NASA TECHNICAL STANDARD	NASA-STD-6012
National Aeronautics and Space Administration Washington, DC 20546-0001	Approved: 03-08-2012

CORROSION PROTECTION FOR SPACE FLIGHT HARDWARE

MEASUREMENT SYSTEM IDENTIFICATION:
METRIC/SI (ENGLISH)

APPROVED FOR PUBLIC RELEASE—DISTRIBUTION IS UNLIMITED

DOCUMENT HISTORY LOG

Status	Document Revision	Approval Date	Description
Baseline		03-08-2012	Initial Release This standard was transitioned from MSFC-SPEC-250A, dated 10-01-1977.

FOREWORD

This Standard is published by the National Aeronautics and Space Administration (NASA) to provide uniform engineering and technical requirements for processes, procedures, practices, and methods that have been endorsed as standard for NASA programs and projects, including requirements for selection, application, and design criteria of an item.

This Standard is approved for use by NASA Headquarters and NASA Centers, including Component Facilities and Technical and Service Support Centers.

This Standard establishes requirements for the protective finishes of space vehicles and associated flight hardware.

Requests for information, corrections, or additions to this Standard should be submitted via "Feedback" in the NASA Standards and Technical Assistance Resource Tool at http://standards.nasa.gov.

Original Signed By: ***03-08-2012***

Michael G. Ryschkewitsch
NASA Chief Engineer

Approval Date

TABLE OF CONTENTS

APPENDIX

LIST OF TABLES

TABLE **PAGE**

APPROVED FOR PUBLIC RELEASE—DISTRIBUTION IS UNLIMITED

CORROSION PROTECTION FOR SPACE FLIGHT HARDWARE

1. SCOPE

1.1 Purpose

The purpose of this Standard is to describe the general corrosion protection requirements applicable to the surface treatment and finishing of space flight hardware. This Standard contains the minimum requirements necessary to qualify materials and processes for corrosion control of space flight hardware. Additional testing may be required to meet the requirements for materials and processes used in space flight hardware systems contained in NASA-STD-6016, Standard Materials and Processes Requirements for Spacecraft.

Materials and processes used in interfacing ground support equipment, test equipment, hardware processing equipment, hardware packaging, and hardware shipment are to be controlled to prevent damage to or contamination of flight hardware.

1.2 Applicability

This Standard is applicable to all National Aeronautics and Space Administration (NASA) space flight hardware, including launch vehicles.

This Standard is approved for use by NASA Headquarters and NASA Centers, including Component Facilities and Technical and Service Support Centers, and may be cited in contract, program, and other Agency documents as a technical requirement. This Standard may also apply to the Jet Propulsion Laboratory or to other contractors, grant recipients, or parties to agreements only to the extent specified or referenced in their contracts, grants, or agreements.

Requirements are numbered and indicated by the word "shall." Explanatory or guidance text is indicated in italics beginning in section 4.

a. Programs shall apply these controls to program/project hardware. Programs, projects, and elements are responsible for flowing requirements down to contractors, subcontractors, and the lowest component-level suppliers.

b. Programs shall be responsible for demonstrating compliance with these requirements.

1.3 Tailoring

a. Tailoring of this Standard for application to a specific program or project shall be documented formally as part of program or project requirements and approved by the Technical Authority. Tailoring also includes using existing or previously developed contractor processes and standards as a submittal of the various required plans.

b. The tailoring of requirements shall be documented in the Materials and Processes Selection, Control, and Implementation Plan in accordance with NASA-STD-6016 or as part of a Corrosion Prevention and Control Plan by providing the degree of conformance and the method of implementation for each requirement identified in this Standard.

c. Once a Corrosion Prevention and Control Plan has been approved as an acceptable means of compliance with the technical requirements of this Standard, the Corrosion Prevention and Control Plan shall be used for the implementation and verification of requirements on the applicable program/project.

2. APPLICABLE DOCUMENTS

2.1 General

The documents listed in this section contain provisions that constitute requirements of this Standard as cited in the text.

2.1.1 The latest issuances of cited documents shall apply unless specific versions are designated.

2.1.2 Non-use of specific versions as designated shall be approved by the responsible Technical Authority.

The applicable documents are accessible via the NASA Standards and Technical Assistance Resource Tool at http://standards.nasa.gov or may be obtained directly from the Standards Developing Organizations or other document distributors.

2.2 Government Documents

Military

MIL-A-8625	Anodic Coatings for Aluminum and Aluminum Alloys
MIL-A-22262	Abrasive Blasting Media Ship Hull Blast Cleaning
MIL-DTL-5541	Chemical Conversion Coatings on Aluminum and Aluminum Alloys
MIL-DTL-16232	Phosphate Coating, Heavy, Manganese or Zinc Base
MIL-DTL-45204	Gold Plating, Electrodeposited.
MIL-DTL-83488	Coating, Aluminum, High Purity

MIL-STD-810	Environmental Engineering Considerations and Laboratory Tests (Test Method 508)
MIL-STD-869	Flame Spraying
MIL-STD-1501	Chromium Plating, Low Embrittlement, Electro-Deposition

NASA

NASA-STD-4003	Electrical Bonding for NASA Launch Vehicles, Spacecraft, Payloads, and Flight Equipment
NASA-STD-5008	Protective Coating of Carbon Steel, Stainless Steel, and Aluminum on Launch Structures, Facilities, and Ground Support Equipment
NASA-STD-6016	Standard Materials and Processes Requirements for Spacecraft

2.3 Non-Government Documents

American Welding Society (AWS)

AWS C2.23M	Specification for the Application of Thermal Spray Coatings (Metallizing) of Aluminum, Zinc, and Their Alloys and Composites for the Corrosion Protection of Steel

ASTM International (ASTM – formerly American Society for Testing and Materials**)**

ASTM B 117	Standard Practice for Operating Salt Spray (Fog) Apparatus
ASTM B488	Standard Specification for Electrodeposited Coatings of Gold for Engineering Uses
ASTM B545	Standard Specification for Electrodeposited Coatings of Tin
ASTM B 700	Standard Specification for Electrodeposited Coatings of Silver for Engineering Use
ASTM B733	Standard Specification for Autocatalytic (Electroless) Nickel-Phosphorus Coatings on Metal
ASTM D 1654	Standard Test Method for Evaluation of Painted or Coated Specimens Subjected to Corrosive Environments

ASTM D2247	Standard Practice for Testing Water Resistance of Coatings in 100 % Relative Humidity
ASTM D 3273	Standard Test Method for Resistance to Growth of Mold on the Surface of Interior Coatings in an Environmental Chamber
ASTM D5894	Standard Practice for Cyclic Salt Fog/UV Exposure of Painted Metal, (Alternating Exposures in a Fog/Dry Cabinet and a UV/Condensation Cabinet)
ASTM G 1	Standard Practice for Preparing, Cleaning, and Evaluating Corrosion Test Specimens
ASTM G7	Standard Practice for Atmospheric Environmental Exposure Testing of Nonmetallic Materials
ASTM G50	Standard Practice for Conducting Atmospheric Corrosion Tests on Metals
ASTM G 52	Standard Practice for Exposing and Evaluating Metals and Alloys in Surface Seawater
ASTM G85	Standard Practice for Modified Salt Spray (Fog) Testing

Society of Automotive Engineers (SAE)/Aerospace Material Specification (AMS)

SAE AMS 2403	Plating, Nickel General Purpose
SAE AMS2417	Plating, Zinc-Nickel Alloy
SAE AMS2418	Plating, Copper
SAE AMS 2423	Plating, Nickel Hard Deposit
SAE AMS 2447	Coating, Thermal Spray, High Velocity Oxygen/Fuel Process
SAE AMS 2460	Plating, Chromium
SAE AMS2700	Passivation of Corrosion Resistant Steels
SAE AMS2759/9	Hydrogen Embrittlement Relief (Baking) of Steel Parts

The Society for Protective Coatings (SPPC)

SSPC-AB 1	Mineral and Slag Abrasives
SSPC-SP 10	Near-White Metal Blast Cleaning

2.4 Order of Precedence

This Standard establishes requirements for protective finishes for all space flight hardware, including launch vehicles, but does not supersede nor waive established Agency requirements found in other documentation.

2.4.1 Conflicts between this Standard and other requirements documents shall be resolved by the responsible Technical Authority.

3. ACRONYMS AND DEFINITIONS

3.1 Acronyms, Abbreviations, and Symbols

°C	degree Celsius
°F	degree Fahrenheit
>	greater than
≥	greater than or equal to
<	less than
μA	microampere
ASTM	ASTM International (formerly American Society for Testing and Materials)
AMS	Aerospace Material Specification
AWS	American Welding Society
CDR	critical design review
Cm	centimeter
CRES	corrosion-resistant steel
DRD	data requirements document
DTL	detail specification
EMF	electromotive force
hr	hour
in	inch
IVD	ion vapor deposited
KSC	Kennedy Space Center
ksi	kilo-pound per square inch
MIL	military
mo	month
MPa	megapascal
MUA	materials usage agreement

NASA	National Aeronautics and Space Administration
PDF	portable document format
PDR	preliminary design review
SAE	Society of Automotive Engineers
SOW	statement of work
SSPC	The Society for Protective Coatings
STD	standard
UTS	ultimate tensile strength
UV	ultraviolet
V	volt

3.2 Definitions

Corrosion-Resistant Aluminum Alloys: 1000, 3000, 5000, and 6000 series alloys and all clad alloys.

Corrosion-Resistant Steel (CRES): Steel having 12 percent or more effective chromium content.

Effective Chromium: Total percent chromium minus 11 percent carbon.

Non-Corrosion-Resistant Aluminum Alloys: All other aluminum alloys not considered to be corrosion-resistant alloys.

Non-Corrosion-Resistant Steel: Steel having less than 12 percent effective chromium.

Interior and Exterior Surfaces: Any surface that, during normal service life of the item involved, customarily forms an exterior surface of the equipment in its assembled condition, such that on outdoor exposure of the equipment the surface might be exposed to direct action of the elements (sunlight, rain, sand, dust, etc.). All other surfaces are considered interior surfaces. (Materials or parts inside a hermetically sealed enclosure do not require surface protection; however, if protection is used, it is done in accordance with the applicable requirements of this Standard.) In the case of large assemblies, such as one stage of a multi-stage space vehicle, that spend a major portion of the service life as end items subject to transportation, outdoor exposure, etc., determination of interior and exterior surfaces is based on the configuration of the large assembly and identification of those surfaces with direct exposure (contact) with the surrounding environment.

Metal Dendrites: A characteristic fern-like structure of crystals growing across the metal surface as molten metal freezes. Dendrites usually form in multiphase alloys.

Metal Whiskering: A crystalline metallurgical phenomenon involving the spontaneous growth of tiny filiform hairs that project at a right angle to the metallic surface.

Technical Authority: The Office of the Chief Engineer serves as the lead Technical Authority for engineering. The Chief Engineer or a designate is responsible for providing technical checks and balances by assuring that safety and mission success, relevant technical standards, engineering work, and safety and reliability analysis products are being conducted properly in accordance with established, high-reliability processes independent of nontechnical program/project constraints. The Chief Engineer reports to the NASA Associate Administrator.

4. REQUIREMENTS

Some of the protective coatings described in this Standard are subject to environmental (including Environmental Protection Agency), safety, and health regulations and requirements.

4.1 Corrosion Prevention and Control Plan

a. A Corrosion Prevention and Control Plan shall describe the hardware developer's activities involved in the identification, testing, evaluation, documentation, and reporting of materials and processes required for corrosion protection of space flight hardware and be submitted in accordance with the applicable Data Requirements Document (DRD).

Appendix A in this Standard contains a sample DRD for a Corrosion Prevention and Control Plan.

b. The Corrosion Prevention and Control Plan shall document the method of implementation for each requirement in this Standard.

c. The Corrosion Prevention and Control Plan shall identify all specifications used to comply with this Standard.

d. Proposed deviations from the requirements of this Standard shall be identified and accompanied by sufficient explanation, including appropriate test data, to permit an engineering evaluation by the Technical Authority.

4.1.1 Materials and Processes

a. Approval of the use of materials and processes that differ from the approved Corrosion Prevention and Control Plan shall be obtained through a materials usage agreement (MUA).

The MUA identifies the material or process to be used and provides full justification, including test and analysis where applicable, of how use of the material or process is acceptable for a particular application. NASA-STD-6016 provides a description of the MUA process.

b. Necessary process and quality control requirements shall be established.

c. Technical data developed to substantiate the acceptability of the proposed coatings or processes shall be made available to NASA.

d. Specifications, drawings, and /or relevant procurement details, sufficient to fully define the materials and/or processes, shall be made available to NASA and any flight hardware reuse and restoration activity.

4.1.2 Order of Precedence

In the case of a conflict between the requirements of this Standard and the approved Corrosion Prevention and Control Plan, the latter shall prevail.

4.2 Classification of Corrosive Environments

a. The Corrosion Prevention and Control Plan shall identify from the following list the applicable class(es) of environments to which space flight hardware materials are exposed during hardware life cycle and list specific protective systems for each:

Class 1: Exposure to seawater (immersion) environments.

Class 2: Exposure to seacoast (atmospheric) environments.

Class 3: Exposure to inland (≥50 miles from seacoast), outdoor environments.

Class 4: Exposure to potentially corrosive chemical systems or microbial induced corrosion.

Class 5: Exposure to indoor/uncontrolled humidity environments.

Class 6: Continuous and exclusive exposure to temperature- and humidity-controlled (non-condensing) environments, such as clean room, dry air, and nitrogen-purged environments (maximum humidity 65 percent).

The definition of the class of environment is based on worst-case hardware exposure.

The above examples of classes are not exhaustive. A Corrosion Prevention and Control Plan may contain additional definitions of environmental classes. For example, significant exposure to gypsum sand in desert environments (such as White Sands Space Harbor) might require a class with more aggressive testing than the standard Class 3 environment.

b. Areas of the vehicle subject to corrosive environments, as listed above, shall be identified and protected by finishes that have been demonstrated by test and/or analysis to be suitable for the application.

4.3 Cleaning and Surface Preparation

a. Cleaning and surface preparation requirements shall be included in the Corrosion Prevention and Control Plan.

b. At the time of application of any finish, all surfaces shall be clean and free from dirt, grease, oil, or other contamination that may interfere with the satisfactory performance of the finish of the part.

c. Cleaning methods or solutions used shall not adversely affect the functioning of the part or application of the finish.

For example, abrasive blast cleaning is the preferred method for corrosion removal and cleaning of large structures. However, close tolerance parts, light gauge areas, parts requiring very smooth surfaces, sealing surfaces, or notch-sensitive materials should not be blast cleaned with large abrasive grit. Metal surfaces may be cleaned by blasting with a non-abrasive grit, such as glass bead, or with a less abrasive cleaning method, such as plastic media blast or high-pressure water blast.

SSPC-SP 10, Near-White Metal Blast Cleaning, (abrasive blast to a near-white finish) is an approved method for low alloy and carbon steel using blast media conforming to MIL-A-22262, Abrasive Blasting Media Ship Hull Blast Cleaning, or SSPC-AB 1, Mineral and Slag Abrasives.

The use of steel and aluminum wools is not recommended.

In general, the use of wire brushes is restricted to the same alloy type, e.g., carbon steel brushes on carbon or low-alloy steel structures. CRES brushes may be used on other alloy classes, provided that use of that brush is restricted to a single alloy or is appropriately cleaned, rinsed, and dried before use on a different alloy.

d. All cleaning fluids and other chemicals used during manufacturing and processing of titanium hardware shall be verified to be compatible with the hardware.

Hydrochloric acid, chlorinated solvents, chlorinated cutting fluids, fluorinated hydrocarbons, and anhydrous methyl alcohol can all produce stress corrosion cracking. Mercury, cadmium, silver, and gold have been shown to cause liquid-metal-induced embrittlement and/or solid-metal-induced embrittlement in titanium and its alloys. Liquid-metal-induced embrittlement of titanium alloys by cadmium can occur at temperatures as low as 149 °C (300 °F), and solid-metal-induced embrittlement of titanium alloys by cadmium can occur at temperatures as low as room temperature.

e. Suitable precautions to maintain cleanliness and prevent corrosion shall be maintained during the time between cleaning and finishing or between various finishing steps.

4.4 Performance Requirements

a. All environmentally exposed surfaces shall be qualified in accordance with the test methods listed in table 1, Matrix of Class Environments and Test Methods.

b. All corrosion protection system tests shall be conducted using alloys (with the appropriate heat treatment) specified in the design of hardware.

For alloys in the same family, the most corrosion-susceptible alloy may be tested in lieu of the testing of all alloys in that family.

c. Corrosion protection system tests shall be conducted for the most severe environmental conditions anticipated.

d. If the protective finish is a coating, it shall be graded ≥9 in accordance with ASTM D 1654, Standard Test Method for Evaluation of Painted or Coated Specimens Subjected to Corrosive Environments, and not exhibit blistering, film failure, cracking, or substrate corrosion after exposure.

e. At the conclusion of testing, there shall be no visible signs of corrosion to the unaided eye.

Minimum requirements for coatings do not apply to the stand-alone coating but do apply to the coating system with primer and topcoat.

f. Sensitivity studies shall be performed to establish acceptable processing parameters for protective finishes being qualified and be defined in the process specification.

Table 1—Matrix of Class Environments and Test Methods

Test Method	Applicable Document	Environmental Class					
		1	2	3	4	5	6
		Seawater Immersion	**Seacoast[1]**	**Inland, Outdoor[2]**	**Chemical or Microbial-Induced**	**Indoor, Uncontrolled**	**Indoor, Controlled**
Salt Spray	ASTM B 117		1000 hr for each 45 days of anticipated exposure (minimum). Alternate with UV test.	500 hr. Alternate with UV test.		168 hr for <50 miles from seacoast	
Chemical Resistance					For chemical environments, data to support corrosion protection methods to be provided		
Humidity	ASTM D2247					336 hr for ≥50 miles from seacoast	
Beach Exposure[3]	NASA-STD-5008		2x maximum on-pad stay time	9 mo			
Atmospheric Exposure	ASTM G50 ASTM G7			1.5x actual for location			
Cyclic Corrosion	ASTM G85		60 days for each 3 mo of anticipated exposure (minimum). Alternate with UV test.	60 days exposure. Alternate with UV test.			
UV	ASTM D5894		Alternate 7-day UV exposure with 7-day salt spray or 7-day cyclic, depending on test method choice.	Alternate 7-day UV exposure with 7-day salt spray or 7-day cyclic, depending on test method choice.			
Seawater Immersion	ASTM G 52	2x maximum allowed exposure					

Notes:
1. Class 2: (a) Beach exposure OR (b) UV + Salt Spray OR (c) UV + Cyclic
2. Class 3: (a) Beach exposure OR (b) Atmospheric exposure OR (c) UV + Salt Spray OR (d) UV + Cyclic
3. Consider seasonality effect on beach exposure results.

The following subsections provide additional information on environmental classes listed in table 1.

4.4.1 Class 1: Seawater Immersion

In Class 1 environments, the protective finish shall withstand two times the maximum defined duration of immersion in seawater, when tested in accordance with ASTM G 52, Standard Practice for Exposing and Evaluating Metals and Alloys in Surface Seawater.

4.4.2 Class 2: Seacoast

In Class 2 environments, the protective finish shall be tested by one of the following test methods/combination of test methods:

The methods below are listed in order of preference.

a. Beach Exposure at Kennedy Space Center (KSC) Beach Corrosion Test Site: The protective finish shall be tested in accordance with NASA-STD-5008, Protective Coating of Carbon Steel, Stainless Steel, and Aluminum on Launch Structures, Facilities, and Ground Support Equipment, for two times the maximum duration of on-pad stay.

b. Ultraviolet (UV) and Cyclic Corrosion:

(1) The protective finish shall be tested in 7-day alternating cycles, starting with UV testing, followed by cyclic corrosion testing, in accordance with ASTM D5894, Standard Practice for Cyclic Salt Fog/UV Exposure of Painted Metal, (Alternating Exposures in a Fog/Dry Cabinet and a UV/Condensation Cabinet).

(2) The test shall be performed so that the total duration of cyclic corrosion testing is 60 days for every 3 months of anticipated exposure to a seacoast environment.

(3) The minimum test duration shall be 60 days and the maximum test duration 240 days.

(4) Bare metallic specimens shall be tested according to ASTM G85, Standard Practice for Modified Salt Spray (Fog) Testing, A5, Dilute Electrolyte Cyclic Fog/Dry Test.

c. UV and Salt Spray (Fog):

(1) The protective finish shall be tested in 7-day alternating cycles, starting with UV testing, followed by salt spray (fog) testing, in accordance with ASTM D5894, and ASTM B 117, Standard Practice for Operating Salt Spray (Fog) Apparatus, respectively.

(2) The test shall be performed so that the total duration of salt spray (fog) is 1000 hours for every 45 days of anticipated exposure to a seacoast environment.

(3) The minimum test duration shall be 1000 hours and the maximum test duration 2000 hours.

(4) Bare metallic specimens shall be exempted from UV testing.

4.4.3 Class 3: Inland, Outdoor

In Class 3 environments, the protective finish shall be tested by one of the following test methods/combination of test methods:

a. UV and Salt Spray (Fog):

(1) The protective finish shall be tested in 7-day alternating cycles, starting with UV testing, followed by salt spray (fog) testing, in accordance with ASTM D5894 and ASTM B 117, respectively.

(2) The test shall be performed so that the total duration of salt spray (fog) is 500 hours.

b. UV and Cyclic Corrosion:

(1) The protective finish shall be tested in 7-day alternating cycles starting with UV testing, followed by cyclic corrosion testing, in accordance with ASTM D5894.

(2) The test shall be performed so that the total duration of salt cyclic corrosion is 60 days.

c. Beach Exposure at KSC Beach Corrosion Test Site: The protective finish shall be tested in accordance with NASA-STD-5008 for 9 months.

d. Atmospheric Exposure: The protective finish shall be tested for 1.5 times the actual atmospheric exposure at the location, in accordance with ASTM G50, Standard Practice for Conducting Atmospheric Corrosion Tests on Metals, for uncoated metals or ASTM G7, Standard Practice for Atmospheric Environmental Exposure Testing of Nonmetallic Materials, for coated materials.

4.4.4 Class 4: Chemical or Microbial-Induced Corrosion

In Class 4 environments, testing shall be performed to confirm that the corrosion protection systems are adequate to protect hardware during anticipated chemical exposure or during exposure to microorganisms that induce corrosion.

There are no standard tests for microbial corrosion. Test methods such as the MIL-STD 810, Environmental Engineering Considerations and Laboratory Tests (Test Method 508), and ASTM D 3273, Standard Test Method for Resistance to Growth of Mold on the Surface of Interior Coatings in an Environmental Chamber, evaluate the susceptibility of corrosion protection coatings to fungus attack. For chemical-induced corrosion, small-scale laboratory testing and monitoring can be performed, e.g., coupon exposures, instrumental methods, and visual inspections. Field testing can also be performed. Common test methods include ASTM G 1, Standard Practice for Preparing, Cleaning, and Evaluating Corrosion Test Specimens, and ASTM D 1654 for evaluating test specimens.

4.4.5 Class 5: Indoor, Uncontrolled

In Class 5 environments, the protective finish shall be tested by one of the following test methods:

a. Salt Spray (Fog): When the facility is located within 50 miles of the seacoast, the protective finish shall be tested for 168 hours in accordance with ASTM B 117.

b. Humidity: When the facility is located 50 miles or more from a seacoast, the protective finish shall be tested for 336 hours in accordance with ASTM D2247, Standard Practice for Testing Water Resistance of Coatings in 100 % Relative Humidity.

4.4.6 Class 6: Indoor, Controlled

In Class 6 environments, all exposed surfaces shall be maintained in an continuous and exclusive exposure to temperature- and humidity-controlled (non-condensing) environments, such as clean room, dry air, and nitrogen-purged environments (maximum humidity 65 percent).

4.5 Process Verification

The process specification shall indicate the test methods to be used for process verification and the requirements to be met, including but not limited to, dry film thickness tolerances and coating adhesion.

Depending on final applications, other process verification test considerations may include flexibility, abrasion resistance, and impact resistance.

4.6 Metallic Finishes

4.6.1 Approved Finishes

a. The metallic finishes listed below shall be considered approved processes.

b. Alternative finishes shall be submitted for approval by MUA or tailored Corrosion Prevention and Control Plan.

4.6.1.1 Nickel Plating

a. Electrodeposited nickel plating shall be applied according to the requirements of SAE AMS 2403, Plating, Nickel General Purpose, or SAE AMS 2423, Plating, Nickel Hard Deposit.

b. Electroless nickel plate shall be applied in accordance with ASTM B733, Standard Specification for Autocatalytic (Electroless) Nickel-Phosphorus Coatings on Metal.

c. The nickel-aluminum interface in nickel-plated aluminum shall be protected from exposure to corrosive environments.

Nickel and aluminum form a strong galvanic cell at the nickel-aluminum interface, and exposure of the aluminum alloy to a corrosive environment can produce rapid debonding of the nickel plate.

Nickel plating may be used for applications up to 538 °C (1,000 °F).

Electroless nickel is preferred for irregularly shaped parts when a uniform thickness is required and for applications requiring a hard surface.

Electroless nickel plating with low (<3 percent) phosphorous content provides superior corrosion resistance in alkaline environments.

Electroless nickel plating with high (>9 percent) phosphorous content provides superior corrosion resistance in acidic environments.

d. Nickel plating on steel heat treated to an ultimate tensile strength (UTS) over 1,000 MPa (145 ksi) shall receive a post-plating bake cycle.

ASTM B733 contains guidance on post-plating bake cycles for electroless nickel plating.

e. For steels above 1,240 MPa (180 ksi), post-plating heat treatment shall conform to SAE AMS2759/9, Hydrogen Embrittlement Relief (Baking) of Steel Parts.

4.6.1.2 Chromium Plating

a. Chromium plating shall conform to SAE AMS 2460, Plating, Chromium.

Chromium plating may be used for applications up to 538 °C (1,000 °F) or when an abrasion-resistant surface is required.

b. Chromium plating on steel heat treated to a UTS of 1,100 to1,240 MPa (160 to180 ksi) shall receive a post-plating bake cycle in accordance with SAE AMS2759/9.

c. For steels above 1,240 MPa (180 ksi), chromium plating and post-plating heat treatment shall conform to MIL-STD-1501, Chromium Plating, Low Embrittlement, Electro-Deposition.

4.6.1.3 Zinc-Nickel Plating

Zinc-nickel coatings shall conform to SAE AMS2417, Plating, Zinc-Nickel Alloy.

Zinc-nickel coatings offer several advantages over cadmium plating (improved corrosion resistance, low embrittlement process, and lower environmental hazard) and may be considered as a cadmium alternative.

4.6.1.4 Copper Plating

Copper plating shall conform to the requirements of SAE AMS2418, Plating, Copper.

4.6.1.5 Silver Plating

a. Silver plating shall conform to the requirements of ASTM B 700, Standard Specification for Electrodeposited Coatings of Silver for Engineering Use.

b. Electrically deposited silver shall not be used as a plating on printed wiring boards and terminal boards because of potential dendrite growth.

This requirement does not apply to chemically deposited immersion silver, which does not have the same tendency for dendrite growth.

c. Silver plating shall not be used on bus bars and mechanical electrical contacts such as connector pins and sockets because it can tarnish and degrade electrical conductivity.

d. Because silver plating over copper can cause the formation of cuprous oxide corrosion (red plague) when stored in a high humidity environment, mitigation requirements for such shall be included in the Corrosion Prevention and Control Plan.

Silver plating is susceptible to attack by atomic oxygen in low Earth orbit applications.

Silver plating is also susceptible to forming dendrites when exposed to sulfur-/sulfide-containing environments.

Silver plating maybe used only in special applications requiring good electrical conductivity or high seizure resistance.

4.6.1.6 Tin Plating

a. Tin plating shall conform to the requirements of ASTM B545, Standard Specification for Electrodeposited Coatings of Tin.

b. Tin and tin plating shall not be used in any applications unless the tin is alloyed with at least 3 percent lead to prevent tin whisker growth.

High-purity tin plating can undergo the degrading allotropic transformation known as "tin pest" when exposed to the low temperatures in the space environment. Alloying with at least 3 percent lead is normally sufficient to prevent tin pest.

c. The presence of at least 3 percent lead shall be verified by lot sampling.

4.6.1.7 Gold Plating

a. Gold plating shall conform to the requirements of ASTM B488, Standard Specification for Electrodeposited Coatings of Gold for Engineering Uses.

b. Gold plating shall not be used in contact with indium or an indium alloy, such as indium solder.

Indium reacts with gold to form a succession of gold-indium intermetallic compounds. The brittle gold-indium intermetallics cause an unreliable electrical interconnection. The gold-indium intermetallic formation occurs significantly even at room temperature and at an enhanced level at elevated temperatures.

4.6.1.8 Ion Vapor Deposited (IVD) Aluminum

IVD aluminum may be used as a replacement for cadmium and may be particularly useful for protecting high-strength, non-corrosion-resistant aluminum and steel alloys.

IVD aluminum coated parts shall meet the requirements of MIL-DTL-83488, Coating, Aluminum, High Purity.

4.6.1.9 Sprayed Metal Coatings

Sprayed metal coatings shall conform to the requirements of MIL-STD-869, Flame Spraying, AWS C2.23M, Specification for the Application of Thermal Spray Coatings (Metallizing) of Aluminum, Zinc, and Their Alloys and Composites for the Corrosion Protection of Steel, or SAE AMS 2447, Coating, Thermal Spray, High Velocity Oxygen/Fuel Process.

4.6.2 Prohibited Finishes

The following finishes shall be prohibited unless approved by an MUA.

4.6.2.1 Cadmium Plating

Cadmium plating shall not be used.

Cadmium can cause contamination of electrical surfaces or optical devices. Deposition of cadmium contamination can cause embrittlement of metallic materials, and particulates from damaged or corroded plating can be a toxicity hazard in crewed environments.

4.6.2.2 Zinc Plating

Zinc plating shall not be used.

Zinc has the ability to grow whiskers and contaminate optical surfaces or electrical devices.

4.7 Inorganic Finishes

The following application documents, which describe the application of inorganic finishes, shall be considered approved process specifications.

These process specifications are approved processes, but the finish still needs to meet the requirements of section 4.4 in this Standard.

a. Aluminum and Its Alloys

(1) MIL-A-8625, Anodic Coatings for Aluminum and Aluminum Alloys, (anodizing).

(2) MIL-DTL-5541, Chemical Conversion Coatings on Aluminum and Aluminum Alloys, (chemical conversion coating).

(3) Additionally, hexavalent chromium conversion coated parts shall not be exposed to temperatures exceeding 54 °C (130 °F).

b. Low Alloy and Carbon Steel: MIL-DTL-16232, Phosphate Coating, Heavy, Manganese or Zinc Base, (manganese phosphate or zinc phosphate bases).

c. CRES Alloys: SAE AMS2700, Passivation of Corrosion Resistant Steels.

4.8 Organic Finishes

Organic corrosion protection finishes and coatings shall meet the requirements contained in NASA-STD-6016.

4.9 Design Considerations for Corrosion Control

4.9.1 Cut Edges

a. The edges of all metals in exterior locations shall be rounded or chamfered to permit adhesion of an adequate thickness of protective coatings.

b. After rounding or chamfering of edges and before the application of paint, applicable chemical surface treatments shall be applied.

4.9.2 Drainage

Drain holes shall be provided to prevent collection and/or entrapment of rain, seawater, or other unwanted fluids.

All designs should include considerations for the prevention of water or fluid entrapment and ensure drain holes are located for maximum drainage of accumulated fluids.

4.10 Dissimilar Metals

Dissimilar metals, as defined in table 2, Compatible Couples in Seawater, require special considerations, particularly in severe environments.

a. The potential difference between galvanic couples for alloy combinations not listed in table 2 shall not exceed 0.25 V unless the couple current density is $\leq 1\ \mu A/cm^2$ without the presence of any corrosion pits.

When calculating the couple current density, the ratio of the areas of the electrodes should be the same as the ratio of the areas of the metals exposed to the environment in the design.

b. All contacts between graphite-based composites and metallic materials shall be treated as dissimilar metal couples and sealed.

c. Galvanic corrosion of incompatible assemblies shall be evaluated at the assembly level in accordance with the requirements of section 4.4 in this Standard.

Table 2—Compatible Couples in Seawater

GROUP NUMBER	METALLURGICAL CATEGORY	EMF (V)	ANODIC INDEX (0.01 V)	COMPATIBLE COUPLES (see note)
1	Gold, solid and plated; gold-platinum alloys; wrought platinum	+0.15	0	○
2	Rhodium plated on silver-plated copper	+0.05	10	● ○
3	Silver, solid or plated; high silver alloys	0	15	● ● ○
4	Nickel, solid or plated; monel metal; high nickel-copper alloys	-0.15	30	● ● ○
5	Copper, solid or plated; low brasses or bronzes; silver solder; German silvery high copper-nickel alloys; nickel-chromium alloys; austenitic corrosion-resistant steels	-0.20	35	● ● ● ○
6	Commercial yellow brasses and bronzes	-0.25	40	● ● ● ○
7	High brasses and bronzes; naval brass; Muntz metal	-0.30	45	● ● ● ○
8	18 percent chromium type corrosion-resistant steels	-0.35	50	● ● ● ● ○
9	Chromium plated; tin plated; 12 percent chromium type corrosion-resistant steels	-0.45	60	● ● ● ● ○
10	Tin plate; terneplate; tin-lead solder	-0.50	65	● ● ● ● ○
11	Lead, solid or plated; high lead alloys	-0.55	70	● ● ● ● ○
12	Aluminum; wrought alloys of the 2000 series	-0.60	75	● ● ● ○
13	Iron, wrought, gray, or malleable; plain carbon and low-alloy steels; armco iron	-0.70	85	● ● ● ● ○
14	Aluminum, wrought alloys other than 2000 series aluminum; cast alloys of the silicon type	-0.75	90	● ● ● ● ○
15	Aluminum, cast alloys other than silicon type; cadmium, plated and chromated	-0.80	95	● ● ● ● ○
16	Hot-dip zinc plate; galvanized steel	-1.05	120	● ○
17	Zinc, wrought; zinc-base die-casting alloys; zinc, plated	-1.10	125	●
18	Magnesium and magnesium-base alloys, cast or wrought	-1.60	175	●

Note: ○ indicates the most cathodic member of the series, ● indicates an anodic member. Arrows indicate the anodic direction.

4.11 Faying Surfaces, Joints, and Seams

4.11.1 Faying Surfaces

a. All metal alloy faying surfaces exposed to any Class 1 through Class 5 environment shall be sealed, unless testing/experience has shown the alternative corrosion protection scheme is sufficient.

b. Regardless, the configuration shall meet or exceed the requirements in table 1.

4.11.2 Fasteners

a. Fasteners and associated parts such as rivets, screws, bolts, washers, nuts, and clamps shall be wet installed with sealant or primer materials for permanent installation in Class 1 and 2 environments.

b. Fastener nuts shall be overcoated and sealed.

Protective finishes can be developed and qualified by the requirements in table 1.

Caution should be used as application of sealant or primer to fasteners and associated parts can affect the torque tension behavior and be critical to preload levels.

Caution should be used as application of sealant or primer and wet installation of fasteners such as blind fasteners, swaged collar fasteners (lockbolts), and many proprietary types of threaded fasteners can adversely affect the proper functioning of the installation tools or proper functioning of the fasteners.

Caution should be used when wet installed fasteners are in or near fluid lines, fittings, vessels, or blind holes as excessive internal pressure may result.

Fasteners intended for on-orbit removal may be exempt from the wet install requirement of section 4.11.2.a of this Standard.

c. Temporary installation of fasteners and associated parts shall be installed with corrosion preventive materials.

Through holes and blind holes in structures that are sealed with sealant materials do not require paint before fastener installation.

d. In cases where dissimilar metal contact between fastener and structure cannot be avoided, the fastener shall be the cathodic member of the couple.

e. For Class 1 through Class 5 environments, fasteners used to make electrical bond connections between structures shall be oversealed with a protective coating or sealant or an alternative method of protection be developed and qualified by the requirements in table 1.

4.11.3 Electrical Bonding and Grounding

All corrosion protection systems for electrical bonding connections shall meet the requirements of table 1 in this Standard and NASA-STD-4003, Electrical Bonding for NASA Launch Vehicles, Spacecraft, Payloads, and Flight Equipment.

APPENDIX A

SAMPLE DATA REQUIREMENTS DESCRIPTION

A.1 Purpose

This appendix provides guidance for writing a DRD for a Corrosion Prevention and Control Plan.

A.2 Sample DRD

1. DRD:

2. DRD NO.: XXXX

3. DATA TYPE: 1

4. DATE REVISED

5. PAGE: 1/2

6. TITLE: Corrosion Prevention and Control Plan

7. DESCRIPTION/USE:

The Corrosion Prevention and Control Plan defines implementation measures to control corrosion of flight hardware and fluid systems during manufacturing, assembly, test, transportation, launch site processing, and post-flight refurbishment.

8. DISTRIBUTION: As determined by the Contracting Officer.

9. INITIAL SUBMISSION: PDR

10. SUBMISSION FREQUENCY: Final at CDR.

11. REMARKS:

12. INTERRELATIONSHIP: Parent SOW Paragraph: XXXX

13. DATA PREPARATION INFORMATION:

13.1 SCOPE:

The Corrosion Prevention and Control Plan shall describe the hardware developer's activities involved in the identification, testing, evaluation, documentation, and reporting of materials and processes required for corrosion protection of space flight hardware.

13.2 APPLICABLE DOCUMENTS:

NASA-STD-6012, Corrosion Protection for Space Flight Hardware
NASA-STD-6016, Standard Materials and Processes Requirements for Spacecraft

13.3 CONTENTS:

The necessary interfaces with procuring activity in the operation of this Plan shall be defined. The method for materials and processes control and verification of subcontractors and vendors shall be included in the hardware developer's Plan. As a minimum and as applicable, the Plan shall address the following:

1. Conformance – The Plan shall describe the method of implementation and degree of conformance for all applicable requirements of NASA-STD-6012. If tailoring of the requirements is planned or necessary, alternate approaches to NASA-STD-6012 may be identified, provided that they meet or exceed the stated requirements.

2. Testing – The Plan shall include logic, procedures, and data documentation for any proposed test program to support materials screening and performance verification testing.

3. Materials and Process Controls – The Plan shall identify all materials and process specifications used in finishing metallic hardware in accordance with NASA-STD-6012.

4. Subcontractor and Vendor Control – The Plan shall describe the methods used to control compliance with these requirements by subcontractors and vendors.

13.4 FORMAT: Electronic, MS-Word®-compatible document or Adobe® PDF. For each paragraph in section 4 of NASA-STD-6012, the Plan shall state the requirement from NASA-STD-6012, identify the degree of conformance under the subheading “Degree of Conformance,” and identify the method of implementation under the subheading “Method of Implementation.”

13.5 MAINTENANCE: Contractor-proposed changes to the document shall be submitted to NASA for approval. Complete re-issue of the document is required.