INTERNATIONAL

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Standard Practice for the Selection of Spacecraft Materials[1]

This standard is issued under the fixed designation E1997; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 The purpose of this practice is to aid engineers, designers, quality and reliability control engineers, materials specialists, and systems designers in the selection and control of materials and processes for spacecraft, external portion of manned systems, or man-tended systems. Spacecraft systems are very different from most other applications. Space environments are very different from terrestrial environments and can dramatically alter the performance and survivability of many materials. Reliability, long life, and inability to repair defective systems (or high cost and difficulty of repairs for manned applications) are characteristic of space applications. This practice also is intended to identify materials processes or applications that may result in degraded or unsatisfactory performance of systems, subsystems, or components. Examples of successful and unsuccessful materials selections and uses are given in the appendices.

1.2 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

E595 Test Method for Total Mass Loss and Collected Volatile Condensable Materials from Outgassing in a Vacuum Environment

G64 Classification of Resistance to Stress-Corrosion Cracking of Heat-Treatable Aluminum Alloys

2.2 *Marshall Space Flight Center (MSFC) Standard:*[3]

MSFC-STD-3029 Guidelines to the Selection of Metallic Materials for Stress Corrosion Cracking Resistance in Sodium Chloride Environments

2.3 *Military Standards:*[4]

MIL-STD-889 Dissimilar Materials

MIL-HDBK-5 Metallic Materials and Elements for Aerospace Vehicle Structures

MIL-HDBK-17 Properties of Composite Materials

2.4 *European Space Agency (ESA) Standard:*

PSS-07/QRM-0 Guidelines for Space Materials Selection[5]

2.5 *Federal Standard:*[4]

QQ-A-250 Aluminum and Aluminum Alloy Plate and Sheet, Federal Specification for

3. Significance and Use

3.1 This practice is a guideline for proper materials and process selection and application. The specific application of these guidelines must take into account contractual agreements, functional performance requirements for particular programs and missions, and the actual environments and exposures anticipated for each material and the equipment in which the materials are used. Guidelines are not replacements for careful and informed engineering judgment and evaluations and all possible performance and design constraints and requirements cannot be foreseen. This practice is limited to unmanned systems and unmanned or external portions of manned systems, such as the Space Station. Generally, it is applicable to systems in low earth orbit, synchronous orbit, and interplanetary missions. Although many of the suggestions and cautions are applicable to both unmanned and manned spacecraft, manned systems have additional constraints and requirements for crew safety which may not be addressed adequately in unmanned designs. Because of the added constraints and concerns for human-rated systems, these systems are not addressed in this practice.

4. Design Constraints

4.1 *Orbital Environment*—The actual environment in which the equipment is expected to operate must be identified and defined. The exposures and requirements for material performance differ for various missions. Environment definition

[1] This practice is under the jurisdiction of ASTM Committee E21 on Space Simulation and Applications of Space Technology and is the direct responsibility of Subcommittee E21.05 on Contamination.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For Annual Book of ASTM Standards volume information, refer to the standard's Document Summary page on the ASTM website.

[3] Marshall Space Flight Center, AL 35812, or everyspec.com.

[4] Available from U.S. Government Printing Office Superintendent of Documents, 732 N. Capitol St., NW, Mail Stop: SDE, Washington, DC 20401, http://www.access.gpo.gov.

[5] European Space Agency, 8–10, Rue Mario-Nikis, 75738 Paris Cedex, France.

includes defining the range of temperature exposure, number and rate of thermal cycles, extent of vacuum exposure, solar electromagnetic radiation particulate radiation, (trapped by the earth's magnetosphere, solar wind, solar flares, and gamma rays) micrometeroids, launch loads and vibration, structural loads, and so forth. Materials suitable for one orbit or mission environment may be unsuitable for others. The applications and requirements will define the suitability of the materials.

4.2 *Low Earth Orbit (Up to 100 km)*—Materials in this region could be exposed to trapped Van Allen belt (ionizing) radiation, solar ultraviolet radiation, corrosive attack by atomic oxygen (A.O.), and more frequent and more extreme thermal cycling and thermal shock as a result of frequent excursions into and out of the earth's shadow. Orbital impacts may be a problem because of the large amount of debris in low orbits. Design life in orbit typically is on the order of 5 to 15 years. Inclination of the orbit affects the service environment, that is, polar orbits have a different flight profile than equatorial orbits and have different profiles for radiation exposure.

4.3 *Synchronous Orbit (35 900 km)*—Materials in this region are not exposed to significant atomic oxygen or very high energy trapped radiation but may have more exposure to medium energy ionizing electrons and protons, solar flares, and relatively high levels of electromagnetic solar radiation (ultraviolet, VUV photons, and X-rays). The number of thermal cycles is less and may be over a narrower temperature range than low earth orbit. Meteoroids also should be considered but are less likely to be significant compared to the manmade debris found in low orbits. Design life in orbit typically is 5 to 15 years, with recent designs ranging from 10 to 17 years.

4.4 *Interplanetary (Out-of-Earth Orbit)*—In addition to the thermal extremes and environments of synchronous orbit, in the interplanetary environment, temperatures may be more extreme, and micrometeoroids, solar wind, and cosmic rays may be critical. Ability to survive and remain functional for many years is important. Probes to the inner plants typically have design lifetimes of 5 to 10 years. Those to the outer planets and beyond may have design lifetimes of 15 to 30 years.

5. Materials to Avoid

5.1 Certain materials are known to be undesirable and should be avoided no matter what the mission. Others are of concern for certain missions or of more concern for some missions than others. In general, it is recommended that one avoid the materials described below:

5.1.1 *Metals with High Vapor Pressure in Vacuum and Unusual Behaviors*—Avoid the use of metals such as mercury, cadmium, and zinc, either as plating or monolithic metals. It is important to exclude these metals both from the flight equipment and vacuum chambers. If these metals are used in vacuum and heated even moderately, they will vacuum metallize both the cold walls of the chamber and any cold surfaces on equipment in the chamber. Also, pure tin has the curious property of dendritic growth as a result of compressive stresses, or thermal or electrical gradients, forming whiskers which can cause shorts in electrical components or break off and become conductive contaminants. Some other metals such as cadmium and zinc have similar whisker-growing properties, but not to the extent that tin has. Since they can also grow whiskers, they should not be used.

5.1.2 *Stress-Corrosion Sensitive Metals*—Metals, which are stress-corrosion sensitive, should be avoided. Examples are 2024 T6 and 7075 T6 Aluminum, which can be used if heat treated to conditions, such as 2024 T81 and 7075 T73, which are not stress-corrosion sensitive. Many brasses and some steel alloys also are stress-corrosion sensitive; however, even alloys, which are stress-corrosion sensitive can be used if loaded in compression or if loaded to low sustained tensile stress levels, typically no more than 25 % of yield strength (see Classification G64 and MSFC-SPEC-522).

5.1.3 *Materials Forming Galvanic Couples*—Material combinations, which form galvanic couples greater than 0.5 ev when exposed to a temperature and humidity controlled environment, such as during fabrication, testing, and storage, should be prohibited under most circumstances. Providing protection from electrolytes and maintaining them in a controlled environment, such as during fabrication and testing, inhibits galvanic corrosion. Some alloys, such as magnesium, magnesium lithium alloys, and gold, form a galvanic couple with most common structural materials and must be protected adequately to prevent creating galvanic couples which cause the anodic metal to corrode. Carbon composites are included in the materials, which must be evaluated for galvanic potential, since carbon forms galvanic couples with metals. If there is no electrolyte present, galvanic couples greater than 0.5 ev are permissible. Galvanic protection can be obtained by preventing electrolyte from contacting the interfaces, interposing a dielectric material, or adding a material that is compatible with each of the other materials separately.

5.1.4 *Materials With Thermal or Environmental Limitations*—Materials that are weak or brittle at the expected service temperature or environment should be avoided. These materials included polymeric materials used at very low or very high temperatures and some metals used at low temperatures. In this context, "low" can be from -40 to -120°C and "high" can be from 150 to 200°C for polymers. Some materials are readily attacked by certain chemicals or solutions. For example, aluminum alloys should not be used in strongly basic or acidic environments. Steels, particularly high carbon and ferritic grades, are embrittled by halogens and hydrogen. Silicones are attacked by toluene. Titanium is attacked by methanol.

5.1.5 *Materials Difficult to Fabricate or Test*—Materials that are difficult to fabricate, form, test, or inspect, or do not have a history of consistency of properties or performance, should be avoided. Some materials, such as ceramics and most refractory metals, are relatively difficult to machine or form. Others are difficult to weld by conventional means. Some cannot be formed easily. Certain applications such as elevated temperature service may require use of ceramics or refractory metals. That should not reduce the need for careful review and functional design of the equipment. All materials must be very