basic standard contains information summarized in Figure 7.

1) The exposure monitoring or other methods that must be used to characterize employee exposures relative to the permissible exposure limit for cadmium.
2) The establishment of regulated areas when exposures can be reasonably expected to exceed the permissible exposure limit. The elements of regulated areas are discussed, including marking boundaries, limiting access to authorized persons, respirator use, and prohibited activities (for example, eating, chewing gum or tobacco, smoking, applying cosmetics).
3) The use of engineering controls and work practice controls to reduce employee exposures to cadmium.
4) Selection and use of respiratory protection.
5) The written work area compliance plan stating how engineering and work practice controls will be used to reduce cadmium exposures to below the PEL and a written emergency response plan should there be a substantial release of airborne cadmium.
6) The requirement that employers:
    a) Ensure employees do not inadvertently carry cadmium-contaminated protective clothing or equipment out of the immediate work area.
    b) Provide employees exposed to airborne cadmium above the permissible exposure limit with clean change rooms, handwashing facilities, showers, and eating facilities free from cadmium.
    c) Work area housekeeping requirements to ensure all surfaces are as free as practicable of accumulations of cadmium.
    d) The type of medical surveillance the employer must provide.
    e) How the employer will communicate cadmium hazards to the employees, such as warning signs and labels, and Hazard Communication (HAZCOM) and cadmium-specific training.
    f) Employer record-keeping requirements.
    g) The requirement that employers offer affected employees or their designated representatives and opportunity to observe monitoring of employee exposure to cadmium.
    h) The effective dates of the Standard.

Figure 7. OSHA's Basic Cadmium Standard

Cadmium can enter the water environment from plating operations when spent plating solutions are discarded. Wastewater sludge from electroplating operations is subjected to treatment standards established under the Resources Conservation and Recovery Act (RCRA). Environmental accumulation of groundwater contamination from electroplating operations has been reported to cause concentration levels of up to 3.2 mg/l. Additionally, with the pending Metal Products and Machinery Proposed Effluent limits will reduce the cadmium wastewater discharge limit to less than 0.09 mg/l monthly maximum.

European countries have developed additional regulations or "bans" on the use of cadmium. For example, Sweden enacted a comprehensive cadmium ban in 1985. Finland also restricted cadmium usage in 1992 and Germany has prohibitions against the use of some cadmium compounds.

Overview of the Ion Vapor Deposited (IVD) Aluminum Process

McDonnell Aircraft, now Boeing, developed the IVD aluminum process in the 1960's. The technology has been successfully used as a replacement for cadmium plating. IVD aluminum is a suitable cadmium replacement for many applications, but it does not provide the lubricity of cadmium, nor does it always provide sufficient corrosion protection due to coating porosity. To densify the aluminum coating and improve its adhesion to the substrate material, glass bead peening is often used. Subsequently, a chromate conversion coating is applied to impart greater corrosion resistance, lubricity, and provide a surface amenable to painting. A description and applicability of IVD aluminum is provided below.

Process Description

The IVD process is used to apply sacrificial aluminum coatings on metallic parts. Figure 8 provides a schematic of a typical IVD aluminum process, which include pretreatment, processing, and finishing operations. In the pretreatment process, parts to be coated are first prepared by a degreasing operation. This is followed by a blasting step to texture the part's surface and remove any debris. The pretreatment process also includes masking with low out-gassing tapes or metal foils.

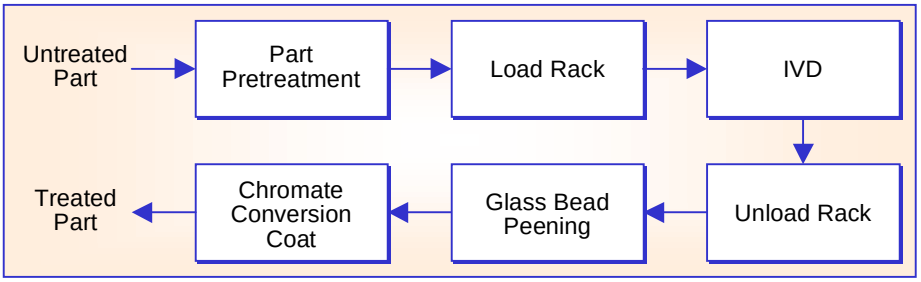

Figure 8. Conventional Ion Vapor Deposited (IVD) Aluminum Process Flow

The processing step begins with racking or barrel loading the parts in the IVD vacuum chamber. The process is performed in an airtight chamber that is evacuated to high vacuum levels by a series of vacuum pumps. During the process, the parts are held at a high negative potential with respect to the vapor source anode and the parts become the cathode of a high voltage circuit. By maintaining a proper pressure in the chamber, a DC glow discharge is established about the parts and a portion of the evaporated aluminum is ionized and accelerated toward the parts.

The vacuum chamber is then evacuated to purge the system before it is backfilled with Argon to a pressure of $6x10^{-5}$ torr. A glow discharge is created around the parts by the application of a high negative potential between the parts to be coated and the evaporation source. This bombards the parts with the ionized argon gas and serves as the final surface preparation prior to coating.

After IVD coating, surfaces of the IVD coated parts are burnished with glass beads to provide a denser surface that provides better paint adhesion. The parts are then immersed into a chromate conversion coating solution and rinsed in hot water. At OC-ALC, the Iridite 14 compound is initially dissolved in water at 120°F, then the temperature of the bath is dropped to room temperature for operation. The immersion coating process is performed in a 304 stainless steel tank and takes one to five minutes. This imparts greater corrosion resistance, lubricity, and provides a surface amenable to painting.

Following the conversion coating application, the part is rinsed in de-ionized hot water, using a quick drop in method. The temperature of the water is less than 140°F. After rinsing, the part is air dried at room temperature.

Applicability

IVD aluminum works for a range of parts. It is capable of coating complex shaped parts, but cannot coat deep recesses or internal diameters well. IVD aluminum can be used for fasteners and threaded applications provided that a dry-film lube is used as the aluminum coating has a tendency to gall and seize. Another limitation of IVD aluminum is the size of parts that can be processed.