	METRIC/SI (ENGLISH)
NASA TECHNICAL STANDARD Office of the NASA Chief Engineer	NASA-STD-6012A
	Approved: 2022-03-23 Superseding NASA-STD-6012 (Baseline)

CORROSION PROTECTION FOR SPACE FLIGHT HARDWARE

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DOCUMENT HISTORY LOG

Status	Document Revision	Change Number	Approval Date	Description
Baseline			2012-03-08	Initial Release This standard was transitioned from MSFC-SPEC-250A, dated 10-01-1977.
Revision	A		2022-03-23	Changes to improve readability and understanding were made. A new environment class for crew compartments was added. A method for “X” scribing test panels as described in ARL-TN-0855 was also added and it appears in Appendix C. Topics such as joints and hardware reuse were addressed. Unpainted chromate conversion coating temperature and exposure time guidance was provided in Appendix E. It is recommended the document be reviewed in its entirety before implementation.

FOREWORD

This NASA Technical 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 NASA Technical Standard is approved for use by NASA Headquarters and NASA Centers and Facilities, and applicable technical requirements may be cited in contract, program, and other Agency documents. It may also apply to the Jet Propulsion Laboratory (a Federally Funded Research and Development Center [FFRDC]), other contractors, recipients of grants and cooperative agreements, and parties to other agreements only to the extent specified or referenced in applicable contracts, grants, or agreements.

This NASA Technical Standard establishes requirements for the corrosion protection of space vehicles and associated flight hardware.

Requests for information should be submitted via "Feedback" at https://standards.nasa.gov. Requests for changes to this NASA Technical Standard should be submitted via MSFC Form 4657, Change Request for a NASA Engineering Standard.

Original Signed by Adam West for	March 23, 2022
Ralph R. Roe, Jr. NASA Chief Engineer	Approval Date

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CORROSION PROTECTION FOR SPACE FLIGHT HARDWARE

1. SCOPE

1.1 Purpose

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

This NASA Technical Standard allows hardware developers to document their approach to controlling and preventing corrosion in a plan unique to the hardware being built. Hardware developers are encouraged to qualify unique coating systems consisting of new organic finishes, new inorganic finishes, new metal finishes, or a combination thereof. Instead of developing new metal or new inorganic finishes, existing metal finishes are listed in section 4.5 and existing inorganic finishes are listed in section 4.6 of this NASA Technical Standard. These existing finishes may be used singly or in combination with organic finishes as a coating system. A coating system will be approved once performance requirements in section 4.4.1 are met per the environmental exposure of the hardware.

M&P 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

The controls described herein are applicable to all NASA spacecraft programs and are to be applied to program/project hardware. Programs are responsible for demonstrating compliance with these requirements. Programs, projects, and elements are responsible for flowing requirements down to contractors, subcontractors, and the lowest component-level suppliers.

This NASA Technical Standard is approved for use by NASA Headquarters and NASA Centers and Facilities, and applicable technical requirements may be cited in contract, program, and other Agency documents. It may also apply to the Jet Propulsion Laboratory (a Federally Funded Research and Development Center [FFRDC]), other contractors, recipients of grants and cooperative agreements, and parties to other agreements only to the extent specified or referenced in applicable contracts, grants, or agreements.

Verifiable requirement statements are designated by the acronym “CPR” (Corrosion Protection Requirement), numbered, and indicated by the word “shall.” This NASA Technical Standard contains 42 requirements. To facilitate requirements selection and verification by NASA programs and projects, a Requirements Compliance Matrix is provided in Appendix A. Explanatory or guidance text is indicated in italics. The terms “may” or “can” denote discretionary privilege or permission, “should” denotes a good practice and is recommended, but not required, “will” denotes expected outcome, and “are/is” denotes descriptive material.

1.3 Tailoring

Tailoring of this NASA Technical Standard’s requirements for specific programs/projects is acceptable when formally documented in program or project requirements and formally approved by the responsible program/project NASA M&P organization, the responsible project/program, and the delegated Technical Authority in accordance with NPR 7120.5, NASA Space Flight Program and Project Management Requirements, or NPR 7120.8, NASA Research and Technology Program and Project Management Requirements. These requirements may be tailored simply by constructing a matrix of applicable paragraphs and inapplicable paragraphs; Appendix A may be used. A tailored response to the requirements could include using existing or previously developed contractor processes and standards. Otherwise, document the tailoring of requirements in the Corrosion Prevention and Control Plan (CPCP) by providing the degree of conformance and the method of implementation for each requirement identified here.

EXCEPTION: Environment classes are not subject to modification or deletion when this NASA Technical Standard is tailored. Additional classes for unique environments may be added in accordance with section 4.1e.

2. APPLICABLE DOCUMENTS

2.1 General

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

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

2.1.2 Use of a version other than as specifically designated must be approved by the delegated Technical Authority.

Applicable documents may be accessed at https://standards.nasa.gov or obtained directly from the Standards Developing Body or other document distributors. When not available from these sources, information for obtaining the document is provided.

2.2 Government Documents

Military

ARL-TN-0855	Standard Operating Procedure for Accelerated Corrosion Testing at ARL, by Thomas A. Considine
MIL-A-8625	Anodic Coatings for Aluminum and Aluminum Alloys
MIL-DTL-5541	Chemical Conversion Coatings on Aluminum and Aluminum Alloys
MIL-DTL-16232	Phosphate Coating, Heavy, Manganese or Zinc Base
MIL-DTL-83488	Coating, Aluminum, High Purity
MIL-STD-1501	Chromium Plating, Low Embrittlement, Electrodeposition

NASA

NPR 7120.5	NASA Space Flight Program and Project Management Requirements
NPR 7120.8	NASA Research and Technology Program and Project Management Requirements
NASA-STD-4003	Electrical Bonding for NASA Launch Vehicles, Spacecraft, Payloads, and Flight Equipment
NASA-STD-6016	Standard Materials and Processes Requirements for Spacecraft

2.3 Non-Government Documents

American Welding Society (AWS)

AWS C2.23M/C2.23	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 B117	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 B700	Standard Specification for Electrodeposited Coatings of Silver for Engineering Use
ASTM B733	Standard Specification for Autocatalytic (Electroless) Nickel-Phosphorus Coatings on Metal
ASTM B841	Standard Specification for Electrodeposited Coatings of Zinc Nickel Alloy Deposits
ASTM D1654	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 D4587	Standard Practice for Fluorescent UV-Condensation Exposures of Paint and Related Coatings
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 G7	Standard Practice for Atmospheric Environmental Exposure Testing of Nonmetallic Materials
ASTM G50	Standard Practice for Conducting Atmospheric Corrosion Tests on Metals
ASTM G52	Standard Practice for Exposing and Evaluating Metals and Alloys in Surface Seawater
ASTM G85	Standard Practice for Modified Salt Spray (Fog) Testing

SAE International Aerospace Material Specification (AMS)

SAE AMS2403	Plating, Nickel General Purpose
SAE AMS2404	Plating, Electroless Nickel
SAE AMS2417	Plating, Zinc-Nickel Alloy
SAE AMS2418	Plating, Copper

SAE AMS2423	Plating, Nickel Hard Deposit
SAE AMS2447	Coating, Thermal Spray High Velocity Oxygen/Fuel Process
SAE AMS2460	Plating, Chromium
SAE AMS2700	Passivation of Corrosion Resistant Steels
SAE AMS2759/9E	Hydrogen Embrittlement Relief (Baking) of Steel Parts
SAE AMS-QQ-N-290	Nickel Plating (Electrodeposited)

Reference documents are listed in Appendix F.

2.4 Order of Precedence

2.4.1 The requirements and standard practices established in this NASA Technical Standard do not supersede or waive existing requirements and standard practices found in other Agency documentation.

2.4.2 Conflict between this NASA Technical Standard and other requirements documents will be resolved by the delegated Technical Authority.

3. ACRONYMS, ABBREVIATIONS, SYMBOLS, AND DEFINITIONS

3.1 Acronyms, Abbreviations, and Symbols

°C	degree Celsius
°F	degree Fahrenheit
+	plus
-	minus
>	greater than
≥	greater than or equal to
<	less than
≤	less than or equal to
µA	microampere
AMPP	Association for Materials Protection and Performance (formerly NACE International and SSPC)
AMS	Aerospace Material Specification
ARL	U.S. Army Research Laboratory
ARP	Aerospace Recommended Practice
ASTM	ASTM International (formerly American Society for Testing and Materials)

AWS	American Welding Society
CDR	critical design review
cm	centimeter
CPCP	Corrosion Prevention and Control Plan
CPR	Corrosion Protection Requirement
CRES	corrosion-resistant steel
DPD	Data Procurement Document
DRD	Data Requirements Description
DTL	detail specification
EMF	electromotive force
FFRDC	Federally Funded Research and Development Center
FOD	foreign object debris
GSFC	Goddard Space Flight Center
IVD	ion vapor deposited
KSC	Kennedy Space Center
ksi	kilo-pound per square inch
M&P	materials and processes
max	maximum
MIL	military
min	minimum
mm	millimeter
MPa	megapascal
MRB	Material Review Board
MSFC	Marshall Space Flight Center
MUA	material usage agreement
NACE	NACE International (formerly National Association of Corrosion Engineers)
NASA	National Aeronautics and Space Administration
PDF	portable document format
PDR	preliminary design review
PICA	phenolic-impregnated carbon ablative
SI	Système Internationale or metric system of measurement
SOW	Statement of Work
SSPC	The Society for Protective Coatings
STD	Standard
TN	Technical Note
URL	Uniform Resource Locator
UTS	ultimate tensile strength
UV	ultraviolet
V	Volt

3.2 Definitions

Bevel: A slope between two principle faces.

Reference "Bevel vs. Chamfer: What's the Difference?," Plethora, posted 8 July 2021, https://www.plethora.com/insights/bevel-vs-chamfer-whats-the-difference-pt (accessed September 20, 2021)

Chamfer: A forty-five degree angle cut between two right-angled surfaces.

Reference "Bevel vs. Chamfer: What's the Difference?," Plethora, posted 8 July 2021, https://www.plethora.com/insights/bevel-vs-chamfer-whats-the-difference-pt (accessed September 20, 2021)

Coating System: A finish, sealant, or combination of materials applied on a surface exposed to the environment to protect the surface against corrosion or prevent corrosion.

Corrosion: A naturally occurring phenomenon commonly defined as the deterioration of a material (usually a metal) that results from a chemical or electrochemical reaction with its environment.

Reference Corrosion Basics, An Introduction, L.S. Van Delinder, ed. (Houston, TX: NACE, 1984)

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

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

Corrosive Environment: Solid, liquid, or gaseous environment that deteriorates the materials by reaction with the environment. Clean rooms and vacuum are normally considered noncorrosive environments.

Effective Chromium Content: Effective chromium content equals total percent chromium minus the quantity of eleven times percent carbon. [$Cr_{eff} = Cr - (11 \times C)$]

Exterior and Interior Surfaces: An exterior surface is any surface exposed to direct action of the elements (sunlight, rain, sand, dust, etc.). All other surfaces are considered interior surfaces.

Faying Surface: A surface that contacts another surface at a joint.

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

Mission-Critical Hardware: Hardware, the failure of which may result in the inability to retain operational capability for mission continuation if a corrective action is not successfully performed.

Non-Corrosion-Resistant Aluminum Alloys: All aluminum alloys not identified in the Corrosion-Resistant Aluminum Alloys definition are non-corrosion-resistant aluminum alloys.

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

Passivation: Make a metal surface unreactive by altering the surface layer or coating the surface. On CRES parts, passivation is a final treatment/cleaning process used to remove free iron and other anodic contaminants, so a uniform passive layer is obtained. Passivation induces a more noble (cathodic) potential on the CRES part thus enhancing corrosion resistance.

Reference a paraphrase from MIL-STD-753C, Military Standard, Corrosion-Resistant Steel Parts, Sampling, Inspection and Testing for Surface Passivation, Cancelled, para. 3.1, p. 3.

Protective System: The combination of materials and design features that provide corrosion protection for a part or assembly.

Technical Authority: The Technical Authority mentioned in this NASA Technical Standard conforms to NPR 7120.5.

Whisker (Metal): A spontaneous growth that may form on surfaces of metals, primarily tin, zinc, and cadmium. Metal whiskers may also detach from the surfaces on which they form, producing conductive foreign object debris (FOD).

4. REQUIREMENTS

4.1 Corrosion Prevention and Control Plan (CPCP)

[CPR 1] A CPCP **shall** be required and include the following:

a. A description of the hardware developer's activities in identifying, testing, evaluating, documenting, and reporting of M&P required for corrosion protection of space flight hardware to be submitted in accordance with the Data Requirements Description (DRD) included in the contract.

Appendix B in this NASA Technical Standard contains a sample DRD for a CPCP.

b. Documentation of the implementation method for each requirement in this NASA Technical Standard.

c. Identification of all specifications used to comply with this NASA Technical Standard.

d. Identification of proposed deviations from the requirements of this NASA Technical Standard accompanied by an explanation, including appropriate test data, to permit an engineering evaluation by the delegated Technical Authority.

e. Identification of applicable classes of environments from the following list to which space flight hardware materials are exposed, both internally and externally, during the hardware's life cycle (see tailoring exception in section 1.3):

(1) Class 1: Exposure to seawater (immersion) environments.
(2) Class 2: Exposure to seacoast (atmospheric) environments.
(3) Class 3: Exposure to inland (≥50 miles from seacoast), outdoor environments.
(4) Class 4: Exposure to potentially corrosive chemical systems or microbial-induced corrosion.
(5) Class 5: Exposure to indoor/uncontrolled humidity environments.
(6) 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).
(7) Class 7: Crew Compartments

The definition of the class of environment is established separately for internal and external surfaces of the item under evaluation, and each is based on the worst-case hardware exposure condition for the associated set of surfaces.

Crewed crew cabin (Class 7) environments can vary widely from vehicle to vehicle. The specific environment is to be captured in the hardware CPCP, and include post-processing, shipment, and storage between missions.

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

f. Identification and protection of areas subject to the corrosive environments listed in section 4.1e by finishes that have been demonstrated by test and/or analysis to be suitable for application.

g. Identification of cleaning and surface preparation requirements (refer to section 4.3 in this NASA Technical Standard).

h. Document the test methods and acceptance criteria used to verify each corrosion control measure.

i. Document the process specifications, process controls, and test methods for protective coatings and surface treatments.

j. Document the implementation of the design requirements in sections 4.9-4.11.

k. 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 in the process specification.

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

l. When there is no Program or Project M&P control panel, establish a corrosion prevention and control panel to include each contractor hardware provider (excluding subcontractors).

m. Describe the panel’s scope and membership in the CPCP.

The corrosion prevention and control panel plans, manages, and coordinates the selection, application, procurement, control, and standardization of corrosion prevention and control for the contract. Typically, an M&P control panel is established by NASA-STD-6016; the M&P control panel would determine if a separate corrosion prevention and control panel is required. Single use vehicles and payloads may choose to not establish a corrosion prevention and control panel.

The panel also resolves and dispositions corrosion prevention and control problems.

The responsible NASA M&P organization is an active member of the panel and has the right of disapproval of panel decisions.

4.2 Material Usage Agreements (MUAs)

a. [CPR 2] Approval to use M&P differing from the approved CPCP **shall** be obtained through an MUA in accordance with NASA-STD-6016.

The MUA identifies materials and processes to be used and provides full justification, including test and analysis where applicable, of how the material or process is acceptable for a specific application.

Deviations from the CPCP occurring because of manufacturing deviations from engineering drawings are addressed with the Material Review Board (MRB), not MUAs.

b. [CPR 3] Process and quality control requirements **shall** be established.

c. [CPR 4] Technical data developed to substantiate the acceptability of the proposed coatings or processes **shall** be made available to NASA.

d. [CPR 5] Specifications, drawings, and/or relevant procurement details that fully define the materials and/or processes and any flight hardware reuse and restoration activity **shall** be made available to NASA.

4.3 Cleaning and Surface Preparation

a. [CPR 6] At the time of any finish application, all surfaces **shall** be clean and free from dirt, grease, oil, or other contamination that may interfere with the satisfactory performance of the finish.

Cleanliness verification should be in accordance with individual surface preparation, plating, coating specifications, or in accordance with a Contamination Control Plan.

b. [CPR 7] 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.

In April 2020, The Society for Protective Coatings (SSPC) and NACE International members both voted to combine and form a new association, Association for Materials Protection and Performance (AMPP). SSPC document numbers may change in the future.

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. Corrosion-resistant steel (CRES) brushes may be used on other alloy classes, provided use of the CRES brush is restricted to a single alloy or the CRES brush is appropriately cleaned, rinsed, and dried before use on a different alloy.

c. [CPR 8] 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, tap water, and anhydrous methyl alcohol can all produce stress corrosion cracking of titanium.

d. [CPR 9] Precautions to maintain cleanliness and prevent corrosion **shall** be maintained during the time between cleaning and finishing and between various finishing steps.

Exposure to contaminants such as dust, oil from finger marks, condensable moisture, insects, animal droppings, etc., can be detrimental to plating or application of organic coatings.

4.4 Performance Requirements

Flight experience, including teardown inspections, is usually the best measure of effectiveness of a corrosion protection approach. However, that approach is not usually feasible in the NASA environment where an extensive flight test program and teardown inspections are not the norm. Testing hardware configurations, panels, or coupons in a real-time environment is generally preferred (as compared to accelerated testing); however, providing a realistic test environment may be difficult due to time limitations or the difficulty of recreating the environment.

Accelerated testing is best used to evaluate comparative performance between coating systems with limitations as is described in the applicable ASTM test methods. Accelerated testing may not precisely correlate with atmospheric testing and the intended use environment. Accelerated testing may indicate false positives and false negatives in relation to the intended use environment. These tests are included to provide options to the hardware developer to meet environment class requirements.

Joints are generally not directly addressed by existing testing standards. Conventional corrosion testing of joints may not represent performance of a sealant in real world application. Exposure of the joint to stress, cyclic loading, and thermal design limits with corrosion testing should be included in evaluating the joint and sealant performance.

Qualification of corrosion protection systems for reuse require additional and unique testing above the requirements for a given class of exposure. Data from actual hardware use may dictate a change in design and required testing.

Sealants, and their associated sealing configurations, used on heritage hardware with similar environments, may be acceptable with little or no qualification testing when proposed and accepted in the CPCP, provided documentation of the prior successful performance is provided or referenced in the plan.

4.4.1 Environment Class Requirements

[CPR 10] All coating systems on exterior surfaces and interior surfaces subject to environmental exposure **shall** be qualified in accordance with the following test methods, as applicable for the specific environment class exposure:

a. **Class 1: Seawater Immersion**

In Class 1 environments, ensure the coating system withstands two times the maximum defined duration of immersion in seawater when tested in accordance with ASTM G52, Standard Practice for Exposing and Evaluating Metals and Alloys in Surface Seawater.

b. **Class 2: Seacoast**

In Class 2 environments, test each coating system by one of the following test methods/combination of test methods listed in order of preference*:*

(1) A Beach Exposure at Kennedy Space Center (KSC) Beachside Atmospheric Corrosion Test Site for one times the maximum anticipated environmental exposure: Test the coating system in accordance with a test plan approved by the delegated Technical Authority.

or

(1) B Pad Exposure at Kennedy Space Center (KSC) Atmospheric Corrosion Test Site for two times the maximum anticipated environmental exposure: Test the coating system in accordance with a test plan approved by the delegated Technical Authority.

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 contain guidance for testing at the KSC Beachside Atmospheric Corrosion Test Site.

(2) Cyclic Corrosion:

A. Perform 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).

B. Perform the test so the total duration of cyclic corrosion testing is 60 days for every 3 months of anticipated exposure to a seacoast environment.

C. Test for a minimum duration of 60 days and a maximum duration of 240 days.

Two hundred forty (240) days represents the maximum accelerated test time necessary for exposures of one year or more. Test time beyond this maximum duration risks increased loss of correlation with actual usage.

D. Test bare metal specimens according to ASTM G85, Standard Practice for Modified Salt Spray (Fog) Testing, A5, Dilute Electrolyte Cyclic Fog/Dry Test.

(3) Ultraviolet (UV) and Salt Spray (Fog):

A. Test the coating system in 7-day alternating cycles, starting with UV testing in accordance with ASTM D4587, Standard Practice for Fluorescent UV-Condensation Exposures of Paint and Related Coatings, followed by salt spray (fog) testing, in accordance with ASTM B117, Standard Practice for Operating Salt Spray (Fog) Apparatus.

B. Perform the test so that the duration is 2,000 hours for every 45 days of anticipated exposure to a seacoast environment; this duration includes both salt spray (fog) and UV as noted above.

C. Test for a minimum duration of 2,000 hours and a maximum duration of 4,000 hours.

Four thousand (4,000) hours represents the maximum accelerated test time necessary for exposures of 90 days or more. Test time beyond this maximum duration risks increased loss of correlation with actual usage.

D. Exempt bare metal specimens from UV testing.

This cuts the test duration in half. Note the test remains cyclic.

c. **Class 3: Inland, Outdoor**

In Class 3 environments, test the coating system by one of the following test methods/combination of test methods:

(1) UV and Salt Spray (Fog):

A. Test the coating system in 7-day alternating cycles, starting with UV testing, followed by salt spray (fog) testing, in accordance with ASTM D5894 and ASTM B117, respectively.

B. Perform the test so the total duration of salt spray (fog) with UV is 1,000 hours.

(2) UV and Cyclic Corrosion:

A. Test the coating system in 7-day alternating cycles starting with UV testing, followed by cyclic corrosion testing, in accordance with ASTM D5894.

B. Perform the test so the total duration of UV with salt cyclic corrosion is 120 days.

(3) Beach Exposure at the KSC Beachside Atmospheric Corrosion Test Site for 9 months: Test the coating system in accordance with a test plan approved by the delegated Technical Authority.

Guidance for testing uncoated materials at the KSC Beachside is contained in ASTM G50, Standard Practice for Conducting Atmospheric Corrosion Tests on Metals. Guidance for testing coated metals at the KSC Beachside is contained in ASTM G7, Standard Practice for Atmospheric Environmental Exposure Testing of Nonmetallic Materials.

(4) Atmospheric Exposure: Test the coating system 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.

d. **Class 4: Chemical or Microbial-Induced Corrosion**

In Class 4 environments, perform testing to confirm the coating system is adequate to protect hardware during anticipated chemical exposure or during exposure to microorganisms that induce corrosion.

NASA has not adopted a standard test for microbial corrosion. Test methods such as MIL-STD-810, Environmental Engineering Considerations and Laboratory Tests (Test Method 508), and ASTM D3273, 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.

NASA has not adopted a standard test 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 G1, Standard Practice for Preparing, Cleaning, and Evaluating Corrosion Test Specimens, and ASTM D1654, Standard Test Method for Evaluation of Painted or Coated Specimens Subjected to Corrosive Environments, for evaluating test specimens.

e. **Class 5: Indoor, Uncontrolled Humidity**

In Class 5 environments, test the coating system by one of the following test methods:

(1) Salt Spray (Fog): When the facility is located within 50 miles of the seacoast, test the protective finish for 168 hours in accordance with ASTM B117.

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

f. **Class 6: Indoor, Controlled Humidity**

In Class 6 environments, maintain all exposed surfaces in a 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).

In Class 6 environments, no testing is required.

g. **Class 7: Crew Compartments**

Hardware in Class 7 environments may be single flight, or reuse after saltwater landing when disassembly for inspection for corrosion may not be practical. Environments may be baselined as non-condensing, but circumstances may result in condensation after temporary or extended loss of thermal control. The exposure to seawater or condensation may be short, but the *hardware lifetime may be extended indefinitely. Hardware is often removed and reinstalled during missions, and hardware may be transferred to another vehicle permanently.*

Environments should be clearly described in the CPCP with a requirement to perform tests or inspections for corrosion when the qualified environments are exceeded.

(1) For acreage surfaces in Class 7 environments, test the coating system with a salt spray (fog) for 168 hours in accordance with ASTM B117.

(2) For joints with faying surfaces, in Class 7 environments, use test configurations as follows:

A. Vibrate/fatigue/strain the joint configuration to a simulated mission environment.
B. Thermally cycle the joint configuration to envelope the maximum mission range.
C. Cycle joint configurations between immersion and humidity.

The humidity portion of the test is 80-percent relative humidity minimum in an enclosed environment.

The immersion/humidity testing should represent the exposure from mission start until refurbishment. ASTM G44, Standard Practice for Exposure of Metals and Alloys by Alternate Immersion in Neutral 3.5% Sodium Chloride Solution, can be used as a guide to develop the immersion test.

D. Specify the joint test configuration in the CPCP.

A representative joint configuration may simply be two mating surfaces sealed with candidate materials.

4.4.2 [CPR 11] Sealing methods **shall** be qualified by test to demonstrate the sealing system protects from environmental intrusion as well as prevents corrosion.

Except for Class 6 environments, most faying joints need to be sealed to prevent intrusion and entrapment of fluids, either during assembly, checkout and test, transportation to the launch site, and mission, and recovery unless the specific material combination in configuration can be demonstrated to be not susceptible to corrosion. Faying surface seals are generally more robust compared to fillet seals and have superior environmental intrusion resistance. This superior environmental intrusion resistance is because sealant is only applied to the edges of mating surfaces in a fillet seal compared to sealant being applied to the contact surfaces in a faying surface seal.

4.4.3 [CPR 12] Per ARL-TN-0855, Standard Operating Procedure for Accelerated Corrosion Testing at ARL, all corrosion protection system tests using panels **shall** use “X” scribed panels by scribing two (2) intersecting lines from one corner to the opposite corner across the face of the specimen to initiate and terminate no closer than 1/2 inch from the edge of the sample with the scribe width not exceeding 0.5 mm and exposing the bare substrate.

Guidance for applying the X-scribe can be found in ARL-TN-0855, which is summarized in Appendix C.

4.4.4 [CPR 13] 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.

4.4.5 [CPR 14] Corrosion protection system tests **shall** be conducted for the most severe environmental conditions anticipated.

4.4.6 [CPR 15] If the protective finish is a coating, the test acceptance criteria for all test methods **shall** be a test panel graded ≥9 in accordance with ASTM D1654 and not exhibit blistering, film failure, cracking, or substrate corrosion beneath the coating after exposure.

4.4.7 [CPR 16] At the conclusion of testing for bare metal panels, the test acceptance criteria for all test methods is no visible signs of corrosion to the unaided eye **shall** exist.

4.4.8 [CPR 17] Sensitivity studies **shall** be performed to establish acceptable processing parameters for qualifying protective finishes.

4.4.9 [CPR 18] If testing involves exposed components or devices other than scribed panels or similar test articles without mechanical, electrical, or sealing capability, the component **shall** undergo functional checks consistent with the expected operation of the hardware in service following exposure.

A summary matrix of class environments and test methods is in Appendix D.

4.5 Metal Finishes

Metal finishes may be used singly or in combination with other finishes, including organic finishes, to meet section 4.4.1 environment class exposure requirements.

4.5.1 Standard Metal Finishes

[CPR 19] Standard metal finishes are listed below and **shall** be as follows:

a. **Nickel Plating**

(1) Conform electroless nickel plate to SAE AMS2404, Plating Electroless Nickel, or ASTM B733, Standard Specification for Autocatalytic (Electroless) Nickel-Phosphorus Coatings on Metal.

(2) Conform electrodeposited nickel plating to SAE AMS-QQ-N-290, Nickel Plating (Electrodeposited), SAE AMS2403, Plating, Nickel General Purpose, or SAE AMS2423, Plating, Nickel Hard Deposit.

(3) Protect the nickel-aluminum interface in nickel-plated aluminum 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 de-bonding of the nickel plate. It is difficult to anodize (or chemical conversion coat) up to nickel plating. This generally results in unprotected aluminum at the interface. The best practice is to apply an organic primer to the interface.

Nickel plating may be used for applications up to 538°C (1,000°F), though wear and/or corrosion resistance may degrade as service temperature increases.

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.

(4) Ensure nickel plating on steel heat treated to an ultimate tensile strength (UTS) over 1,000 MPa (145 ksi) receives a post-plating bake cycle per ASTM B733, class 3.

(5) For nickel plating on steels above 1,240 MPa (180 ksi) UTS, apply post-plating heat treatment in accordance with SAE AMS2759/9E, Hydrogen Embrittlement Relief (Baking) of Steel Parts.

b. **Chromium Plating**

(1) Conform chromium plating to SAE AMS2460, Plating, Chromium.

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

(2) Ensure chromium plating on steel heat treated to a UTS of 1,100 to 1,240 MPa (160 to 180 ksi) receives a post-plating bake cycle in accordance with SAE AMS2759/9E.

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

c. **Zinc-Nickel Plating**

Conform zinc-nickel coatings to SAE AMS2417, Plating, Zinc-Nickel Alloy, or to ASTM B841, Standard Specification for Electrodeposited Coatings of Zinc Nickel Alloy Deposits, type D (black), applied over a suitable under-plate to withstand 500 hours of dynamic salt spray testing.

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.

d. **Copper Plating**

Conform copper plating to SAE AMS2418, Plating, Copper.

e. **Silver Plating**

(1) Conform silver plating to ASTM B700, Standard Specification for Electrodeposited Coatings of Silver for Engineering Use.

(2) Do not use electrically deposited silver 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.

(3) Do not use silver plating on bus bars and mechanical/electrical contacts such as connector pins and sockets because it can tarnish and degrade electrical conductivity.

(4) Include mitigation requirements for red plague corrosion in the CPCP.

Silver plating over copper can cause the formation of cuprous oxide corrosion when stored in a high humidity environment. Cuprous oxide corrosion is often referred to as red plague corrosion in technical literature.

Silver plating is susceptible to attack by atomic oxygen in low Earth orbit applications. Exposure time should be limited.

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

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

f. **Tin Plating**

(1) Conform tin plating to ASTM B545, Standard Specification for Electrodeposited Coatings of Tin.

(2) Do not use tin and tin plating in any applications providing mission-critical functions or in any applications where whiskers could migrate to mission-critical functions unless the tin is alloyed with at least 3 percent lead or other proven alloying elements to prevent tin whisker growth.

NASA Goddard Space Flight Center (GSFC) maintains a Tin Whisker (and Other Metal Whisker) Homepage on the World Wide Web. Per the Basic Info/FAQ tab: "NASA GSFC experiments have shown that use of Arathane 5750 (formerly Uralane 5750) conformal [coating] when applied uniformly to a nominal 2 to 3 mils thickness can provide significant benefit by containing whisker growth outward through the coating. This coating is also resistant to being penetrated by whiskers attempting to puncture the coating from the outside." Homepage accessed on 20 September 2021, at the following Uniform Resource Locator (URL) reference: https://nepp.nasa.gov/whisker/

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 or other proven alloying elements is normally enough to prevent tin pest.

g. **Gold Plating**

Conform gold plating to the requirements of ASTM B488, Standard Specification for Electrodeposited Coatings of Gold for Engineering Uses.

Gold plating may be required for functional purposes such as electrical leads or the interior of an X-ray telescope.

h. **Ion Vapor Deposited (IVD) Aluminum**

Conform IVD aluminum to MIL-DTL-83488, Coating, Aluminum, High Purity.

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.

i. **Sprayed Metal Coatings**

Conform sprayed metal coatings to AWS C2.23M/C2.23, 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 AMS2447, Coating, Thermal Spray High Velocity Oxygen/Fuel Process.

4.5.2 Plating

[CPR 20] Edges of plated parts **shall** be rounded to reduce incomplete plating and protect against impact flaking that will breech the plating and cause corrosion.

This is particularly important for dissimilar metal plating like nickel-plated aluminum because a breech in the plating will cause rapid corrosion. Creating a beveled edge or a chamfered edge are both discouraged because ~~it~~ either results in two sharp edges in place of one.

4.5.3 Alternative Finishes

[CPR 21] Alternative finish specifications **shall** be identified in the CPCP.

Alternative finish specifications should have similar or better process control requirements than the standard metal finish specification they replace.

4.5.4 Prohibited Finishes

[CPR 22] The following finishes **shall** be prohibited unless approved by a MUA:

a. Cadmium Plating

Do not use cadmium plating in crew environments, vacuum environments, or for mission-critical functions.

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

b. Zinc Plating

Do not use zinc plating for mission-critical functions or in an application where whiskers could migrate to affect mission-critical functions.

Whiskers can grow on zinc plating and contaminate optical surfaces or electrical devices.

4.6 Inorganic Finishes

Inorganic finishes may be used singly or in combination with other finishes, including organic finishes, to meet section 4.4.1 environment class exposure requirements. MIL-DTL-5541, Chemical Conversion Coatings on Aluminum and Aluminum Alloys, would generally fail to meet Class 1 and Class 2 environment requirements when applied to an aluminum alloy alone.

4.6.1 [CPR 23] Inorganic finishes are listed below and **shall** be as follows:

a. Aluminum and Its Alloys

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

Anodic coatings may cause a reduction in fatigue life; understand the design and application prior to using anodic coatings.

(2) MIL-DTL-5541 (chemical conversion coating), when used as a primer base or as a temporary coating during fabrication.

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.

4.6.2 Hexavalent Chromate Conversion Coating Temperature Limitation

[CPR 24] Unpainted hexavalent chromate conversion coated parts **shall** not be exposed to temperatures exceeding 60°C (140°F).

Appendix E presents guidance concerning temperature and exposure time affecting unpainted chromate conversion coatings.

4.6.3 Mandatory Passivation for Corrosion-Resistant Steel (CRES) Alloys

[CPR 25] Uncoated CRES alloys **shall** be passivated in accordance with SAE AMS2700 after machining.

4.7 Organic Finishes, Coatings, and Sealants

Organic finishes, coatings, and sealants may be used singly or as a coating system in combination with other organic finishes, inorganic finishes, and metal finishes, to meet section 4.4.1 environment class exposure requirements.

[CPR 26] Organic finishes, coatings, and sealants **shall** meet section 4.4.1 performance requirements for the environment class exposure to which the hardware is subjected.

4.8 Design Requirements for Corrosion Control

Design features can prevent corrosion; examples of such features include rounded edges and adding drain holes. This section defines these minimal design requirements to control or prevent corrosion.

4.8.1 Cut Edges

a. [CPR 27] The edges of all metals in exterior locations **shall** be rounded to permit adhesion of an adequate thickness of protective coatings.

Rounding edges implies no radius requirement. Simple wording can be placed on drawings to accomplish this requirement. An example of this wording is as follows: "Remove all burrs and sharp edges."

b. [CPR 28] Applicable chemical surface treatments **shall** be applied after rounding of edges and before the application of paint.

4.8.2 Drainage

[CPR 29] 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.

4.9 Faying Surfaces, Joints, and Seams

NASA does not have a standard test for sealing joints. Candidate test methods will challenge the performance of the seal from environmental effects, such as loading, vibration, and temperature excursions. The test method may be tailored to specific mission environments; it *may make sense to envelope the environments with a test that qualifies the method to cover hardware elsewhere in the design.*

Reuse scenarios are particularly difficult to duplicate because of the long periods of mild environments between flights, but where salt water may be entrapped in joints. Reuse without complete teardown presents a special challenge because saltwater intrusion from a water landing cannot be removed with rinsing or wiping and can cause corrosion that continues during storage or future missions.

4.9.1 Faying Surfaces

[CPR 30] All faying surface couples exposed to any Class 1 through Class 5 and Class 7 environments **shall** be sealed.

Exceptions, such as stainless/stainless joints in milder environments may be permitted through the CPCP.

Sealing of aluminum to aluminum joints, such as Alodine®/Alodine® or anodize/anodize are susceptible to crevice corrosion, and sealing is always recommended for all classes except Class 6. Use of aluminum more resistant to crevice corrosion in design may allow the use of unsealed aluminum to aluminum joints in milder, chloride free environments.

Any alternative corrosion protection system based on testing/experience may be submitted in the CPCP for approval.

4.9.2 Fasteners

a. [CPR 31] Fasteners and associated parts such as rivets, screws, bolts, washers, nuts, and clamps **shall** be wet installed with sealant or primer materials except for fasteners and add-ons used for electrical bonding which are protected per section 4.10.3 below.

Wet installation is the application of a primer or sealant on the faying surfaces of fasteners. The fastener is then installed before the sealant or primer is cured.

Protective finishes can be developed and qualified by the requirements in section 4.4, as applicable.

Caution should be used, as wet 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 and 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 blind holes because excessive internal pressure may result from filling the void space with the sealant or primer. Through holes and blind holes in structures sealed with sealant materials do not require paint before fastener installation.

Fasteners intended for on-orbit removal may be exempted in the CPCP from the wet install requirement of section 4.10.2.a of this NASA Technical Standard.

b. [CPR 32] If corrosive environmental conditions are expected, temporary installation of fasteners and associated parts **shall** be installed with corrosion preventive material.

Grease can be used as a corrosion preventive material, but other preventive materials exist. Grease may be difficult to clean off surfaces, which may impact wet installation with a primer or sealant after the temporary installation.

c. [CPR 33] In Class 1 environments, fastener heads and nuts **shall** be sealed by applying a topical overcoat of a sealant or primer.

d. [CPR 34] In cases where dissimilar metal contact between fastener and structure cannot be avoided, the fastener **shall** be the cathodic member of the couple.

e. [CPR 35] CRES fasteners **shall** be passivated in accordance with SAE AMS2700.

4.9.3 Electrical Bonding and Grounding

a. [CPR 36] All corrosion protection systems for electrical bonding connections **shall** meet the requirements of section 4.4, as applicable in this NASA Technical Standard and NASA-STD-4003, Electrical Bonding for NASA Launch Vehicles, Spacecraft, Payloads, and Flight Equipment.

b. [CPR 37] The protection method or finish selected **shall** not negate the electrical bond between the two mating surfaces nor the ability to protect the hardware from corrosion.

To achieve compliant electrical bonds, select corrosion protective materials that are electrically conductive and apply them to the surface-to-surface contact. Occasionally, strict metal-to-metal contact is required to achieve a satisfactory bond. When strict metal-to-metal contact is required, all coatings should be removed from the contact area. For example, mask the contact area on aluminum alloys during anodization. Then apply a topical overcoat using a sealant or primer to the edge of the metal-to-metal interface. An alternate strategy is to plate both metals (for example with electroless nickel), which achieves surface-to-surface contact with zero galvanic difference.

Additional guidance on electrical bonding and corrosion control can be found in SAE Aerospace Recommended Practice (ARP) 1481A, Corrosion Control and Electrical Conductivity in

Enclosure Design, and SAE ARP1870A, Aerospace Systems Electrical Bonding and Grounding for Electromagnetic Compatibility and Safety.

c. [CPR 38] For Class 1 through Class 5 and Class 7 environments, fasteners used to make electrical bond connections between structures and add-ons meant to provide electrical bonding **shall** be over-sealed with a protective coating or sealant after fastener installation or an alternative method of protection be developed and qualified by the requirements in section 4.4.

4.9.4 Dissimilar Metals

If sealing faying surfaces is not feasible, justification should be included in the CPCP. Consideration of environment, specific materials, and galvanic difference should be included in the justification.

a. [CPR 39] The potential difference between galvanic couples **shall** not exceed 0.25 V unless the couple current density ≤ 1 µA/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.

Guidance for measuring the potential difference between galvanic couples can be found in ASTM G71, Standard Guide for Conducting and Evaluating Galvanic Corrosion Tests in Electrolytes.

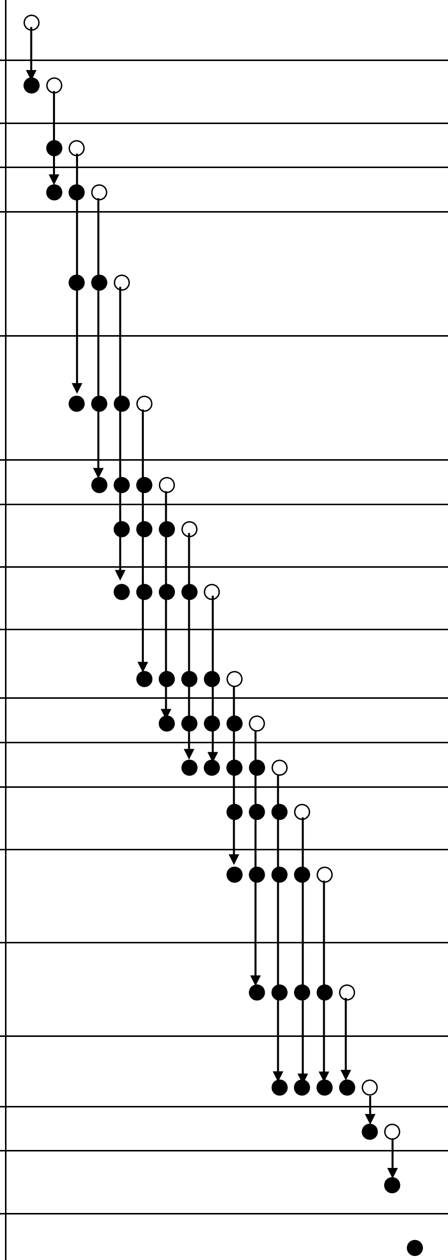
b. [CPR 40] All contacts between graphite-based composites and metal materials **shall** be treated as dissimilar metal couples and sealed.

Titanium fasteners may be used in contact with graphite composites provided the titanium fasteners are wet installed with a sealant or primer.

c. [CPR 41] Galvanic corrosion of incompatible assemblies **shall** be evaluated at the assembly level in accordance with the requirements of section 4.4 in this NASA Technical Standard.

Table 1, Compatible Couples in Seawater, is provided as guidance for coupling dissimilar metals.

Table 1—Compatible Couples in Seawater

GROUP NUMBER	METALLURGICAL CATEGORY	EMF (V)	ANODIC INDEX (0.01 V)	COMPATIBLE COUPLES[1]
0	Inorganic carbon (carbon fibers, graphite, graphene, etc.)[2]	+0.30	0	
1	Gold, solid or plated; gold-platinum alloys; wrought platinum	+0.15	15	
2	Rhodium plated on silver-plated copper	+0.05	25	
3	Silver, solid or plated; high silver alloys	0	30	
4	Nickel, solid or plated; Monel® metal; high nickel-copper alloys; Titanium and Titanium alloys, Inconel® alloys, Hastelloy® C276	-0.15	45	
5	Copper, solid or plated; low brasses or bronzes; silver solder; high copper-nickel alloys; nickel-chromium alloys; austenitic corrosion-resistant steels	-0.20	50	
6	Commercial yellow brasses and bronzes	-0.25	55	
7	High brasses and bronzes; naval brass; Muntz metal	-0.30	60	
8	18 percent chromium type corrosion-resistant steels	-0.35	65	
9	Chromium plated; tin plated; 12 percent chromium-type corrosion-resistant steels	-0.45	75	
10	Tin plate; terneplate; tin-lead solder	-0.50	80	
11	Lead, solid or plated; high lead alloys	-0.55	85	
12	Aluminum; wrought alloys of the 2000 series	-0.60	90	
13	Iron, wrought, gray, or malleable; plain carbon and low-alloy steels; Armco® iron	-0.70	100	
14	Aluminum, wrought alloys other than 2000 series aluminum; cast alloys of the silicon type	-0.75	105	
15	Aluminum, cast alloys other than silicon type; cadmium, plated and chromated	-0.80	110	
16	Hot-dip zinc plate; galvanized steel	-1.05	135	
17	Zinc, wrought; zinc-base die-casting alloys; zinc, plated	-1.10	140	
18	Magnesium and magnesium-base alloys, cast or wrought	-1.60	190	

Notes:
1. ○ indicates the most cathodic member of the series, ● indicates an anodic member. Arrows indicate the anodic direction. All corrosion-resistant steel (CRES) in this table is passivated.
2. All conductive carbon forms, including structures and coatings comprised of carbon composites, carbon fibers, graphite, pitch carbons, carbon black, vitreous carbons, carbon/carbon, graphene, phenolic-impregnated carbon ablative (PICA) materials, etc.

Since the baseline version of NASA-STD-6012, the Inconel® alloys and Hasteloy® C-276 were added to Table 1 based on testing at MSFC. A new Group 0 was added; and all forms of *inorganic carbon (carbon fibers, graphite, graphene, etc.) were added to it based on Figure 1 of ASTM G82, Standard Guide for Development and Use of a Galvanic Series for Predicting Galvanic Corrosion Performance.*

Other sources of guidance for coupling dissimilar metals include MIL-STD-889, Dissimilar Metals, and Report No. RS-TR-67-11, Practical Galvanic Series, by Charles M. Forman and E. A. Verchot. When in doubt, measure the galvanic voltage difference.

4.10 Verification

[CPR 42] Verification of compliance with the requirements of this NASA Technical Standard **shall** consist of the following steps, as a minimum:

a. NASA approval of the contractor CPCP.

b. Contractor M&P signature on engineering drawings to verify compliance with the requirements of this NASA Technical Standard or the CPCP.

c. NASA reviews of contractor corrosion prevention and control activities relating to hardware design and manufacturing.

d. If required, M&P establishment and operation of the corrosion prevention and control panel in accordance with section 4.1, sub-sections l and m of this NASA Technical Standard.

Additional aspects of the verification process should be documented in the CPCP.

APPENDIX A

REQUIREMENTS COMPLIANCE MATRIX

A.1 PURPOSE

Due to the complexity and uniqueness of space flight, it is unlikely all the requirements in a NASA technical standard will apply. The Requirements Compliance Matrix below contains this NASA Technical Standard's technical authority requirements and may be used by programs and projects to indicate requirements that are applicable or not applicable. Follow the process of tailoring in section 1.3 of this NASA Technical Standard. Enter "Yes" in the "Applicable" column if the requirement is applicable to the program or project or "No" if the requirement is not applicable to the program or project. The "Comments" column may be used to provide specific instructions on how to apply the requirement or to specify proposed tailoring.

NASA-STD-6012A				
Section	**Description**	**Requirements in this Standard**	**Applicable (Enter Yes or No)**	**Comments**
4.1	Corrosion Prevention and Control Plan (CPCP)	[CPR 1] A CPCP shall be required and include the following: a. A description of the hardware developer's activities in identifying, testing, evaluating, documenting, and reporting of M&P required for corrosion protection of space flight hardware to be submitted in accordance with the Data Requirements Description (DRD) included in the contract. b. Documentation of the implementation method for each requirement in this NASA Technical Standard. c. Identification of all specifications used to comply with this NASA Technical Standard. d. Identification of proposed deviations from the requirements of this NASA Technical Standard accompanied by an explanation, including appropriate test data, to permit an engineering evaluation by the delegated Technical Authority.		

Section	Description	Requirements in this Standard	Applicable (Enter Yes or No)	Comments
4.1 Continued	Corrosion Prevention and Control Plan Continued	e. Identification of applicable classes of environments from the following list to which space flight hardware materials are exposed, both internally and externally, during the hardware's life cycle (see tailoring exception in section 1.3): (1) Class 1: Exposure to seawater (immersion) environments. (2) Class 2: Exposure to seacoast (atmospheric) environments. (3) Class 3: Exposure to inland (≥50 miles from seacoast), outdoor environments. (4) Class 4: Exposure to potentially corrosive chemical systems or microbial-induced corrosion. (5) Class 5: Exposure to indoor/uncontrolled humidity environments. (6) 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). (7) Class 7: Crew Compartments f. Identification and protection of areas subject to the corrosive environments listed in section 4.1e by finishes that have been demonstrated by test and/or analysis to be suitable for application. g. Identification of cleaning and surface preparation requirements (refer to section 4.3 in this NASA Technical Standard). h. Document the test methods and acceptance criteria used to verify each corrosion control measure. i. Document the process specifications, process controls, and test methods for protective coatings and surface treatments. j. Document the implementation of the design requirements in sections 4.9-4.11. k. 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 in the process specification. l. When there is no Program or Project M&P control panel, establish a corrosion prevention and control panel to include each contractor hardware provider (excluding subcontractors). m. Describe the panel's scope and membership in the CPCP.		

Section	Description	Requirements in this Standard	Applicable (Enter Yes or No)	Comments
4.2a	Material Usage Agreements (MUAs)	[CPR 2] Approval to use M&P differing from the approved CPCP shall be obtained through an MUA in accordance with NASA-STD-6016.		
4.2b	MUAs	[CPR 3] Process and quality control requirements shall be established.		
4.2c	MUAs	[CPR 4] Technical data developed to substantiate the acceptability of the proposed coatings or processes shall be made available to NASA.		
4.2d	MUAs	[CPR 5] Specifications, drawings, and/or relevant procurement details that fully define the materials and/or processes and any flight hardware reuse and restoration activity shall be made available to NASA.		
4.3a	Cleaning and Surface Preparation	[CPR 6] At the time of any finish application, all surfaces shall be clean and free from dirt, grease, oil, or other contamination that may interfere with the satisfactory performance of the finish.		
4.3b	Cleaning and Surface Preparation	[CPR 7] Cleaning methods or solutions used shall not adversely affect the functioning of the part or application of the finish.		
4.3c	Cleaning and Surface Preparation	[CPR 8] All cleaning fluids and other chemicals used during manufacturing and processing of titanium hardware shall be verified to be compatible with the hardware.		
4.3d	Cleaning and Surface Preparation	[CPR 9] Precautions to maintain cleanliness and prevent corrosion shall be maintained during the time between cleaning and finishing and between various finishing steps.		
4.4.1	Environment Class Requirements	[CPR 10] All coating systems on exterior surfaces and interior surfaces subject to environmental exposure shall be qualified in accordance with the following test methods, as applicable for the specific environment class exposure:		

Section	Description	Requirements in this Standard	Applicable (Enter Yes or No)	Comments
4.4.1 Continued	Environment Class Requirements	a. **Class 1: Seawater Immersion** In Class 1 environments, ensure the coating system withstands two times the maximum defined duration of immersion in seawater when tested in accordance with ASTM G52, Standard Practice for Exposing and Evaluating Metals and Alloys in Surface Seawater. b. **Class 2: Seacoast** In Class 2 environments, test each coating system by one of the following test methods/combination of test methods listed in order of preference: (1) A Beach Exposure at Kennedy Space Center (KSC) Beachside Atmospheric Corrosion Test Site for one times the maximum anticipated environmental exposure: Test the coating system in accordance with a test plan approved by the delegated Technical Authority. or (1) B Pad Exposure at Kennedy Space Center (KSC) Atmospheric Corrosion Test Site for two times the maximum anticipated environmental exposure: Test the coating system in accordance with a test plan approved by the delegated Technical Authority. (2) Cyclic Corrosion: A. Perform 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). B. Perform the test so the total duration of cyclic corrosion testing is 60 days for every 3 months of anticipated exposure to a seacoast environment. C. Test for a minimum duration of 60 days and a maximum duration of 240 days.		

Section	Description	Requirements in this Standard	Applicable (Enter Yes or No)	Comments
4.4.1 Continued	Environment Class Requirements Continued	D. Test bare metal specimens according to ASTM G85, Standard Practice for Modified Salt Spray (Fog) Testing, A5, Dilute Electrolyte Cyclic Fog/Dry Test. (3) Ultraviolet (UV) and Salt Spray (Fog): A. Test the coating system in 7-day alternating cycles, starting with UV testing in accordance with ASTM D4587, Standard Practice for Fluorescent UV-Condensation Exposures of Paint and Related Coatings, followed by salt spray (fog) testing, in accordance with ASTM B117, Standard Practice for Operating Salt Spray (Fog) Apparatus. B. Perform the test so that the duration is 2,000 hours for every 45 days of anticipated exposure to a seacoast environment; this duration includes both salt spray (fog) and UV as noted above. C. Test for a minimum duration of 2,000 hours and a maximum duration of 4,000 hours. D. Exempt bare metal specimens from UV testing. c. **Class 3: Inland, Outdoor** In Class 3 environments, test the coating system by one of the following test methods/combination of test methods: (1) UV and Salt Spray (Fog): A. Test the coating system in 7-day alternating cycles, starting with UV testing, followed by salt spray (fog) testing, in accordance with ASTM D5894 and ASTM B117, respectively. B. Perform the test so the total duration of salt spray (fog) with UV is 1,000 hours. (2) UV and Cyclic Corrosion: A. Test the coating system in 7-day alternating cycles starting with UV testing, followed by cyclic corrosion testing, in accordance with ASTM D5894. B. Perform the test so the total duration of UV with salt cyclic corrosion is 120 days. (3) Beach Exposure at the KSC Beachside Atmospheric Corrosion Test Site for 9 months: Test the coating system in accordance with a test plan approved by the delegated Technical Authority.		

Section	Description	Requirements in this Standard	Applicable (Enter Yes or No)	Comments
4.4.1 Continued	Environment Class Requirements	(4) Atmospheric Exposure: Test the coating system 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. d. **Class 4: Chemical or Microbial-Induced Corrosion** In Class 4 environments, perform testing to confirm the coating system is adequate to protect hardware during anticipated chemical exposure or during exposure to microorganisms that induce corrosion. e. **Class 5: Indoor, Uncontrolled Humidity** In Class 5 environments, test the coating system by one of the following test methods: (1) Salt Spray (Fog): When the facility is located within 50 miles of the seacoast, test the protective finish for 168 hours in accordance with ASTM B117. (2) Humidity: When the facility is located 50 miles or more from a seacoast, test the protective finish for 336 hours in accordance with ASTM D2247, Standard Practice for Testing Water Resistance of Coatings in 100% Relative Humidity. f. **Class 6: Indoor, Controlled Humidity** In Class 6 environments, maintain all exposed surfaces in a 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). g. **Class 7: Crew Compartments** (1) For acreage surfaces in Class 7 environments, test the coating system with a salt spray (fog) for 168 hours in accordance with ASTM B117.		

Section	Description	Requirements in this Standard	Applicable (Enter Yes or No)	Comments
4.4.1	Environment Class Requirements Continued	(2) For joints with faying surfaces, in Class 7 environments, use test configurations as follows: A. Vibrate/fatigue/strain the joint configuration to a simulated mission environment. B. Thermally cycle the joint configuration to envelope the maximum mission range. C. Cycle joint configurations between immersion and humidity. D. Specify the joint test configuration in the CPCP.		
4.4.2	Environment Class Requirements	[CPR11] Sealing methods shall be qualified by test to demonstrate the sealing system protects from environmental intrusion as well as prevents corrosion.		
4.4.3	Environment Class Requirements	[CPR 12] Per ARL-TN-0855, Standard Operating Procedure for Accelerated Corrosion Testing at ARL, all corrosion protection system tests using panels shall use “X” scribed panels by scribing two (2) intersecting lines from one corner to the opposite corner across the face of the specimen to initiate and terminate no closer than 1/2 inch from the edge of the sample with the scribe width not exceeding 0.5 mm and exposing the bare substrate.		
4.4.4	Environment Class Requirements	[CPR 13] All corrosion protection system tests shall be conducted using alloys (with the appropriate heat treatment) specified in the design of hardware.		
4.4.5	Environment Class Requirements	[CPR 14] Corrosion protection system tests shall be conducted for the most severe environmental conditions anticipated.		
4.4.6	Environment Class Requirements	[CPR 15] If the protective finish is a coating, the test acceptance criteria for all test methods shall be a test panel graded ≥9 in accordance with ASTM D1654 and not exhibit blistering, film failure, cracking, or substrate corrosion beneath the coating after exposure.		
4.4.7	Environment Class Requirements	[CPR 16] At the conclusion of testing for bare metal panels, the test acceptance criteria for all test methods is no visible signs of corrosion to the unaided eye shall exist.		
4.4.8	Environment Class Requirements	[CPR 17] Sensitivity studies shall be performed to establish acceptable processing parameters for qualifying protective finishes.		

Section	Description	Requirements in this Standard	Applicable (Enter Yes or No)	Comments
4.4.9	Environment Class Requirements	[CPR 18] If testing involves exposed components or devices other than scribed panels or similar test articles without mechanical, electrical, or sealing capability, the component shall undergo functional checks consistent with the expected operation of the hardware in service following exposure.		
4.5.1	Standard Metal Finishes	[CPR 19] Standard metal finishes are listed below and shall be as follows: a. **Nickel Plating** (1) Conform electroless nickel plate to SAE AMS2404, Plating Electroless Nickel, or ASTM B733, Standard Specification for Autocatalytic (Electroless) Nickel-Phosphorus Coatings on Metal. (2) Conform electrodeposited nickel plating to SAE AMS-QQ-N-290, Nickel Plating (Electrodeposited), SAE AMS2403, Plating, Nickel General Purpose, or SAE AMS2423, Plating, Nickel Hard Deposit. (3) Protect the nickel-aluminum interface in nickel-plated aluminum from exposure to corrosive environments. (4) Ensure nickel plating on steel heat treated to an ultimate tensile strength (UTS) over 1,000 MPa (145 ksi) receives a post-plating bake cycle per ASTM B733, class 3. (5) For nickel plating on steels above 1,240 MPa (180 ksi) UTS, apply post-plating heat treatment in accordance with SAE AMS2759/9E, Hydrogen Embrittlement Relief (Baking) of Steel Parts. b. **Chromium Plating** (1) Conform chromium plating to SAE AMS2460, Plating, Chromium. (2) Ensure chromium plating on steel heat treated to a UTS of 1,100 to 1,240 MPa (160 to 180 ksi) receives a post-plating bake cycle in accordance with SAE AMS2759/9E. (3) For steels above 1,240 MPa (180 ksi) UTS, conform chromium plating and post-plating heat treatment to MIL-STD-1501, Chromium Plating, Low Embrittlement, Electrodeposition. c. **Zinc-Nickel Plating** Conform zinc-nickel coatings to SAE AMS2417, Plating, Zinc-Nickel Alloy, or to ASTM B841, Standard Specification for Electrodeposited Coatings of Zinc Nickel Alloy Deposits, type D (black), applied over a suitable under-plate to withstand 500 hours of dynamic salt spray testing.		

Section	Description	Requirements in this Standard	Applicable (Enter Yes or No)	Comments
4.5.1	Standard Metal Finishes Continued	d. **Copper Plating** Conform copper plating to SAE AMS2418, Plating, Copper. e. **Silver Plating** (1) Conform silver plating to ASTM B700, Standard Specification for Electrodeposited Coatings of Silver for Engineering Use. (2) Do not use electrically deposited silver as a plating on printed wiring boards and terminal boards because of potential dendrite growth. (3) Do not use silver plating on bus bars and mechanical/electrical contacts such as connector pins and sockets because it can tarnish and degrade electrical conductivity. (4) Include mitigation requirements for red plague corrosion in the CPCP. f. **Tin Plating** (1) Conform tin plating to ASTM B545, Standard Specification for Electrodeposited Coatings of Tin. (2) Do not use tin and tin plating in any applications providing mission-critical functions or in any applications where whiskers could migrate to mission-critical functions unless the tin is alloyed with at least 3 percent lead or other proven alloying elements to prevent tin whisker growth. g. **Gold Plating** Conform gold plating to the requirements of ASTM B488, Standard Specification for Electrodeposited Coatings of Gold for Engineering Uses. h. **Ion Vapor Deposited (IVD) Aluminum** Conform IVD aluminum to MIL-DTL-83488, Coating, Aluminum, High Purity.		

Section	Description	Requirements in this Standard	Applicable (Enter Yes or No)	Comments
4.5.1	Standard Metal Finishes Continued	i. **Sprayed Metal Coatings** Conform sprayed metal coatings to AWS C2.23M/C2.23, 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 AMS2447, Coating, Thermal Spray High Velocity Oxygen/Fuel Process.		
4.5.2	Plating	[CPR 20] Edges of plated parts shall be rounded to reduce incomplete plating and protect against impact flaking that will breech the plating and cause corrosion.		
4.5.3	Alternative Finishes	[CPR 21] Alternative finish specifications shall be identified in the CPCP.		
4.5.4	Prohibited Finishes	[CPR 22] The following finishes shall be prohibited unless approved by a MUA: a. **Cadmium Plating** Do not use cadmium plating in crew environments, vacuum environments, or for mission-critical functions. b. **Zinc Plating** Do not use zinc plating for mission-critical functions or in an application where whiskers could migrate to affect mission-critical functions.		
4.6.1	Inorganic Finishes	[CPR 23] Inorganic finishes are listed below and shall be as follows: a. Aluminum and Its Alloys (1) MIL-A-8625, Anodic Coatings for Aluminum and Aluminum Alloys (anodizing). (2) MIL-DTL-5541 (chemical conversion coating), when used as a primer base or as a temporary coating during fabrication.		

Section	Description	Requirements in this Standard	Applicable (Enter Yes or No)	Comments
4.6.1	Inorganic Finishes Continued	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.		
4.6.2	Hexavalent Chromate Conversion Coating Temperature Limitation	[CPR 24] Unpainted hexavalent chromate conversion coated parts shall not be exposed to temperatures exceeding 60°C (140°F).		
4.6.3	Mandatory Passivation for Corrosion-Resistant Steel (CRES) Alloys	[CPR 25] Uncoated CRES alloys shall be passivated in accordance with SAE AMS2700 after machining.		
4.7	Organic Finishes, Coatings, and Sealants	[CPR 26] Organic finishes, coatings, and sealants shall meet section 4.4.1 performance requirements for the environment class exposure to which the hardware is subjected.		
4.8 Design Requirements for Corrosion Control				
4.8.1a	Cut Edges	[CPR 27] The edges of all metals in exterior locations shall be rounded to permit adhesion of an adequate thickness of protective coatings.		
4.8.1b	Cut Edges	[CPR 28] Applicable chemical surface treatments shall be applied after rounding of edges and before the application of paint.		

Section	Description	Requirements in this Standard	Applicable (Enter Yes or No)	Comments
4.8.2	Drainage	[CPR 29] Drain holes shall be provided to prevent collection and/or entrapment of rain, seawater, or other unwanted fluids.		
4.9.1	Faying Surfaces	[CPR 30] All faying surface couples exposed to any Class 1 through Class 5 and Class 7 environments shall be sealed.		
4.9.2a	Fasteners	[CPR 31] Fasteners and associated parts such as rivets, screws, bolts, washers, nuts, and clamps shall be wet installed with sealant or primer materials except for fasteners and add-ons used for electrical bonding which are protected per section 4.10.3 below.		
4.9.2b	Fasteners	[CPR 32] If corrosive environmental conditions are expected, temporary installation of fasteners and associated parts shall be installed with corrosion preventive materials.		
4.9.2c	Fasteners	[CPR 33] In Class 1 environments, fastener heads and nuts shall be sealed by applying a topical overcoat of a sealant or primer.		
4.9.2d	Fasteners	[CPR 34] In cases where dissimilar metal contact between fastener and structure cannot be avoided, the fastener shall be the cathodic member of the couple.		
4.9.2e	Fasteners	[CPR 35] CRES fasteners shall be passivated in accordance with SAE AMS2700.		
4.9.3a	Electrical Bonding and Grounding	[CPR 36] All corrosion protection systems for electrical bonding connections shall meet the requirements of section 4.4, as applicable in this NASA Technical Standard and NASA-STD-4003, Electrical Bonding for NASA Launch Vehicles, Spacecraft, Payloads, and Flight Equipment.		
4.9.3b	Electrical Bonding and Grounding	[CPR 37] The protection method or finish selected shall not negate the electrical bond between the two mating surfaces nor the ability to protect the hardware from corrosion.		
4.9.3c	Electrical Bonding and Grounding	[CPR 38] For Class 1 through Class 5 and Class 7 environments, fasteners used to make electrical bond connections between structures and add-ons meant to provide electrical bonding shall be over-sealed with a protective coating or sealant after fastener installation or an alternative method of protection be developed and qualified by the requirements in section 4.4.		
4.9.4a	Dissimilar Metals	[CPR 39] The potential difference between galvanic couples shall not exceed 0.25 V unless the couple current density $\leq 1\ \mu A/cm^2$ without the presence of any corrosion pits.		
4.9.4b	Dissimilar Metals	[CPR 40] All contacts between graphite-based composites and metal materials shall be treated as dissimilar metal couples and sealed.		
4.9.4c	Dissimilar Metals	[CPR 41] Galvanic corrosion of incompatible assemblies shall be evaluated at the assembly level in accordance with the requirements of section 4.4 in this NASA Technical Standard.		

Section	Description	Requirements in this Standard	Applicable (Enter Yes or No)	Comments
4.10	Verification	[CPR 42] Verification of compliance with the requirements of this NASA Technical Standard shall consist of the following steps, as a minimum: a. NASA approval of the contractor CPCP. b. Contractor M&P signature on engineering drawings to verify compliance with the requirements of this NASA Technical Standard or the CPCP. c. NASA reviews of contractor corrosion prevention and control activities relating to hardware design and manufacturing. d. If required, M&P establishment and operation of the corrosion prevention and control panel in accordance with section 4.1, sub-sections l and m of this NASA Technical Standard.		

APPENDIX B

SAMPLE DATA REQUIREMENTS DESCRIPTION

B.1 PURPOSE

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

B.2 SAMPLE DRD

1.	**DPD NO.: XXX** **2. ISSUE: XXXX**	**3.**	**DRD NO.: XXXX**
4.	**DATA TYPE: 1**	**5.**	**DATE ISSUED/REVISED:**
		6.	**PAGE: 1/2**

7. **TITLE**: Corrosion Prevention and Control Plan

8. **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.

9. **OPR**: XXX 10. **DM**: XXX

11. **DISTRIBUTION**: As determined by the Contracting Officer.

12. **INITIAL SUBMISSION**: PDR

13. **SUBMISSION FREQUENCY**: Final at CDR

14. **REMARKS**:

15. **INTERRELATIONSHIP**: Parent SOW Paragraph: XXXX

16. **DATA PREPARATION INFORMATION**:

16.1 **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.

16.2 **APPLICABLE DOCUMENTS**:

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

16.3 **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:

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

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

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

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

16.4 **FORMAT**: Electronic, Microsoft® Word® or Excel®-compatible document or Adobe® portable document format (PDF). For each paragraph in section 4 of NASA-STD-6012A, the Plan shall state the requirement from NASA-STD-6012A, identify the degree of conformance under the subheading “Degree of Conformance,” and identify the method of implementation under the subheading “Method of Implementation.”

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

APPENDIX C

X-SCRIBE GUIDANCE

Per ARL-TN-0855, Standard Operating Procedure for Accelerated Corrosion Testing at ARL, prepare “X” scribed panels as follows:

a. Prior to scribing, clean the specimens/parts so they are thoroughly free of oil, grease, wax, dirt, scale, and other foreign matter and they show no visible signs of corrosion products and clean specimens with a dry, lint-free cloth; perform additional cleaning with appropriate solvent or detergent if the dry wipe is not sufficient.

b. Manually scribe specimens using a tungsten carbide scribe as described in ASTM D1654, Section 5.1.2, to make an “X” scribe (see Figure 1, Example of a Tungsten Carbide Scribe Tool).

Automated scribing procedures may be used so long as proper objective quality evidence can be provided to prove that the automated procedure does not produce results that deviate from the traditional manual procedure.

c. Ensure the scribe tool is in good order with a sharp, unbent, and un-dulled tip that provides clean scribe lines.

d. Scribe so the width does not exceed 0.5 mm.

e. Do not use scribes used on ferrous materials to scribe nonferrous materials, which will prevent contamination of the substrate during the process.

f. Make the "X" scribe by scribing two (2) intersecting lines from one corner to the opposite corner across the face of the sample using a straight metal guide rule to initiate and terminate no closer than 1/2 inch from the edge of the sample.

g. Re-scribe those scribes that do not penetrate the coating to the substrate, taking care to stay within the trough cut by the original scribe.

Occasionally, scribes may deviate from a straight line due to surface profile of the substrate, various properties of the coating, or slipping of the guide rule. These scribes are acceptable for use in testing when agreed upon by testing authorities.

Figure 1—Example of a Tungsten Carbide Scribe Tool

APPENDIX D

Summary Matrix of Class Environments and Test Methods

		Environment Class						
		1	2	3	4	5	6	7
Test Method	**Applicable Document**	**Seawater Immersion**	**Seacoast[1]**	**Inland, Outdoor[2]**	**Chemical or Microbial-Induced**	**Indoor, Uncontrolled Humidity**	**Indoor, Controlled Humidity**	**Crew Compartments[3]**
Salt Spray	ASTM B-117		Alternate 7-day UV exposure with 7-day salt spray, 2000 hours for each 45 days 2,000 hours min and 4,000 hours max	Alternate 7-day salt spray with 7-day UV test, 1,000 hours total		168 hours for <50 miles from seacoast		For acreage surfaces, 168 hours
Chemical Resistance					For Class 4 environments, provide data to support corrosion protection methods			
Humidity	ASTM D2247					336 hours for ≥50 miles from seacoast		
Beach Exposure[3]			2× maximum anticipated exposure	9 months				
Atmospheric Corrosion	ASTM G50 ASTM G7			1.5× actual exposure for location				
Cyclic Corrosion	ASTM G85		60 days for each 3 months of anticipated exposure with 60 days min and 240 days max	Alternate 7-day UV exposure with 7-day cyclic corrosion, 120 days total				

Test Method	Applicable Document	Environment Class						
		1	2	3	4	5	6	7
		Seawater Immersion	**Seacoast[1]**	**Inland, Outdoor[2]**	**Chemical or Microbial-Induced**	**Indoor, Uncontrolled Humidity**	**Indoor, Controlled Humidity**	**Crew Compartments[3]**
Ultraviolet (UV)	ASTM D5894		Alternate 7-day UV exposure with 7-day salt spray, 2,000 hours for each 45 days 2,000 hours min and 4,000 hours max	Alternate 7-day UV exposure with 7-day salt spray, 1,000 hours OR Alternate UV exposure with 7-day cyclic corrosion, 120 days total				
Seawater Immersion	ASTM G52	2× maximum defined duration						

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. Class 7: For joints with faying surfaces, in Class 7 environments, use test configurations as follows:

A. Vibrate/fatigue/strain the joint configuration to a simulated mission environment.
B. Thermally cycle the joint configuration to envelope the maximum mission range.
C. Cycle joint configurations between immersion and humidity.
D. Specify the joint test configuration in the CPCP.

APPENDIX E

UNPAINTED CHROMATE CONVERSION COATINGS TEMPERATURE AND EXPOSURE TIME GUIDANCE

E.1 PURPOSE

This Appendix provides guidance for unpainted chromate conversion coatings temperature and exposure time.

E.1 GUIDANCE

Per MIL-DTL-5541F, paragraph 6.14: “Unpainted conversion coatings will commence losing corrosion resistance properties if exposed to temperatures of 60ºC (140ºF) or higher, during drying, subsequent fabrication, or service. As temperatures and exposure times increase, the corrosion protection of unpainted conversion coated parts decreases. The reduction is believed to result from the coating dehydrating and the resulting insolubility of the chromates within the coating.”

Chromate conversion coatings are partially hydrated coatings which will undergo dehydration. The 140°F limit should also be subject to an exposure time limit. Currently, there is no literature supporting exposure time limits. Guidance concerning elevated temperature exposure limits for unpainted conversion coatings is as follows:

1 minute at 60ºC (140°F)
4 minutes at 54ºC (130°F)
15 minutes at 49ºC (120°F)
1 hour at 43ºC (110°F)
3 hours at 38ºC (100°F)
12 hours at 32ºC (90°F
48 hours at 27ºC (80°F)
168 hours at 21ºC (70°F)

Dewpoints also affect elevated temperature exposure time. Consider an example where conditions are very dry (low dew point) and/or the atmospheric pressure is low (relative to the vapor pressure of water). It might only take a few minutes in the 60-65ºC (140-150°F) range to render the coating useless. In high dewpoint situations, the coating might be able to tolerate an hour or more at 71ºC (160°F) and several minutes at 82ºC (180°F).

Lower temperatures will also damage hydrated coatings. Unpainted hexavalent chromate conversion coated parts should not be exposed to temperatures below 0°C (32°F) for longer than 1 minute. Pure water freezes at 0°C (32°F) as the molecules lose their mobility and the Cr6+ ions become unavailable. Associated water molecules may freeze or sublime as the coating structure cracks, possibly exposing the base metal.

APPENDIX F

REFERENCES

F.1 Purpose

Appendix E provides references and guidance documents related to this NASA Technical Standard.

F.2 Reference Documents

MIL-A-22262, Abrasive Blasting Media Ship Hull Blast Cleaning

MIL-STD-810, Environmental Engineering Considerations and Laboratory Tests (Test Method 508)

MIL-STD-889, Dissimilar Metals

MIL-STD-7179, Finishes, Coatings, and Sealants, for the Protection of Aerospace Weapons Systems

ASTM D3273, Standard Test Method for Resistance to Growth of Mold on the Surface of Interior Coatings in an Environmental Chamber

ASTM G1, Standard Practice for Preparing, Cleaning, and Evaluating Corrosion Test Specimens

ASTM G44, Standard Practice for Exposure of Metals and Alloys by Alternate Immersion in Neutral 3.5% Sodium Chloride Solution

ASTM G71, Standard Guide for Conducting and Evaluating Galvanic Corrosion Tests in Electrolytes

ASTM G82, Standard Guide for Development and Use of a Galvanic Series for Predicting Galvanic Corrosion Performance

SAE ARP1481A, Corrosion Control and Electrical Conductivity in Enclosure Design

SAE ARP1870A, Aerospace Systems Electrical Bonding and Grounding for Electromagnetic Compatibility and Safety

RS-TR-67-11, Practical Galvanic Series, by Charles M. Forman and E. A. Verchot

SSPC-AB 1 (E 2017), Mineral and Slag Abrasives

SSPC-SP 10 (January 1, 2007), Near-White Metal Blast Cleaning

MSFC Form 4657, Change Request for a NASA Engineering Standard