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(Stamp Revision: (10-2-2007))

**TM-584C**  
**REVISION C**

# **CORROSION CONTROL AND TREATMENT MANUAL**

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National Aeronautics and  
Space Administration

**John F. Kennedy Space Center**

KSC FORM 16-12 (REV. 7/92)



**TM-584C**  
**REVISION C**

# **CORROSION CONTROL AND TREATMENT MANUAL**

**This Revision Supersedes All  
Previous Editions of This Manual**

**NOVEMBER 1, 1994**

TM-584C

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## ABBREVIATIONS AND ACRONYMS

|                                 |   |
|---------------------------------|---|
| cm                              | centimeter                                  |
| CP                              | cathodic protection                         |
| DOD                             | Department of Defense                       |
| gal                             | gallon                                      |
| GN <sub>2</sub>                 | gaseous nitrogen                            |
| HF                              | hydrofluoric acid                           |
| HNO <sub>3</sub>                | nitric acid                                 |
| in                              | inch  |
| IVD                             | ion vapor deposition                        |
| kg                              | kilogram                                    |
| KSC                             | John F. Kennedy Space Center                |
| ksi                             | kips per square inch                        |
| MIL                             | military                                    |
| m <sup>3</sup>                  | cubic meter                                 |
| mm                              | millimeter                                  |
| MPa                             | megapascal                                  |
| NACE                            | National Association of Corrosion Engineers |
| NH <sub>4</sub> HF <sub>2</sub> | ammonium bifluoride                         |
| oz                              | ounce                                       |
| psi                             | pounds per square inch                      |
| SCC                             | stress corrosion cracking                   |
| SPEC                            | specification                               |
| SSPC                            | Steel Structures Painting Council           |
| STD                             | standard                                    |
| TM                              | technical manual                            |
| UTS                             | ultimate tensile strength                   |
| μm                              | micrometer                                  |
| °C                              | degree Celsius                              |
| °F                              | degree Fahrenheit                           |

## SECTION I

### INTRODUCTION

#### 1.1 GENERAL

This manual provides guidelines for the control of corrosion of materials in facilities, systems, and equipment at the John F. Kennedy Space Center (KSC), Florida.

#### 1.2 RESPONSIBILITY

The design agency has a responsibility to deliver hardware and equipment to the operator without "built-in" corrosion problems. Cooperation and communication between design, operation, and maintenance activities are vital to identify existing problems so design errors are not repeated in new designs. Minor design changes to existing equipment will often serve to eliminate a major corrosion problem.

Each organization must develop and implement a corrosion-control program to satisfy its particular requirements. Responsibility for maintaining an item must be fixed and controls must be stringent enough to ensure accomplishment. Scheduled inspection and preventive maintenance are essential to determine system status and to provide early correction of weaknesses. Preventive maintenance reduces the total amount of labor used and the expense incurred and ensures corrosion will not prevent the particular system from performing its design function.

Corrosion control and treatment are of vital concern because corrosion of equipment and primary structures has a great effect on the operational and structural integrity of systems. Economy is another basic consideration since severe corrosion will eventually weaken structural members to the point where replacement or reinforcement is required in order to sustain design loads.

#### 1.3 REFERENCE DOCUMENTATION

The following documents are referenced in this manual.

KSC-SPEC-E-0001

Application of Coating, Conformal (Polyurethane), Printed-Circuit Assemblies, Specification for

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|                       |  |
|-----------------------|--|
| <b>KSC-STD-132</b>    | <b>Potting and Molding Electrical Cable Assembly Terminations</b>  |
| <b>KSC-STD-C-0001</b> | <b>Standard for Protective Coating of Carbon Steel, Stainless Steel, and Aluminum on Launch Structures, Facilities, and Ground Support Equipment</b> |
| <b>KSC-STD-Z-0004</b> | <b>Structural Steel Building and Other Structures, the Design of, Standard for</b>   |
| <b>MIL-STD-889</b>    | <b>Dissimilar Metals</b>   |
| <b>MIL-A-9962</b>     | <b>Abrasive Mats, Non-Woven, Non-Metallic</b>  |
| <b>MIL-C-5541</b>     | <b>Chemical Conversion Coatings on Aluminum and Aluminum Alloys</b>  |
| <b>MIL-C-10578</b>    | <b>Corrosion Removing and Metal Conditioning Compound</b>  |
| <b>MIL-C-14460</b>    | <b>Corrosion Removing Compound, Sodium Hydroxide Base; for Electrolytic or Immersion Application</b>   |
| <b>MIL-C-16173</b>    | <b>Corrosion Preventive Compound, Solvent Cutback, Cold-Application</b>  |
| <b>MIL-C-83488</b>    | <b>Coating, Aluminum, Ion Vapor Deposited</b>  |
| <b>MIL-C-87936</b>    | <b>Cleaning Compounds, Aircraft Exterior Surfaces, Water Dilutable</b>   |
| <b>MIL-G-23549</b>    | <b>Grease, General Purpose</b>   |
| <b>MIL-G-81322</b>    | <b>Grease, Aircraft, General Purpose, Wide Temperature Range</b>   |
| <b>MIL-L-46000</b>    | <b>Lubricant, Semi-Fluid (Automatic Weapons)</b>   |
| <b>MIL-L-46010</b>    | <b>Lubricant, Solid Film, Heat Cured, Corrosion Inhibiting</b>   |

|             |  |
|-------------|--|
| MIL-P-46002 | Preservative Oil, Contact and Volatile Corrosion-Inhibited   |
| MIL-S-8802  | Sealing Compound, Temperature-Resistant, Integral Fuel Tanks and Fuel Cell Cavities, High Adhesion   |
| MIL-S-29574 | Sealing Compound, Polythioether, for Aircraft Structures, Fuel and High Temperature Resistant, Fast Curing at Ambient and Low Temperatures |
| MIL-T-23142 | Tape, Pressure-Sensitive Adhesive, for Dissimilar Metal Separation   |
| DOD-P-15328 | Primer (Wash) Pretreatment (Formula No. 117 for Metals) (Metric)   |
| TT-E-751    | Ethyl Acetate, Technical   |
| TT-R-248    | Remover, Paint and Lacquer, Solvent Type   |
| TT-S-230    | Sealing Compound, Elastomeric Type, Single Component (for Calking, Sealing, and Glazing in Buildings and Other Structures)                 |
| TT-T-266    | Thinner: Dope and Lacquer (Cellulose-Nitrate)  |

National Association of Corrosion Engineers (NACE)

|                 |  |
|-----------------|--|
| Standard RP0178 | Fabrication Details, Surface Finish Requirements, and Proper Design Considerations for Tanks and Vessels To Be Lined for Immersion Service |
| Standard RP0189 | Standard Recommended Practice On-Line Monitoring of Cooling Waters   |

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**Designing for Corrosion Control by R. James Landrum**

(Application for copies should be addressed to the National Association of Corrosion Engineers, P.O. Box 218340, Houston, TX 77218-8340.)

**Steel Structures Painting Council (SSPC)**

|            |                           |
|------------|---------------------------|
| SSPC SP-1  | Solvent Cleaning          |
| SSPC SP-2  | Hand Tool Cleaning        |
| SSPC SP-3  | Power Tool Cleaning       |
| SSPC SP-10 | Near-White Blast Cleaning |

[Applications for copies should be addressed to the Steel Structures Painting Council (SSPC), 4516 Henry Street, Pittsburgh, PA 15213.]

## SECTION II CORROSION CONTROL

### 2.1 GENERAL

A properly implemented corrosion control program will disclose corrosion attack in the early stages. Minor maintenance can correct such corrosion. Preventive maintenance is the most cost-effective method of controlling corrosion, including problems caused by poor design.

### 2.2 PREVENTIVE MAINTENANCE

Preventive maintenance as related to corrosion control includes the following specific functions:

- a. An adequate cleaning program.
- b. Detailed scheduled inspection of facilities and systems for corrosion and failure of protective coating systems.
- c. Prompt treatment of corrosion after it is detected.
- d. Touchup of damaged paint areas.
- e. Periodic lubrication.
- f. Use of supplementary preservative coatings as necessary.
- g. Adequate drainage of moisture entrapment areas by maintaining drain holes free of obstruction. Holes should be large enough so they can be protected.
- h. Periodic removal of accumulated water and other foreign matter from fuel containers. Keep fuel containers full to minimize the accumulation of water and debris.
- i. Coat exposed critical surfaces (such as pistons) with preservative compounds. Surfaces that must remain bare shall be wiped clean frequently.
- j. Protection of equipment against water, dust, etc., by use of covers or storage in a protected enclosure.

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- k. Periodic and frequent inspections of areas where absorbent materials are in contact with metals.

## 2.3 SURVEILLANCE

Continuing surveillance is required to disclose corrosion attack in its early stages. Without proper preventive maintenance, corrosion can seriously damage equipment. All equipment must be carefully inspected for signs of corrosion during scheduled and random inspections. These activities should be organized and properly managed to produce an effective program. Materials that require special treatment to protect them against corrosion are those most vulnerable to corrosion attack and require careful inspection and maintenance.

## 2.4 DESIGN CONSIDERATIONS

**2.4.1 CORROSION CONTROL.** The atmosphere at KSC contains a high salt content that is readily deposited on exposed surfaces. This, combined with acidic solid rocket booster effluent that is pH of 1 to 2, substantial rainfall, steady winds, low land elevation, and generally high humidity and temperature, results in an ideal environment for extensive metal corrosion. These conditions induce both electrolytic action and chemical reactions dependent upon the metals involved and how they are used. Although corrosion control is primarily the responsibility of the maintainer of the equipment, the designer is responsible for providing hardware that will not present unnecessary problems.

The designer must determine where the end item will be located at KSC. Such locations can vary from the severe conditions present at a launch complex to partially controlled environments in air-conditioned rooms to the carefully controlled conditions in a clean room. The control and treatment of corrosion are of vital concern because of degradation of the operational and structural integrity of the equipment and facilities.

The best procedure for corrosion control is to minimize the potential for corrosive attack while designing the equipment. Many corrosion problems encountered could be avoided by proper design. Frequently, minor design changes can eliminate particularly troublesome corrosion problems. The equipment operator should advise the designer when such situations exist. Basic recommendations for eliminating corrosion in the design phase are summarized as follows:

- a. Use corrosion-resistant materials including plastics and nonmetallics in severe environments where possible. Galvanized supports should be specified for outside installations in neutral atmospheres and for inside installations where corrosive agents are present.



- b. **Avoid dissimilar metal couples (see MIL-STD-889 for a definition of dissimilar metal combinations). Materials classified in different groups are considered dissimilar or incompatible with one another. The tendency toward galvanic corrosion is greater between widely separated groups than between adjacent groups. Metals from different groups may be placed in contact where suitable protection against galvanic action is provided through use of barrier tape protective coatings or other methods of isolation. The method of protection required will be dependent on the design and usage environment.**
- c. **Keep moisture away or provide for its removal.**
- d. **Avoid exposure to corrosive liquids or fumes.**
- e. **Protect surfaces with metallic, inorganic, or organic coatings as required. Consider use of powder coatings such as polyester, epoxy, PVC, and similar coatings applied by the fluidized bed process.**
- f. **Improve the environment by providing seals, dehumidification, purges, adequate ventilation, vapor phase inhibitors, and air-conditioning or by maintaining temperature above the dew point.**
- g. **Protect exposed bearing surfaces with corrosion inhibiting lubricant. Greases in accordance with MIL-G-81322 (Mobilgrease 28) and MIL-G-23549 (Royco 49B or Supermil grease 94532) provide good protection.**
- h. **Apply protective coatings to all buried and submerged metallic facilities in accordance with KSC-STD-C-0001. Where applicable, provide cathodic protection to prolong the effectiveness of the protective coating. Consult NACE RP0189 for cathodic protection (CP) requirements.**
- i. **Consult the book Designing for Corrosion Control by R. James Landrum for more detailed recommendations for corrosion design criteria. This book is available from the National Association of Corrosion Engineers, NACE International, P.O. Box 218340, Houston, TX 77218, (713) 492-0535, ext. 81, or the KSC Library.**
- j. **Use flameproof inorganic zinc sacrificial protective coatings to protect carbon steel in accordance with KSC-STD-C-0001 and comply with NACE inspection requirements as specified.**

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- k. Use acid-resistant topcoats in the launch environment.
- l. Anodize, alodine, or use AR-7 treatment of unpainted aluminum. Follow KSC-STD-C-0001 for application of additional protective coatings.
- m. Use sealed and treated tubular structural columns in tension and compression members. The internal surfaces shall be treated by filling and draining with a volatile corrosion-inhibiting lubricating oil in accordance with MIL-P-46002 grade 1, or approved equal. After treatment, all openings shall be seal welded.
- n. Avoid the use of back-to-back structural shapes, such as boxbeam sections and unistrut. When the exterior use of unistrut cannot be avoided, selection of appropriate material shall be considered, such as stainless steel. In addition, alternate structural shapes shall be considered such as C- or Z-shaped channel, especially in highly corrosive areas.
- o. Provide large drainage holes so the edges can be painted.
- p. Seal faying surfaces of bolted and skip-welded joints with caulking. Use TT-S-230 for caulking.
- q. Consider the plating of steel surfaces in accordance with KSC-STD-C-0001 or MIL-C-83488, Class 1. Avoid the use of cadmium plating due to possible health and outgassing concerns. Bare, cadmium-plated surfaces in exterior applications are prohibited.
- r. Avoid the use of alloys susceptible to stress-corrosion cracking in accordance with KSC-STD-Z-0004.
- s. Consider system compatibility, environment, and location in relation to hypergolic or cryogenic systems and their vapors.
- t. Use galvanized or other corrosion-resistant bolts or rivets, if possible. Avoid lap joints with skip welds wherever possible. Use butt welds or seal welds, if possible. NACE Standard RP0178 should be used in metal tank and vessel design.

## SECTION III TYPES OF CORROSION AND THEIR CAUSES

### 3.1 GENERAL

Corrosion can be defined as the deterioration of material by reaction to its environment. The corrosion occurs because of the natural tendency for most metals to return to their natural state; e.g., iron in the presence of moist air will revert to its natural state, iron oxide. Metals can be corroded by the direct reaction of the metal to a chemical; e.g., zinc will react with dilute sulfuric acid, and magnesium will react with alcohols.

### 3.2 BASIC CAUSES OF CORROSION

**3.2.1 CONDITIONS NECESSARY FOR CORROSION.** For the purpose of this manual, electrochemical corrosion is the most important classification of corrosion. Four conditions must exist before electrochemical corrosion can proceed: (1) there must be something that corrodes (the metal anode), (2) there must be a cathode, (3) there must be continuous conductive liquid path (electrolyte, usually condensate and salt or other contaminations), and (4) there must be a conductor to carry the flow of electrons from the anode to the cathode. This conductor is usually in the form of metal-to-metal contact such as in bolted or riveted joints.

The elimination of any one of the four conditions will stop corrosion. An unbroken (perfect) coating on the surface of the metal will prevent the electrolyte from connecting the cathode and anode so the current cannot flow. Therefore, no corrosion will occur as long as the coating is unbroken.

**3.2.2 EFFECT OF MATERIAL SELECTION.** One of the fundamental factors in corrosion is the nature of the material. Materials are usually selected primarily for structural efficiency, and corrosion resistance is often a secondary consideration in design. The use of corrosion-resistant alloys is not a cure-all for corrosion prevention. Corrosion-resistant metals are by nature passive (more noble) and can cause severe galvanic corrosion of active (less noble) materials. A common occurrence is to replace a corroded part with a corrosion-resistant alloy only to find that the corrosion has shifted to another location and increased in severity.

**3.2.3 WATER INTRUSION.** Water intrusion is the principal cause of corrosion problems encountered in the field use of equipment. Water can enter an enclosure by free entry, capillary action, or condensation. With these three modes of water entry acting and with the subsequent confinement of water, it is almost certain that any enclosure will be susceptible to water intrusion. As a general rule,

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assume that water enters any unit except the hermetically sealed or pressurized designs. Sump-like areas, enclosures, or sealed members wherein water can accumulate should be provided with drain holes at their lowest point or wherever water may collect. The size of the drain holes should be large enough to permit proper application of a protective coating. Typical drainhole size should be 12 millimeters (mm) [0.5-inch (in)] minimum. Where drain holes are not practical, provide dehumidification or purge with dry air or nitrogen.

**3.2.4 ENVIRONMENTAL FACTORS.** At normal atmospheric temperatures the moisture in the air is enough to start corrosive action. Oxygen is essential for corrosion to occur in water at ambient temperatures. Other factors that affect the tendency of a metal to corrode are: (1) acidity or alkalinity of the conductive medium (pH factor), (2) stability of the corrosion products, (3) biological organisms (particularly anaerobic bacteria), (4) variation in composition of the corrosive medium, and (5) temperature. The corrosion problem at KSC is complex. The presence of salts and acids on metal surfaces greatly increases the electrical conductivity of any moisture present and accelerates corrosion. Moisture tends to collect on dirt particles. The maintenance of clean surfaces on passive metals or alloys and alloys plated with more noble metals can be of even greater importance than for plain carbon steel. If small corrosion areas develop, the combination of small active anodes in relation to large passive cathodes causes severe pitting. This principle also applies to metals that have been passivated by chemical treatments as well as for metals that develop passivation due to environmental conditions (e.g., stainless steel and aluminum). Alloys that owe their corrosion resistance to passivity are susceptible to accelerated corrosion within crevices. This phenomenon is caused by the formation of an oxygen cell resulting from a lower oxygen concentration in the crevice. For these reasons, cleanliness must be maintained and corrosion-preventive measures, such as painting as dictated by service conditions, must be observed even on corrosion-resistant materials. Corrosive attack begins on the surface of a metal exposed to a corrosive environment. If allowed to progress, the corrosion works down into the core of the material. Because corrosion never originates in the core, there will always be evidence on the surface when an attack is in progress. The most common visible manifestations of corrosion are pitting on stainless steel or aluminum, rust on carbon steel, and intergranular exfoliation on aluminum.

### **3.3 TYPES OF CORROSION**

**3.3.1 CONCENTRATION CELL CORROSION.** Concentration cell corrosion occurs when two or more areas of a metal surface are in contact with different concentrations of the same solution. There are three general types of concentration cell corrosion: (1) metal ion concentration cells, (2) oxygen concentration cells, and (3) active-passive cells.

**3.3.1.1 Metal Ion Concentration Cells.** In the presence of water, a high concentration of metal ions will exist under faying surfaces and a low concentration of metal ions will exist adjacent to the crevice created by the faying surfaces. An electrical potential will exist between the two points. The area of the metal in contact with the low concentration of metal ions will be cathodic and will be protected, and the area of metal in contact with the high metal ion concentration will be anodic and corroded. This condition can be eliminated by sealing the faying surfaces in a manner to exclude moisture. Proper protective coating application with inorganic zinc primers is also effective in reducing faying surface corrosion.

**3.3.1.2 Oxygen Concentration Cells.** A water solution in contact with the metal surface will normally contain dissolved oxygen. An oxygen cell can develop at any point where the oxygen in the air is not allowed to diffuse uniformly into the solution, thereby creating a difference in oxygen concentration between two points. Typical locations of oxygen concentration cells are under either metallic or nonmetallic deposits (dirt) on the metal surface and under faying surfaces such as riveted lap joints. Oxygen cells can also develop under gaskets, wood, rubber, plastic tape, and other materials in contact with the metal surface. Corrosion will occur at the area of low-oxygen concentration (anode). The severity of corrosion due to these conditions can be minimized by sealing, maintaining surfaces clean, and avoiding the use of material that permits wicking of moisture between faying surfaces.

**3.3.1.3 Active-Passive Cells.** Metals that depend on a tightly adhering passive film (usually an oxide) for corrosion protection; e.g., austenitic corrosion-resistant steel, can be corroded by active-passive cells. The corrosive action usually starts as an oxygen concentration cell; e.g., salt deposits on the metal surface in the presence of water containing oxygen can create the oxygen cell. If the passive film is broken beneath the salt deposit, the active metal beneath the film will be exposed to corrosive attack. An electrical potential will develop between the large area of the cathode (passive film) and the small area of the anode (active metal). Rapid pitting of the active metal will result. This type of corrosion can be avoided by frequent cleaning and by application of protective coatings.

**3.3.2 GALVANIC CORROSION.** Galvanic corrosion is an electrochemical action of two dissimilar metals in the presence of an electrolyte and an electron conductive path. It occurs when dissimilar metals are in contact. It is recognizable by the presence of a buildup of corrosion at the joint between the dissimilar metals. For example, when aluminum alloys or magnesium alloys are in contact with steel (carbon steel or stainless steel), galvanic corrosion can occur.

Appendix A represents a galvanic series in sea water. If electrical contact is made between any two of these materials in the presence of an electrolyte, current must

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flow between them. The farther apart the metals in appendix A are, the greater will be the galvanic corrosion effect or rate. Metals or alloys at the upper end are noble while those at the lower end are active. The more active metal is the anode or the one that will corrode.

The galvanic series of metals and alloys are to be used only for general information and must be augmented by experience and a knowledge gained of the behavior of dissimilar metal combinations in field service. When the use of plated steel bolts is necessary on aluminum flanges, the bolts should be separated from the flange by nonmetallic sleeves and backup washers to prevent conditions favorable to galvanic corrosion. When dissimilar metals must be used, always protect both components. A break in the protective coating on the anodic surface will result in severe pitting if the cathodic surface is not protected. This is because of the concentration of current upon the relatively small anodic area exposed when the cathode is uncoated. When practical, bolts, rivets, and other fasteners should be made of the same material as the main structure. When this is not practical, they should be selected from materials higher in the listing of appendix A so as to distribute the anodic attack over the larger of the two coupled metals. When the anode is large with respect to the cathode, two advantages are realized: (1) because the anode is being dissolved by the electrolyte, uniform corrosion takes place over a relatively large area at a relatively slower rate, thus increasing the service life of the anode, and (2) the small cathode areas tend to become polarized, thereby slowing or stopping the reaction. For more information concerning corrosion control of dissimilar metals, consult MIL-STD-889.

To summarize, the following recommended practices should be observed to keep galvanic corrosion to a minimum.

- a. Avoid the use of widely dissimilar metals in direct contact.
- b. When dissimilar metals must come into contact, they should be separated by using nonconductive barrier materials, a paint coating, or by plating.
- c. The anode should be as large as feasible in relation to the cathode.
- d. Coat both the anode and the cathode with the same material.
- e. When possible, install fasteners that have been dipped in epoxy mastic coatings in accordance with KSC-STD-C-0001.
- f. Seal threaded inserts with epoxy mastic coatings prior to insertion into castings.

- g. Avoid the use of lock or toothed washers over plated or anodized surfaces.
- h. Use only dry-film lubricants that are graphite free [MIL-L-46010 (MR) is graphite free].

**3.3.2.1 Filiform Corrosion.** Filiform corrosion is a unique type of galvanic corrosion occurring under painted surfaces or plated surfaces that do not exhibit good adhesion and under gaskets. It appears as a radial "worm-like" corrosion path emanating from a central core of corrosion. This type of corrosion occurs under painted or plated surfaces when moisture permeates the coating. Lacquers and "quick-dry" paints are most susceptible to the problem; their use should be avoided unless absence of an adverse effect has been proven by field experience. Where a coating is required, it should exhibit low water vapor transmission characteristics and excellent adhesion. Zinc-rich coatings should also be considered for coating carbon steel because of their cathodic protection quality.

**3.3.3 INTERGRANULAR CORROSION.** Intergranular corrosion is an attack on the grain boundaries of a metal or alloy. A highly magnified cross section of any commercial alloy will show its granular structure. This structure consists of quantities of individual grains, and each of these tiny grains has a clearly defined boundary that chemically differs from the metal within the grain center. Frequently, the grain boundaries are anodic to the main body of the grain, and when the grain boundaries are in this condition and in contact with an electrolyte, a rapid selective corrosion of the grain boundaries occurs. One example of this type of corrosion is in unstabilized 300-series stainless steels sensitized by welding or brazing and subsequently subjected to a severe corrosion environment. Another example of intergranular or grain boundary corrosion is that which occurs when aluminum alloys are in contact with steel in the presence of an electrolyte. The aluminum alloy grain boundaries are anodic to both the aluminum alloy grain and the steel. In the later case, intergranular corrosion of the aluminum alloy occurs. Some austenitic steels are unstable when heated in the temperature range of 470 to 915 degrees Celsius ( $^{\circ}\text{C}$ ) [800 to 1600 degrees Fahrenheit ( $^{\circ}\text{F}$ )], after which they become susceptible to corrosion attack at their grain boundaries. The cause of intergranular corrosion has been the subject of much study. Decreased corrosion resistance in austenitic stainless steels is due to depletion of chromium in the area near the grain boundaries, caused by the precipitation of chromium carbide. This condition can be eliminated by the use of stabilized stainless steel, such as columbium, tantalum, or titanium stabilized stainless steels (types 321 and 347), or by the use of low-carbon stainless steels. Molybdenum additions as in type 316 stainless steels decrease the sensitivity to and the severity of the intergranular attack.

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Intergranular corrosion can be prevented by adopting one or more of the following methods:

- a. Select an alloy type that is resistant to intergranular corrosion.
- b. Avoid heat treatments or service exposure that makes a material susceptible. Normally this occurs with austenitic stainless steels when they are held for some time in the sensitizing temperature range of 470 to 915 °C (800 to 1600 °F).
- c. Apply a protective coating.

**3.3.3.1 Exfoliation Corrosion.** Exfoliation is a form of intergranular corrosion. It manifests itself by lifting up the surface grains of a metal by the force of expanding corrosion products occurring at the grain boundaries just below the surface. It is visible evidence of intergranular corrosion and most often seen on extruded sections where grain thickness is less than in rolled forms.

**3.3.4 PITTING CORROSION.** The most common effect of corrosion on aluminum and magnesium alloys is called pitting. It is noticeable first as a white or gray powdery deposit, similar to dust, which blotches the surface. When the deposit is cleaned away, tiny pits or holes can be seen in the surface. Passive metals such as stainless steel resist corrosive media and can perform well over long periods of time. However, if corrosion does occur, it forms a random in pits. Pitting may be a serious type of corrosion because it tends to penetrate rapidly into the metal section. Pits begin by a breakdown of passivity at nuclei on the metal surface. The breakdown is followed by formation of an electrolytic cell, the anode of which is a minute area of active metal and the cathode of which is a considerable area of passive metal. The large potential difference characteristic of this "passive-active cell" (0.5 to 0.6 volt for 18-8 stainless steel) accounts for a considerable flow of current with attendant rapid corrosion at the small anode. The corrosion-resistant passive metal surrounding the anode and the activating (passivity-destroying) property of the corrosion products within the pit account for the tendency of corrosion to penetrate the metal rather than spread along the surface. Pitting is most likely to occur in the presence of chloride ions, combined with such depolarizers as oxygen or oxidizing salts. Methods that can be used to control pitting include maintaining surfaces clean, application of a protective coating, and use of inhibitors or cathodic protection for immersion service.

**3.3.5 UNIFORM ETCH CORROSION.** The surface effect produced by most direct chemical attacks (e.g., as by an acid) is a uniform etching of the metal. On a polished surface, this type of corrosion is first seen as a general dulling of the surface and, if allowed to continue, the surface becomes rough and possibly frosted



in appearance. The discoloration or general dulling of metal created by its exposure to elevated temperatures is not to be considered as uniform etch corrosion. The use of chemical-resistant protective coatings or more resistant materials will control these problems.

**3.3.6 STRESS CORROSION CRACKING.** Stress corrosion cracking (SCC) is caused by the simultaneous effects of tensile stress and corrosion. Stress may be internally or externally applied. Internal stresses are produced by nonuniform deformation during cold working, by unequal cooling from high temperatures, and by internal structural rearrangement involving volume changes. Stresses induced when a piece is deformed, those induced by press and shrink fits, and those in rivets and bolts are internal stresses. Concealed stress is more important than design stress, especially because stress corrosion is difficult to recognize before it has overcome the design safety factor. The magnitude of the stress varies from point to point within the metal. Stresses in the neighborhood of the yield strength are generally necessary to promote SCC, but failures have occurred at lower stresses. A few guides in avoiding the problem are:

- a. Use metal alloys at no greater than 75 percent of their yield strength and use exotic materials only where they are actually required.
- b. Avoid assemblies where high-tensile loads are concentrated in a small area.
- c. Place surfaces under compressive stresses where feasible, by shot-peening, sandblasting, etc.
- d. Remove stress risers from counter bores, grooves, etc.
- e. Metals shall be selected from alloys that are highly resistant to SCC as specified in KSC-STD-Z-0004.

**3.3.7 FATIGUE CORROSION.** Fatigue corrosion is a special case of stress corrosion caused by the combined effects of cyclic stress and corrosion. No metal is immune from some reduction of its resistance to cyclic stressing if the metal is in a corrosive environment. Damage from fatigue corrosion is greater than the sum of the damage from both cyclic stresses and corrosion. Fatigue corrosion failure occurs in two stages. During the first stage, the combined action of corrosion and cyclic stresses damages the metal by pitting and crack formation to such a degree that fracture by cyclic stressing will ultimately occur, even if the corrosive environment is completely removed. The second stage is essentially a fatigue stage in which failure proceeds by propagation of the crack and is controlled primarily by stress concentration effects and the physical properties of the

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metal. Fracture of a metal part due to fatigue corrosion generally occurs at a stress far below the fatigue limit in laboratory air, even though the amount of corrosion is extremely small. For this reason, protection of all parts subject to alternating stress is particularly important wherever practical, even in environments that are only mildly corrosive.

**3.3.8 FRETTING CORROSION.** The rapid corrosion that occurs at the interface between contacting, highly loaded metal surfaces when subjected to slight vibratory motions is known as fretting corrosion. This type of corrosion is most common in bearing surfaces in machinery, such as connecting rods, splined shafts, and bearing supports, and often causes a fatigue failure. It can occur in structural members such as trusses where highly loaded bolts are used and some relative motion occurs between the bolted members. Fretting corrosion is greatly retarded when the contacting surfaces can be well lubricated as in machinery-bearing surfaces so as to exclude direct contact with air.

**3.3.9 CREVICE CORROSION.** Crevice or contact corrosion is the corrosion produced at the region of contact of metals with metals or metals with nonmetals. It may occur at washers, under barnacles, at sand grains, under applied protective films, and at pockets formed by threaded joints. Whether or not stainless steels are free of pit nuclei, they are always susceptible to this kind of corrosion because a nucleus is not necessary. Crevice corrosion may begin through the action of an oxygen concentration cell and continue to form pitting. Contact or crevice corrosion occurs when surfaces of metals are used in contact with each other or with other materials and the surfaces are wetted by the corrosive medium or when a crack or crevice is permitted to exist in a stainless-steel part exposed to corrosive media. Cleanliness, the proper use of sealants, and protective coatings are effective means of controlling this problem.

## SECTION IV CORROSION REMOVAL AND TREATMENT

### 4.1 GENERAL

This section describes typical corrosion removal and treatment for various materials. To provide optimum protection from corrosion, the proper coating systems must be selected for a specific application. The selection of the proper coating system depends on the material to be coated, service conditions, required service life, and surface preparation possible. Consult KSC-STD-C-0001 for recommended coating systems for aluminum.

### 4.2 ALUMINUM AND ALUMINUM ALLOYS

**4.2.1 GENERAL.** Aluminum alloys as a class are normally very resistant to outdoor exposure conditions. However, they are anodic to most common alloys in many aqueous solutions. Thus, galvanic attack is likely to occur on aluminum items in contact with dissimilar metals.

A common type of corrosion attack of aluminum alloys is pitting and crevice corrosion. Under certain conditions, these alloys are susceptible to intergranular corrosion, exfoliation, and stress-corrosion cracking.

Corrosion on aluminum alloys can be removed by first cleaning oil and dirt from affected surfaces and then removing the corrosion by mechanical methods or by use of a corrosion-removing chemical treatment. After cleaning and corrosion removal, the item should be protected against further corrosion by application of a suitable paint system. Acceptable procedures are described below.

**4.2.2 CLEANING TO REMOVE FOREIGN MATTER.** Remove foreign matter with a cleaner in accordance with MIL-C-87936, type I.

Aluminum alloys shall be cleaned using a cleaning compound conforming to MIL-C-87936, type I. The following mixing concentrations are suggested:

- a. Light soil (dirt, dust, mud, salt): 1 part compound, 9 parts water
- b. Moderate soils (hydraulic fluid, lube oils, light preservatives): 1 part compound, 4 parts water
- c. Heavy soils (carbonized oil, grease, aged preservatives, exhaust deposits): 1 part compound, 1 part water

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Apply the solution by spraying or with a mop, sponge, or brush. Allow to remain on the affected surface for several minutes while agitating with a brush. Rinse thoroughly with water. Do not allow compound to dry before rinsing with running water since poor cleaning may result.

**4.2.3 CORROSION REMOVAL.** Remove corrosion by mechanical method such as wire brushing or abrasive blasting as appropriate. Failure to adequately clean all residues will permit corrosion to continue. Light corrosion may be removed from thin members, such as ducts and tubing, with a nonwoven, nonmetallic abrasive mat in accordance with MIL-A-9962, or number 400 aluminum oxide or silicon carbide grit abrasive paper or cloth. Do not use steel wool. Stainless-steel brushes having bristles not exceeding 0.25 mm (0.010 inch) in diameter may be used provided surfaces are finally polished with number 400-grit abrasive paper followed by 600-grit abrasive paper. Dry abrasive blasting with fine abrasives in accordance with KSC-STD-C-0001 is also an acceptable method of removing corrosion products when surfaces will subsequently be painted and where dimensional tolerances are not critical. All abrasive residues should be thoroughly removed using high-pressure clean air or running water. Never use carbon steel wool or wire brushes since particles from these materials may become imbedded in the aluminum surface causing galvanic corrosion problems.

Chemical corrosion removal compounds, such as Pasajell 102 or 105V, or approved equal, may be used in accordance with the manufacturer's printed instructions. Care must be taken when using these materials to prevent exposure of adjacent surfaces.

**4.2.4 SURFACE TREATMENT.** Corrosion protection may be provided by application of a chemical conversion coating or a protective paint system. Where possible, the protective paint system should be used since it affords greater corrosion protection than the chemical conversion coating.

**4.2.4.1 Application of Chemical Conversion Coating.** In areas where corrosion protection is required and a paint system would be objectionable, apply by brush or dipping a chemical conversion coating in accordance with MIL-C-5541. Most materials in accordance with MIL-C-5541 leave a stain. Where a bright metal finish is required, one can specify a clear coating to that specification. Surfaces to be treated must be clean and dry before the conversion coat is applied.

The conversion coating is a toxic chemical and requires that personnel wear rubber gloves when applying the coating. If acid accidentally contacts the skin or eyes, flush immediately with clear water. Do not permit MIL-C-5541 materials to contact paint thinner, acetone, or other combustible materials. Fire may result. The solution should be mixed in a stainless steel, rubber, or plastic container (not

in lead, copper alloy, or glass). Mix in accordance with the manufacturer's instructions. Apply to clean and dry surfaces using a fiber bristle brush or a clean soft cloth. Keep the surface wet with the solution until a coating is formed (1 to 5 minutes depending on the metal surface condition). Do not permit the MIL-C-5541 material to dry because the residue is difficult to flush off, and poor paint adhesion may result if paint is subsequently applied. Misapplication resulting in over conversion will require complete removal and reapplication to produce adequate protection with this material.

**4.2.4.2 Application of Paint System.** All painting of aluminum in the various zones of exposure shall be performed in accordance with the applicable paragraphs in KSC-STD-C-0001.

**4.2.5 CONTACT WITH DISSIMILAR MATERIALS.** Aluminum alloy parts in contact with or fastened to steel members or other dissimilar materials shall be kept from direct contact with the steel or other dissimilar material as follows:

Aluminum surfaces to be placed in contact with steel shall be given a pretreatment in accordance with DOD-P-15328 (wash primer) or MIL-C-5541 (chromate conversion coating) followed by an inhibited polyamide epoxy primer in accordance with KSC-STD-C-0001. An alternate approach would be to apply the pretreatment as above and assemble components with MIL-S-29574, type II, sealing compound. Where severe corrosion conditions are expected, additional protection can be obtained by applying sealing compound in addition to using the inhibited epoxy primer. Primer should be allowed to cure 24 hours prior to assembly of components. Steel surfaces should be coated with a zinc-rich primer in accordance with KSC-STD-C-0001.

Aluminum in contact with wood, concrete, or masonry construction should be given a heavy coat of coal-tar epoxy or epoxy mastic in accordance with KSC-STD-C-0001 before installation. Aluminum surfaces to be imbedded in concrete shall be coated with coal-tar epoxy or epoxy mastic, or shall be wrapped with plastic tape in accordance with MIL-T-23142 applied in such a manner as to provide adequate protection at the overlap.

### **4.3 CARBON STEEL AND LOW-ALLOY STEEL**

**4.3.1 GENERAL.** Ferrous alloys are commonly used construction materials. If the metal is not protected, it will corrode readily in the marine acidic environment at KSC. KSC-STD-C-0001 defines detailed requirements for protecting carbon steel. It defines basic requirements for surface preparation and acceptable protective coatings.

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**4.3.2 CLEANING TO REMOVE FOREIGN MATTER.** If the corroded area is soiled by foreign materials such as grease or dirt, the surfaces must be cleaned before stripping paint or removing corrosion. Surfaces may be cleaned in accordance with SSPC SP-1.

**4.3.3 PAINT STRIPPING (WHEN REQUIRED).** Residual paint or primer may be removed by mechanical or chemical treatment after cleaning surfaces.

**4.3.3.1 Chemical Paint Stripping.** Readily accessible areas may be stripped with thickened stripper in accordance with TT-R-248. Less accessible areas may be stripped with ethyl acetate in accordance with TT-E-751 and lacquer thinner in accordance with TT-T-266.

**4.3.4 CORROSION REMOVAL.** Abrasive blasting is the preferred method of removing corrosion; other mechanical methods (SSPC SP-2 or SSPC SP-3) that may be used are grinding, chipping, sanding, or wire brushing. Chemical corrosion removal may be used when there is no danger of the chemical becoming entrapped. The chemical method should be used on complex shapes and machined surfaces. Chemical rust removers are of two types: acid or alkaline. The acid type can be used in removing rust and black oxide by immersion or brush application. This phosphoric-acid-type remover must not be used on high-strength steel heat treated above 1.24 gigapascals (GPa) [180,000 pounds per square inch (psi)] tensile strength because of possible stress corrosion or hydrogen embrittlement problems. The alkaline type (sodium hydroxide base) is suitable for use by immersion only. It is preferred for use on machined surfaces where a dimensional change would be objectionable.

**4.3.4.1 Phosphoric Acid Base (Brush-On Method).**

- a. Remove foreign matter by a method described previously (SSPC SP-1).
- b. Remove heavy corrosion products by an appropriate mechanical method.
- c. Add one part of MIL-C-10578, type III, solution to one part of water by volume. Always add the acid to water.
- d. Apply the solution to the corroded surface with a brush. Allow the solution to remain on the surface for 2 to 20 minutes, depending on the severity of the rusting.

- e. If available, rinse thoroughly with hot water; otherwise, cold water may be used.
- f. Dry the part quickly and thoroughly and immediately apply a protective coating or corrosion preventive.

#### 4.3.4.2 Phosphoric Acid Base (Immersion Method).

- a. Remove foreign matter by a method described previously (SSPC SP-1).
- b. Remove heavy corrosion products by an appropriate mechanical method.
- c. Add one part of MIL-C-10578, type III, solution to one part of water by volume. Always add the acid to water.
- d. Immerse parts while agitating for sufficient duration to remove the rust. The solution may be warmed to 60 °C (140 °F) to accelerate corrosion removal.
- e. If available, rinse thoroughly with hot water; otherwise, cold water is acceptable.
- f. Dry the part quickly and thoroughly and immediately apply protective coating or corrosion preventive.

#### 4.3.4.3 Alkaline Corrosion Remover (Immersion Method).

- a. Remove grease and loose corrosion products.
- b. Prepare rust remover by mixing the chemical (MIL-C-14460) in accordance with the manufacturers' instructions.
- c. Immerse for sufficient time to remove the rust. The solution may be heated up to the boiling point to increase the rate of corrosion removal.
- d. Rinse in water, preferably hot.
- e. Dry the part thoroughly and immediately apply the protective coating or corrosion-preventive compound.

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#### 4.4 STAINLESS-STEEL ALLOYS

**4.4.1 GENERAL.** Stainless steels owe their inherent corrosion resistance to a condition known as passivity, which is a result of the presence of their oxide films called "passive films." Under favorable conditions, such films are protective; however, unfavorable conditions deficient in oxygen will destroy the films and leave the surface in an "active" state with corrosion resistance comparable to carbon steel. The presence of hygroscopic salt deposits, dirt, dust, and other foreign matter all serve to destroy passivity. Underground exposure of bare stainless steel will result in unacceptable corrosion damage. Consult KSC-STD-C-0001 for coating systems for underground exposure. Under circumstances where localized corrosion occurs, rapid penetration (pitting corrosion) at the point of initiation can occur because an active-passive electrolytic cell is formed between the large cathodic (passive) area and the small anodic area under attack. Attack is particularly severe in the presence of halide salts. Localized attack will also occur in crevices, such as under sleeves on tube fittings.

Superior resistance to pitting is attainable with type 904L unified numbering system (UNS) N08904 stainless steel over other commonly used steels. However, this is only a matter of degree and localized attack can still occur. Maintaining clean surfaces will greatly reduce the opportunity for corrosion, regardless of which alloy is employed.

**4.4.2 CLEANING TO REMOVE FOREIGN MATTER.** Where foreign materials are present on a corroded surface, they must be removed before stripping paint or removing corrosion products. Surfaces should be cleaned in accordance with SSPC SP-1.

#### 4.4.3 CORROSION REMOVAL.

**4.4.3.1 Mechanical Method.** When paint is present, it must be removed prior to corrosion removal by mechanical or chemical means as appropriate. Abrasive blasting shall be used only when a final protective coating will be applied. When mechanical corrosion and paint removal methods other than abrasive blasting are used and a fine finish is required, the treated area shall be polished as a final operation, first with 400-grit emery cloth and then with 500-grit cloth. When a very fine finish is required, 600-grit emery cloth shall be used.

**4.4.3.2 Chemical Method.** Chemical corrosion-removal methods can be used when no danger exists that the chemical being used will become entrapped in recesses and when there is no danger that adjacent materials will be attacked. After cleaning in accordance with 4.4.2, surfaces shall be treated with MIL-C-10578, Type I, II, or III.



Type I (wash off) shall be used when treatment can be by immersion and when a protective coating is to be applied. Stainless-steel brushes or stainless-steel wool may be used to assist in removing corrosion products. The solution should be permitted to remain on long enough to remove rust (2 to 10 minutes) and to lightly etch the surface to promote paint adhesion.

Type II (wipe off) shall be used when treatment is done in the field. The solution may be applied by brush, rag, sponge, or stainless-steel wire brush or stainless-steel wool. The compound should be permitted to remain on the metal surface for approximately 2 to 5 minutes. Residue should be removed with damp rags followed with dry rags.

**4.4.3.2.1 Scale Conditioning.** Scale conditioners may be used as necessary to facilitate oxide scale removal by acid cleaning. The use of scale conditioners shall not cause pitting, intergranular attack, or reduction of mechanical properties below the minimum values as specified in the applicable material specification for the alloy, gage, and heat-treat condition.

**4.4.3.2.2 Acid Cleaning.** When acid cleaning is used to remove heat-treat scale, flux, corrosive media, stains, and other contaminants, it shall be within the limits specified herein. Acid cleaning shall not result in intergranular attack that would be detrimental to the fabrication or use of the material or part. Intergranular attack shall be considered detrimental when it completely surrounds the surface grains and is in an interconnected pattern along with the surface, either continuous or semi-continuous. Evidence of grain boundary attack, exhibited in localized areas, which does not completely surround the grains and is not in an interconnected pattern, shall not be considered detrimental. Acid cleaning shall not result in pitting or smutting, which will not be readily removed by subsequent processing, nor shall it reduce the mechanical properties below the minimum values as specified in the applicable material specification for the gage, alloy, and heat-treat condition. Acid cleaning shall be accomplished in the following bath:

- a. Nitric acid ( $\text{HNO}_3$ ) (42° Baumé): 225 to 375 kilograms per cubic meter ( $\text{kg}/\text{m}^3$ ) [30 to 50 ounces per gallon (oz/gal) weight]
- b. Hydrofluoric acid (HF) (ammonium bifluoride,  $\text{NH}_4\text{HF}_2$  may be used in lieu of HF): 9 to 52  $\text{kg}/\text{m}^3$  (1.2 to 7.0 oz/gal) (weight)
- c. Temperature: room 60 °C (140 °F)
- d. Metal content, HF ratio (replenish bath when the metal concentration exceeds 1 part of metal to 1.8 parts of HF): 1:1.8

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**4.4.4 APPLICATION OF PROTECTIVE COATING.** Stainless-steel components should be painted in accordance with the requirements in KSC-STD-C-0001. When severe corrosive conditions are anticipated in zones 4 and 5, protective coatings should be applied. A protective coating should be selected that is compatible with the corrosive environment.

**4.5 COPPER AND COPPER-BASE ALLOYS**

Protective coatings are normally not required for copper and copper-base alloys because of their inherent corrosion resistance. The green tarnish commonly noted on copper alloys does not normally affect its performance characteristics. The green patina actually provides corrosion protection to the base metal. However, copper-based materials should be protective coated in highly acidic conditions such as the Shuttle launch zone.

**4.6 PLATED SURFACES**

**4.6.1 GENERAL.** Metal parts are usually plated to increase corrosion resistance (for appearance) or to develop special surface properties such as abrasion or wear resistance. Some coatings are anodic to the underlying surface while others are cathodic. Coatings that are anodic to the base metal corrode preferentially thereby protecting the underlying metal. Examples of such plated coatings are zinc and cadmium on steel. Cadmium plating is no longer recommended and should be totally avoided due to both environmental and technical concerns. Use zinc plating in accordance with KSC-STD-C-0001 (galvanizing) or ion vapor deposition (IVD) aluminum in accordance with MIL-C-83488, Class 1 where possible. Cathodic coatings include tin, copper, chromium, silver, gold, and nickel on steel. These cathodic coatings accelerate the corrosion of the underlying material if a break in the film develops and an electrolyte is present.

**4.6.2 CLEANING TO REMOVE FOREIGN MATTER.** If the corroded area is soiled by foreign materials such as grease or dirt, the surfaces must be cleaned before stripping paint or removing corrosion. Surfaces may be cleaned with an alkaline water base cleaner in accordance with MIL-C-87936.

**4.6.3 PAINT STRIPPING (WHEN REQUIRED).** Residual paint or primer may be removed by mechanical or chemical treatment after cleaning surfaces.

**4.6.4 CORROSION REMOVAL AND TREATMENT OF PLATED SURFACES.**

**4.6.4.1 Zinc- and Aluminum-Plated Surfaces.** If requirements do not permit application of a final protective finish to the affected surfaces, special care shall be taken to avoid unnecessary removal of the plating. This is particularly true for

zinc- and aluminum-plated surfaces since they are very soft and, hence, are easily removed by abrasive methods.

Corrosion products may be removed with fine abrasive paper, followed by treatment with phosphoric acid base rust remover in accordance with MIL-C-10578. The solution should contact the affected surfaces only long enough to remove the corrosion. Type I should be used when the surfaces can be rinsed off with water, preferably hot, after application. Type II should be used when rinsing is not possible. Apply by brush, rag, or sponge. Allow the compound to remain on the metal surface about 30 seconds. Wipe off residue first with damp rags and then with dry rags.

**4.6.4.2 Chromium, Nickel, Copper, and Tin Plate.** Treat in accordance with 4.6.4.1 when a protective coating can be applied. Where a coating cannot be applied, surfaces should be protected when possible by coating with a thin film of preservative compound such as Cortec VCI-368 available from Cortec Corporation, 4119 White Bear Parkway, St. Paul, MN 55110 [(612) 429-1100]. Where no protection can be provided, surfaces should be cleaned frequently to remove foreign matter.

## SECTION V TREATMENT OF TYPICAL AREAS

### 5.1 GENERAL

This section describes the safeguards, treatments, and methods of corrosion protection for specific items used at KSC.

### 5.2 COMMUNICATIONS, ELECTRONIC, AND ASSOCIATED ELECTRICAL EQUIPMENT

**5.2.1 GENERAL.** Moisture normally enters components or enclosures as rain or condensate. Condensate can enter a system even though the system is rainproof. Condensate enters nonairtight components in the form of moist air. During the daily temperature cycle, the ambient temperature rises to a peak and causes an expansion of air inside the components and thereby drives part of the air from the enclosures. As the temperature falls, the air within the components cools and contracts, which causes air from the atmosphere to be drawn into the enclosures. If this air is moist and if the temperature of the components drops to the dew point during the temperature cycle, a film of moisture is deposited on the inside of the components. If the enclosure is sealed enough to be waterproof, evaporation of the deposited moisture cannot occur when the temperature rises during the daily cycle. Moisture will therefore accumulate as a result of many temperature cycles. Experience has shown that serious problems, such as corrosion, fungus growth, changes in electrical characteristics, and shorting, can occur as a result of the accumulated moisture.

Preventive procedures for controlling moisture problems include hermetically sealing, application of a conformal coating, pressurizing with dry gas, ventilation of enclosed areas, use of desiccants, use of volatile corrosion inhibitors, potting of electrical connectors, heating to prevent cycling to the dew point, providing static and dynamic dehumidification systems, and providing adequate drain holes to prevent moisture accumulation. Each problem must be inspected to determine the most practical preventive procedure to follow. However, certain procedures and preventive measures are common to most moisture problems and can be readily performed. This includes potting, sealing, and fungusproofing using a conformal coating.

**5.2.2 ENCLOSURES PURGED FOR HAZARD PROTECTION.** Electronic equipment will usually deteriorate rapidly if subjected to conditions of high humidity. Because of requirements for purging of electronic equipment during hazardous periods (when gaseous hydrogen may be present), such equipment must be provided with airtight seals. Since it is practically impossible to make an

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enclosure completely airtight, moisture can accumulate within the equipment due to "breathing" during periods when the purge is not in operation. Under these conditions, moisture can enter the enclosures more readily than it can escape. Because of wide temperature variations and frequent high humidity, moisture can accumulate to the point where it becomes discernible as standing water. This standing water and 100-percent relative humidity within the enclosure tend to accelerate the corrosion and deterioration of many materials. If this moisture can be reduced, the reactions resulting in deterioration are reduced. When lowered below a limiting amount, the reactions cease.

**5.2.3 ENCLOSURES INTERMITTENTLY PURGED FOR HAZARD PROTECTION.** Equipment that is purged with gaseous nitrogen ( $\text{GN}_2$ ) or dry air during hazardous periods when hydrogen may be present is suitably protected during this period of time. During periods when the purge is not operating, the equipment should be protected from corrosion by employing one or more of the following steps, as determined to be the most appropriate:

- a. Purge continuously with dry air or  $\text{GN}_2$  rather than just during hazardous periods. Purging during nonhazardous periods may be intermittent on a daily basis to conserve purge gas. That is, for periods when the ambient temperature is increasing or is remaining constant, no purge would be required. The purge would be activated when the ambient temperature is decreasing to avoid drawing in moist air.
- b. Provide static pressurization.
- c. Install strip heaters to maintain the temperature within the equipment always higher than the external temperature.
- d. Replace unsuitable materials of construction with materials more resistant to corrosion and use protective coatings and potting wherever practical.
- e. Install controllable vents and drains.
- f. Relocate portable equipment to a controlled atmosphere for storage when possible.
- g. Provide static or dynamic dehumidification systems.
- h. Provide sufficient amount of desiccants within the equipment enclosure during periods of nonpurging.

- i. **Attach a breather cartridge containing desiccant to each fitting otherwise used for purging or venting.**
- j. **Install volatile corrosion-inhibitor cartridges on interior to protect metallic surfaces.**

**5.2.4 ENCLOSURES NOT PURGED FOR HAZARD PROTECTION.** Equipment not required to be purged for hazard protection should be protected by application of one or more of the following corrective measures as required:

- a. **Purge continuously or intermittently on a daily basis with dry air or GN<sub>2</sub>.**
- b. **Static pressurization with dry air or GN<sub>2</sub>.**
- c. **Replace corroded components with more corrosion-resistant materials, apply protective coatings, and pot electrical connectors when possible.**
- d. **Install dynamic or static dehumidification systems.**
- e. **Move equipment to a controlled environment for storage when possible.**
- f. **Install vents and drains.**
- g. **Protect during bad weather or inactive periods by use of covers that allow free ventilation.**
- h. **Provide sufficient amount of desiccants within the equipment enclosure during periods of nonpurging.**
- i. **Attach a breather cartridge containing desiccant to each fitting otherwise used for purging or venting.**
- j. **Install volatile corrosion-inhibitor cartridges on interiors to protect metallic surfaces.**

**5.2.5 COATING OF COMMUNICATIONS, ELECTRONIC, AND ASSOCIATED EQUIPMENT.** An effective method of preventing corrosion of external surfaces of electrical components is by treatment with moisture- and fungus-resistant conformal coating in accordance with KSC-SPEC-E-0001. Coating materials to this specification has been proven by experience to be effective in minimizing corrosion and preventing fungus growth.

### CAUTION

Coating should not be applied indiscriminately to electrical equipment. It should be applied in accordance with engineering drawings or as directed by the electrical manufacturer.

**5.2.5.1 Items To Be Treated.** The coating should be applied thoroughly and completely to all moisture and fungus susceptible surfaces such as circuit elements (resistors, capacitors, coils, etc.), surfaces supporting circuit elements, interconnecting wiring, and connections. To determine if the coating has been applied previously, surfaces may be examined with an ultraviolet lamp. Since these thin KSC conformal coatings contain a fluorescent dye, void areas or defects in the coating can be readily detected when inspected under ultraviolet or "black light."

**5.2.5.1.1 Preparation for Treatment.** Equipment to be treated shall be exposed so the coating may be applied effectively over the surfaces to be treated. On assemblies, the cases, cans, covers, shields, etc., shall be removed in order to expose the surfaces fully. Where practical, untreated cables and cords shall be bent back, and untreated terminal boards shall be loosened to expose the underside.

**5.2.5.1.2 Cleaning Before Treatment.** All surfaces to be treated shall be cleaned free from dirt, oil, grease, or other foreign matter that would interfere with the adhesion of the coating. All visible deposits of solder flux shall be cleaned off by scraping, chipping, wiping, or by use of a suitable solvent. Solvents may be used only on readily accessible surfaces that must be dried immediately by wiping clean. Solvents that will soften enamels or cause swelling of insulation, such as ketones, esters, and aromatic hydrocarbons, shall not be used.

**5.2.5.1.3 Drying Before Treatment.** Coating shall be applied only on dry surfaces. Equipment should be dried when obviously wet or damp or when humidity is very high. Drying shall be accomplished at a temperature safely below that which may damage the equipment and at a rate which will not cause shrinking, cracking, warping, or other deterioration. If there are waxed parts in the equipment, drying temperature shall not exceed 60 °C (140 °F). When possible, the coating shall be applied while the temperature of the equipment is at least 5 °C (9 °F) above the room temperature. Time at 60 °C (140 °F) should not be longer than 3 hours.

**5.2.5.1.4 Methods of Treatment.** Coating may be applied by spraying, brushing, dipping, or any combination thereof.

- a. **Spraying.** When spraying is used to apply the coating, a pressure pot spray gun with a tip regulated to give a wet spray shall be used; for small compact equipment, a pencil spray tip regulated to give a narrow wet spray shall be used. The coating shall be applied in a wet coat. A dry spray that forms spray dust shall not be used. Surfaces shall be sprayed from as many directions and angles as necessary to ensure complete coverage with a wet coat. All parts requiring coverage not accessible to the overall spray shall be coated with a brush.
- b. **Brushing.** Brushing shall be used when application by spraying or dipping would require extensive protection of surfaces not to be coated.
- c. **Dipping.** Dipping may be used where that method is advantageous.

**5.2.5.1.5 Repairs to Damaged Conformal Coating.** If the coating is broken during adjustment, handling, or replacement of parts, such breaks shall be recoated. Re-soldering of wire connections shall be done only after cleaning the ends of wire and terminals to remove the old coating. After re-soldering, connections shall be recoated.

**5.2.5.1.6 Inspection.** To determine completeness of coverage, treated equipment can be examined for fluorescence under an ultraviolet lamp having a filtered emission of approximately 360 nanometers; coated areas will glow.

**5.2.5.2 Items Not To Be Treated With Conformal Coating.** Coating should not be applied to any surface or part where the treatment will interfere with the operation or performance of the equipment. Such surfaces or parts shall be protected against the application. The following are examples of items and materials that shall be protected.

- a. Cable, wire braids, and jackets flexed in operation and cable with plastic insulation where treatment would reduce the insulation resistance below or increase the loss factor above the acceptable values.
- b. Components and materials such as:
  - (1) Capacitors, variable, (air-, ceramic-, or mica-dielectric).
  - (2) Resistors (when wattage dissipation would be undesirably affected and when coating may become carbonized).



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- (3) Wirewound resistors.
  - (4) Ceramic insulators subject to over 600 volts operating voltage where danger of flashover exists.
  - (5) Painted, lacquered, or coated surfaces, unless otherwise specified.
  - (6) Rotating parts such as dynamotors, generators, motors, etc. However, their associated electronic components, such as filter units, etc., shall be treated.
  - (7) Waveguides (working surfaces).
  - (8) Electron tubes.
  - (9) Tube clamps.
  - (10) Miniature tube shields.
  - (11) Plug-in relays.
  - (12) Pressure-contact grounds.
  - (13) Coaxial test points or receptacles.
  - (14) Windows, lenses, etc.
  - (15) Transparent plastic parts.
  - (16) Plastic materials of the following types that might be sensitive to the cleaning solvent or coating: polyethylene, polystyrene, acrylic, silicone, fluorosilicon, or fluorocarbon, vinyl, or alkyd.
  - (17) Materials used for their specific arc-resistant properties and classified as "arc resistant" in applicable material specifications, such as mounting boards of a type material where treatment would reduce the insulation resistance below (or increase the loss factor above) the acceptable values and decrease the arc-resistant value of the board.
- c. Organic materials that have otherwise been protected, such as bottoms of plastic skids (cotton fabric-phenolic resin), canvas, duck, cork,

- felt (wool or hair), fiber, leather, rope, wood, natural or synthetic rubber, etc., except that the materials need not be protected from treatment provided the operation and performance of the equipment are not adversely affected.
- d. Electrical contacts, contact portions, or mating surfaces of binding posts, connectors, fuses, jacks, keys, plugs, relays sockets (including tube sockets), switches, and test points.
  - e. Mechanical parts such as:
    - (1) Bearing surfaces (including bearing surfaces of gaskets and sliding surfaces).
    - (2) Gear teeth and gear trains or assemblies.
    - (3) Pivots and pivot portion of hinges, locks, etc.
    - (4) Screw threads and screw adjustments (those moved in the process of operation or adjustment).
    - (5) Springs.
  - f. Surfaces that rub together for electrical or magnetic contact, such as those in bearings, contact fingers, potentiometers, shafts, shields, and variable autotransformers.
  - g. Surfaces whose operating temperatures exceed 130 °C (266 °F) or whose operating temperatures will cause carbonization or smoking.
  - h. The exterior or visible outside portion of indicating instruments (do not open or treat inside).

**5.2.5.2.1 Methods of Protection From Coating.** Items that are not to be coated may be protected by the use of any suitable method or device, such as masking tapes, maskants, metals, cardboard, Teflon jigs, fixtures, or spray masks. Tapes should be tested before use since some are adversely affected by the cleaning or coating solvent.

## **5.2.6 ELECTRICAL CONNECTORS.**

**5.2.6.1 Potting and Molding.** Electrical connectors shall be potted and/or molded to their associated cable where possible in accordance with KSC-STD-132.

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5.2.6.2 Lubricating Connectors. A suitable lubricant should be used to effect a good mating of connectors and to prevent chaffing and scraping of coated surfaces. The lubricant shall not affect the electrical characteristics of the circuits nor attack any components of the connectors.

### 5.3 CARBON STEEL STRUCTURES

5.3.1 GENERAL. KSC-STD-C-0001 defines the detailed requirements for surface preparation and coating of carbon steel.

Inorganic zinc-rich coating applied over abrasively blasted steel is the basic coating for corrosion protection of carbon steel at KSC. Surfaces that exhibit localized breakdown shall be promptly cleaned and touched-up in accordance with KSC-STD-C-0001.

#### 5.3.2 TYPICAL PROBLEM AREAS.

5.3.2.1 Sharp Edges. Sharp edges of metal structures will often be deficient of proper coating thickness. Sharp edges should be rounded when possible in accordance with the National Association of Corrosion Engineers (NACE), although this may not be practical in many instances. In these cases, extra care must be taken to ensure adequate film build on edges. A stripe coat or brush coat of primer prior to spray application will assist in obtaining adequate coverage.

5.3.2.2 Back-To-Back Structures (Faying Surfaces). Such structures are inaccessible for proper coating application and should be avoided. To preclude moisture entry, such faying surfaces should be seal welded.

5.3.2.3 Nuts and Bolts. Premature coating failure and corrosion on nuts and bolt heads are common. These failures can be reduced by conscientious surface preparation prior to application of a protective coating. A brush coat of primer prior to spray application will ensure adequate coverage.

Bolts that pass through dissimilar metals or have a history of exhibiting general corrosion or stress corrosion cracking or galling shall be coated before installation with compound Cortec VCI-368. Bolts and nuts should be specified as hot-dipped galvanized where possible.

5.3.2.4 Tubular Structural Steel. Water can enter a tubular structural member that appears to be watertight by "breathing" through minute defects. This water, if not detected and removed, can cause serious degradation. Tapping with a hammer and observing the ring has been proven to be an effective means of

determining if water is present. A more positive method is by use of ultrasonic inspection.

Where water is detected, it should be removed and the extent of corrosion damage should be determined. If corrosion is significant, internal surfaces should be treated by filling and draining with a volatile corrosion-inhibited lubricating oil in accordance with MIL-L-46000, grade 1. After treatment, all openings should be completely sealed.

**5.3.2.5 Water Traps.** Proper drainage shall be provided in sump or low areas by providing drain holes. Where such drain holes cannot be provided, consideration should be given to filling the pocket, if small, with sealing compound in accordance with MIL-S-8802.

**5.3.2.6 Unistrut Channels.** Use of unistrut channels should be avoided in exterior locations. When the exterior use of unistrut cannot be avoided, selection of appropriate material shall be utilized, such as stainless steel or fiberglass. Where corrosion is noted, the member shall be mechanically cleaned to remove corrosion products followed by application of a zinc-rich coating in accordance with KSC-STD-C-0001. Corroded unistrut should be examined for extent of damage. If the affected surface is inaccessible, the part should be replaced with appropriate material if corrosion is advanced.

**5.3.2.7 Tube Clamps.** Carbon steel clamps for interior applications are normally furnished either zinc-plated or painted. Stainless-steel clamps shall be used for all exterior applications. Corrosion at the interface between the stainless-steel tubing and the clamp can occur due to dissimilar metal and crevice corrosion. The corrosion of the clamp can hasten the corrosion of the stainless-steel tubing due to the presence of carbon steel corrosion products. Corrosion at the interface between tubing and clamps can be controlled by application of protective coatings. Protection should be provided by coating clamps with a thick coating 200 to 500 micrometers (8 to 20 mils) of epoxy or nylon applied by the fluidized bed process. Exterior exposed stainless-steel clamps shall also be coated by the fluidized bed process or alternatively may be coated with 75 micrometers (3 mils) minimum of Aerocoat AR-7 coating.

Fasteners shall be coated with Aerocoat AR-7 by dipping prior to assembly. Following assembly, additional coating shall be applied to exposed surfaces of the fastener as required to repair damage to the coating incurred during assembly. If the tubing that is clamped is not coated with a protective coating, supplementary corrosion protection should be provided by locally coating the contact surfaces between the tubing and the clamps with the Aerocoat AR-7 coating or approved nonconductive tape material.

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**5.3.2.8 Galvanized Steel.** Galvanized steel shall be coated in accordance with KSC-STD-C-0001 unless localized breakdown occurs. Where corrosion is noted, surfaces shall be treated and coated in accordance with KSC-STD-C-0001 with an inorganic zinc-rich coating.

#### **5.4 STAINLESS-STEEL COMPONENTS**

**5.4.1 GENERAL.** Stainless steel, although considered very corrosion resistant, is susceptible to localized corrosion (e.g., pitting, crevice corrosion, etc.) when exposed to a marine environment. A mistake frequently made is to conclude that the corrosion noted on stainless-steel tubing and bellows is only superficial. This conclusion is improperly reached when removal of external corrosion products leave the surface in a condition that appears almost like new except for what appears to be a very tiny pit. A cross section taken through such a typical pit frequently discloses a void considerably greater in diameter than the surface pit diameter. Thus, external appearance normally cannot be used to estimate pit depth. Failure to arrest the apparent superficial corrosion will result in ultimate penetration of thin wall members.

**5.4.2 STAINLESS-STEEL TUBING ASSEMBLIES.** Bare tubing assemblies exposed to the elements shall periodically be cleaned of superficial grime, oil, grease, and salt deposits using water followed by rinsing with a solvent such as methyl ethyl ketone. Frequency of cleaning shall be a minimum of once every 6 months. Should corrosion be noted, prompt action shall be taken to protect the material surfaces as described below.

**5.4.2.1 Application of Protective Coatings.** Tubing assemblies shall be treated as follows:

- a. Accumulated dirt and oil shall be removed by rinsing with water followed by rinsing with methyl ethyl ketone.
- b. Remove corrosion products by mechanical means, such as power tool cleaning in accordance with SSPC SP-3 or hand-tool cleaning in accordance with SSPC SP-2.
- c. Clean surfaces with methyl ethyl ketone using clean rags.
- d. Apply by spraying, brushing, or dipping 75 micrometers (3 mils) minimum of the coating Aerocoat AR-7 manufactured by B.F. Goodrich Aerospace and Defense Products, Vendor Code 03481. Application of this material shall be in accordance with KSC-STD-C-0001.

This material may be obtained from KSC Supply under Federal stock number 8030-00-485-3656.

**5.4.2.1.1 Tubing Assemblies That Will Be Abrasive Blasted.** When tubing assemblies are in close proximity to carbon steel structural members that are to be abrasive blasted and coated with inorganic zinc-rich primer, the tubing assemblies shall be similarly treated. The following procedure shall be used:

- a. Using clean rags, accumulated dirt and oil shall be removed with water followed by wiping with methyl ethyl ketone.
- b. Abrasive blast clean surfaces to be coated in accordance with SSPC SP-10.
- c. Apply a zinc-rich coating in accordance with KSC-STD-C-0001 in accordance with the manufacturer's recommendations to a dry-film thickness of 100 to 150 micrometers (4 to 6 mils).

**5.4.2.1.2 Welded and Brazed Joints.** Welded and brazed joints shall be given the same surface preparation and coated with the same coating as used on tubing.

**5.4.2.1.3 Flared Tube Fittings.**

**5.4.2.1.3.1 Permanent Installations.** Fittings exposed to the weather and not in enclosures shall be completely coated when associated tubing is coated. Coating material and surface preparation shall be the same as that used on the tubing. To prevent line contamination, fittings should not be coated until after assembly. Sufficient coating shall be applied to bridge all crevices to preclude moisture entry. When disassembly of a coated fitting is required and cleanliness of the line must be maintained, appropriate methods shall be employed to locally remove the coating as required prior to disassembly. Mechanical methods will be required to remove the zinc-rich primer. The Aerocoat AR-7 coating can be removed with methyl ethyl ketone solvent using clean rags.

**5.4.2.1.3.2 Fittings Within Enclosures.** Normally, coating of fittings within enclosures is not required. Where corrosion protection is required and the methods described above cannot be utilized, the metal surfaces should be cleaned frequently to remove surface contaminants.

**5.4.3 STAINLESS-STEEL BELLOWS.** Stainless-steel bellows that require protection from corrosion shall be treated in accordance with the method described for tubing in 5.4.2.1. Corroded stainless-steel bellows that require replacement

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shall be fabricated from an extremely corrosion-resistant material such as Hastelloy C-22.

**5.4.4 STAINLESS-STEEL PIPE, FLANGE BOLTS, AND NUTS.** Where supplementary corrosion protection of stainless-steel pipe, flange bolts, and nuts is required, they shall be coated with an inorganic zinc-rich coating in accordance with KSC-STD-C-0001. Where only protection of flange bolts and nuts is required, they shall be coated with 75 micrometers (3 mils) minimum of Aerocoat AR-7 coating. Surface preparation and treatment should be as described in 5.4.2.1 for stainless-steel tubing.

## **5.5 ALUMINUM ALLOY PIPE AND TUBING**

**5.5.1 GENERAL.** Aluminum pipe and tubing that is exposed to the natural environment (humidity extremes, rain, salt-laden air, acid fallout from boosters, etc.) shall be protected with an exterior paint system.

### **5.5.2 CORROSION TREATMENT.**

- a. Clean and condition tubing or pipe by an appropriate method outlined in section 4.
- b. Apply chemical conversion coating in accordance with MIL-C-5541 as a preparation for painting.
- c. Alternately apply one coat of wash primer in accordance with DOD-P-15328 followed by one coat of epoxy primer and one coat of polyurethane enamel in accordance with KSC-STD-C-0001. Where tolerances preclude paint coatings, a chemical conversion coating in accordance with MIL-C-5541 should be applied.
- d. Apply 75 to 125 micrometers (3 to 5 mils) Aerocoat AR-7 in the launch environment in accordance with KSC-STD-C-0001.

## **5.6 MISCELLANEOUS**

### **5.6.1 STEEL CABLING.**

If the surface of the cable is corroded, cable tension should be relieved and the interior of the cable visually examined. If internal corrosion is noted, the cable should be replaced. If internal corrosion is not detected, loose external rust should be removed with clean, dry rags or a fiber brush. Do not use metallic wools to clean cables since metal particles may become imbedded, thus creating other

corrosion problems. Solvents also should not be used as they will remove the internal cable lubrication, thereby allowing cable strands to abrade and further corrode. In questionable cases, a prooftest should be performed.

After thorough cleaning, apply grease in accordance with MIL-G-81322. Do not apply the grease too thick as it will interfere with the operation of cables at fairleads, pulleys, or grooved ballcrank areas.

**5.6.2 PIANO-TYPE HINGES.** This type of hinge is found on access doors. Frequently, the hinge assembly is made of dissimilar materials. Corrosion of this item can be controlled only by frequent lubrication and periodic actuation. Water displacing penetrating preservative in accordance with MIL-C-16173, grade 3, or Cortec VCI-368 is recommended. The hinge should be actuated during application of the preservative to ensure adequate penetration to all surfaces.

**5.6.3 ADJUSTABLE PARTS.** Threads of adjustable parts, such as tie-rod ends, turnbuckles, etc., shall be protected before and after assembly with corrosion preventative compound in accordance with MIL-C-16173, grade 4, or Cortec VCI-368.

**5.6.4 BARE METAL PISTON SURFACES.** Bare metal piston surfaces that require supplementary corrosion protection shall be coated with a thin film of preservative compound in accordance with MIL-C-16173, grade 2. When operational requirements preclude use of the preservative compound, surfaces should be cleaned frequently to remove foreign matter.



## APPENDIX A

## GALVANIC SERIES IN SEA WATER

Noble  
(least active)

Platinum  
Gold  
Graphite  
Silver

18-8-3 Stainless steel, type 316 (passive)

18-8 Stainless steel, type 304 (passive)

Titanium

13 percent chromium stainless steel, type 410 (passive)

more  
active

67NI-33Cu alloy



75NI-16Cr-7Fe alloy (passive)

Nickel (passive)

Silver solder

M-Bronze

G-Bronze

70-30 cupro-nickel

Silicon bronze

Copper

Red brass

Aluminum bronze

Admiralty brass

Yellow brass

76NI-16Cr-7Fe alloy (active)

Nickel (active)

Naval brass

Manganese bronze

Muntz metal

Tin

Lead

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**GALVANIC SERIES IN SEA WATER (cont)**

18-8-3 Stainless steel, type 316 (active)

18-8 Stainless steel, type 304 (active)

13 percent chromium stainless steel, type 410 (active)

Cast iron

Wrought iron

Mild steel



more  
noble

Aluminum 2024

Cadmium

Alclad

Aluminum 6053

Galvanized steel

Zinc

Anodic  
(most active)

Magnesium alloys

Magnesium