INTERIM NASA TECHNICAL STANDARD	NASA-STD-(I)-6016
National Aeronautics and Space Administration Washington, DC 20546-0001	Approved: 09-11-2006 Expiration Date: 09-10-2007

STANDARD MATERIALS AND PROCESSES REQUIREMENTS FOR SPACECRAFT

MEASUREMENT SYSTEM IDENTIFICATION: INCHES-POUND/METRIC

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This document represents the technical consensus of the developing group but does not yet have final NASA approval.

DOCUMENT HISTORY LOG

Status	Document Revision	Approval Date	Description
Interim		09-11-2006	Interim Release

FOREWORD

This Interim Technical Standard is published by the National Aeronautics and Space Administration (NASA) to provide uniform engineering and technical requirements for processes, procedures, practices, and methods to meet urgent program and project technical needs. This interim standard has the consensus of the developing Technical Working Group but does not have Agencywide concurrence required for a NASA Technical Standard.

This interim standard may be cited in contract, program, and other Agency documents as a technical requirement. Mandatory requirements are indicated by the word "shall."

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

Original signed by:

09-11-2006

Christopher J. Scolese
NASA Chief Engineer

Approval Date

TABLE OF CONTENTS

TABLE OF CONTENTS, continued

SECTION **PAGE**

TABLE OF CONTENTS, continued

Standard Materials and Processes Requirements for Spacecraft

1. SCOPE

This document is directed toward Materials and Processes (M&P) used in the design, fabrication, and testing of flight components for all NASA manned, unmanned, robotic, launch vehicle, lander, in-space and surface systems, and spacecraft program/project hardware elements. All flight hardware is covered by the M&P requirements of this document, including vendor-designed, off- the-shelf, and vendor furnished items. Materials and processes used in interfacing ground support equipment (GSE); test equipment; hardware processing equipment; hardware packaging; and hardware shipment shall be controlled to prevent damage to or contamination of flight hardware.

1.1 Purpose

The purpose of this document is to define the minimum requirements for M&P and to provide a general control specification for incorporation in NASA program/project hardware procurements and technical programs

1.2 Applicability

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

These requirements may be tailored for specific programs/projects simply by constructing a matrix of applicable paragraphs and paragraphs that are not applicable, subject to approval by the responsible NASA M&P organization. Tailoring also includes using existing or previously developed contractor processes and standards as a submittal of the various required plans. Otherwise, the tailoring of requirements may be documented in the Materials and Processes Selection, Control, and Implementation Plan by providing the degree of conformance and the method of implementation for each requirement identified here.

When a contractor Materials and Processes Selection, Control, and Implementation Plan has been approved by the responsible program/project as an acceptable means of compliance with the technical requirements of this document, the plan may be used for the implementation and verification of M&P requirements on the applicable program/project.

This standard may be cited in contract, program, and other Agency documents as a technical requirement. Mandatory requirements are indicated by the word "shall." Tailoring of this standard for application to a specific program/project shall be approved by the Technical Authority for that program/project.

2. APPLICABLE DOCUMENTS

2.1 General

The documents listed in this section contain provisions that constitute requirements of this standard as cited in the text of section 4. The applicable documents are accessible via the NASA Technical Standards System at http://standards.nasa.gov, directly from the Standards Developing Organizations (SDOs), or from other document distributors.

2.2 Government Documents

The documents in these paragraphs are applicable to the extent specified.

JSC 20584 (1999) Reference 4.1.2	Spacecraft Maximum Allowable Concentrations for Airborne Contaminants
Materials and Processes Technical Information System (MAPTIS) References 3.2, 4.1.1, 4.1.2, and 4.2	Materials Selection List for Space Hardware Systems
MIL-HDBK-17-1 F Reference 3.7 and 4.3.3	Volume 1. Polymer Matrix Components Guidelines for Characterization of Structural Materials
MIL-HDBK-17-2 F Reference 3.7 and 4.3.3	Composite Materials Handbook Volume 2. Polymer Matrix Composites Materials Properties
MIL-HDBK-17-3 F Reference 3.7 and 4.3.3	Volume 3. Polymer Matrix Composites Materials Usage, Design, and Analysis
MIL-HDBK-17-4 (Baseline) Reference 3.7 and 4.3.3	A Composite Materials Handbook Volume 4. Metal Matrix Composites
MIL-HDBK-17-5 (Baseline) Reference 3.7 and 4.3.3	Volume 5. Ceramic Matrix Composites
MIL-HDBK-454A (2000) Reference 4.3.8	General Guidelines for Electronic Equipment

MIL-STD-810F (2000) Change 3 (2003) Reference 4.3.8	Department of Defense Test Method Standard for Environmental Engineering Considerations and Laboratory Tests
MIL-STD-889B Change 3 (1993) Reference 4.6.3	Dissimilar Metals
MIL-HDBK-6870A (2001) Reference 4.5.1	Inspection Program Requirements, Nondestructive for Aircraft and Missile Materials and Parts
MMPDS-01 (Baseline) Reference 3.7	Metallic Materials Properties Development and Standardization (MMPDS)
MSFC-SPEC-250A (1977) Reference 4.6.3	Protective Finishes for Space Vehicle Structures and Associated Flight Equipment, General Specification for
MSFC-SPEC-445A (1990) Reference 4.4.3	Adhesive Bonding, Process and Inspection, Requirements for
MSFC-STD-557 (1980) Reference 4.6.4	Threaded Fasteners, 6 Al-4V Titanium Alloy, Usage Criteria for Spacecraft Applications
MSFC-STD-2594C (2002)	MSFC Fastener Management and Control Practices Reference 4.6.4
MSFC-STD-3029A (2005) Reference 4.2	Guidelines for the Selection of Metallic Materials for Stress Corrosion Cracking Resistance in Sodium Chloride Environments
NAS 410 (2003) Reference 4.5.1	NAS Certification and Qualification of Nondestructive Test Personnel
NAS 412 (1997) Reference 4.6.5	Foreign Object Damage/Foreigh Object Debris (FOD) Prevention
NASA-STD-5006 (1999) Reference 4.4.4	General Fusion Welding Requirements for Aerospace Materials Used in Flight Hardware
NASA-STD(I)-5009 (2006) Reference 4.5.1	Nondestructive Evaluation Requirements for Fracture-Critical Metallic Components
NASA-STD-6001 (1998) References 4.1, 4.1.1, 4.1.2, 4.1.3, 4.1.4, and 4.1.6	Flammability, Odor, Offgassing and Compatibility Requirements and Test Procedures for Materials in Environments That Support Combustion

NASA-STD-(I)-6008 (2006)	NASA Fastener Management and Control Practices
NASA-TM-86556 (1985) Reference 4.3.4	Lubrication Handbook for the Space Industry, Part A: Solid Lubricants, Part B: Liquid Lubricants
NASA-TM-104823 (1996) Reference 4.1.4	Guide for Oxygen Hazard Analyses on Components and Systems

2.3 Non-Government Documents

2.3.1 Voluntary Consensus Standards

ASTM-E595-93 (reapproved 2003) Reference 4.3.6	Total Mass Loss and Collected Volatile Condensable Materials from Outgassing in a Vacuum Environment
AWS C-3.2M/C3.2 (2001) Reference 4.4.5	Standard Method for Evaluating the Strength of Brazed Joints
AWS C-3.3 (2002) Reference: 4.4.5	Design, Manufacture and Inspection of Critical Brazed Components, Recommended Practices for,
AWS C-3.4 (1999) Reference 4.4.5	Torch Brazing
AWS C-3.5 (1999) Reference 4.4.5	Induction Brazing
AWS C-3.6 (1999) Reference 4.4.5	Furnace Brazing
AWS C-3.7M/C3.7 (2005) Reference 4.4.5	Aluminum Brazing
SAE-AMS-H-6875A (1998, Reaffirmed 2006) Reference 4.2.2.1	Heat Treatment Of Steel Raw Materials
SAE-AMS-STD-401 (1999) Reference 4.6.2	Sandwich Constructions and Core Materials: General Test Methods
SAE-AMS 2175 (2003) Reference 4.4.2	Castings, Classification and Inspection of

SAE-AMS 2375C (1996, Reaffirmed 2001) Reference 4.4.1	Control of Forgings Requiring First Article Approval
SAE-AMS 2488D (2000, Reaffirmed 2006) Reference 4.2.3.3	Anodic Treatment - Titanium & Titanium Alloys, Solution pH 13 or Higher
SAE-AMS 2491D (1989, Reaffirmed 2003) Reference 4.3.10	Surface Treatment of Polytetrafluoroethylene, Preparation for Bonding
SAE-AMS 2759D (2006) Reference 4.2.2.1	Heat Treatment of Steel Parts, General Requirements
SAE-AMS 2759/9B (2003) Reference 4.2.2.1	Hydrogen Embrittlement Relief (Baking) of Steel Parts
SAE-AMS 2770G (2003) Reference 4.2.1	Heat Treatment of Wrought Aluminum Alloy Parts
SAE-AMS 2771C (2004) Reference 4.2.1	Heat Treatment of Aluminum Alloy Castings
SAE-AMS 2772C (2002) Reference 4.2.1	Heat Treatment of Aluminum Alloy Raw Materials
SAE-AMS 2774A (2005) Reference 4.2.9.1	Heat Treatment, Wrought Nickel Alloy and Cobalt Alloy Parts
SAE-AMS-H-81200A (2003) Reference 4.2.3.1	Heat Treatment of Titanium and Titanium Alloys

2.4 Order of Precedence

In the case of conflict, the technical requirements of this standard take precedence.

3. ACRONYMS AND DEFINITIONS

3.1 Acronyms

ASTM	American Society for Testing and Materials
BZT	Benzotriazole
CCP	Contamination Control Plan
CDR	Critical Design Review
COTS	Commercial-Off-The-Shelf
CP	Commercially Pure
CVCM	Collected Volatile Condensable Materials
DRD	Data Requirements Description
EDM	Electrical Discharge Machining
EEE	Electrical, Electronic, and Eletromechanical
ELI	Extra Low Interstitial
ESD	Electrostatic Discharge
ETFE	Ethylene Tetrafluoroethylene
FOD	Foreign Object Debris
FRR	Flight Readiness Review
GOX	Gaseous Oxygen
GSE	Ground Support Equipment
JSC	Johnson Space Center
kPa	Kilopascals
ksi	Kilopounds per Square Inch
LM	Laser Machining
LOX	Liquid Oxygen
M&P	Materials and Processes
MAPTIS	Materials and Processes Technical Information System
MIL	Military
MIUL	Material Identification Usage List
MMPDS	Metallic Materials Properties Development and Standardization
MSFC	Marshall Space Flight Center
MUA	Material Usage Agreement
NASA	National Aeronautics and Space Administration
NDE	Nondestructive Evaluation
NDI	Nondestructive Inspection
NDT	Nondestructive Test

NOTE: Per section 4.1.3: The use of materials and processes that do not comply with the technical requirements of this standard may be acceptable in the actual hardware applications. Material Usage Agreements (MUAs) shall be submitted for all materials and processes that are technically acceptable but do not meet the technical requirements of this standard, as implemented by the approved Materials and Processes Selection, Control, and Implementation Plan.

NHB	NASA Handbook
PDR	Preliminary Design Review
PTFE	Polytetrafluoroethylene
RH	Relative Humidity
RTV	Room Temperature Vulcanizing (rubber)
SMAC	Spacecraft Maximum Allowable Concentration
SPEC	Specification
STD	Standard
TM	Technical Memorandum
TML	Total Mass Loss
UTS	Ultimate Tensile Strength
UV	Ultraviolet

3.2 Definitions

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

Primary Structure: Principal or main structure which sustains the significant applied loads or provides main load paths for distributing reactions to applied loads and which, if it fails, creates a catastrophic hazard.

Refractory Alloys: Alloys with a melting point above 3632° F (2000° C), plus osmium and iridium.

Safety-Critical Hardware: Hardware that, if it fails, creates a critical or catastrophic hazard.

Stress Equalization: A low-temperature heat treatment used to balance stresses in cold-worked material without an appreciable decrease in the mechanical strength produced by cold working.

Structural: Primary load-bearing structure.

Structural Adhesive Bond: Structural joint using adhesive bonds for the purpose of transferring structural load between structures.

Structure: All components and assemblies designed to sustain loads or pressures or to provide stiffness and stability, support or containment.

Subcontractor: A hardware contractor that reports to a higher-level contractor.

Useful Life: Total life span including storage life, installed life in a non-operating mode, and operational service life.

4. REQUIREMENTS

Materials used in the fabrication and processing of flight hardware shall be selected by considering the worst-case operational requirements for the particular application and the design engineering properties of the candidate materials. For example, the operational requirements shall include, but shall not be limited to, operational temperature limits, loads, contamination, life expectancy, moisture or other fluid media exposure, and vehicle-related induced and natural space environments. Properties that shall be considered in material selection include, but are not limited to, mechanical properties, fracture toughness, flammability and offgassing characteristics, corrosion, stress corrosion, thermal and mechanical fatigue properties, glass-transition temperature, coefficient of thermal expansion mismatch, vacuum outgassing, fluids compatibility, microbial resistance, moisture resistance, fretting, galling, and susceptibility to electrostatic discharge (ESD) and contamination. Conditions that could contribute to deterioration of hardware in service shall receive special consideration.

Non-flight materials used in processing and testing of flight hardware shall not cause degradation of the flight hardware.

4.1 General Requirements

4.1.1 Materials and Processes, Selection, Control, and Implementation Plan

Each organization responsible for the design and fabrication of spacecraft flight hardware shall provide a Materials and Processes Selection, Control, and Implementation Plan. This plan shall document the degree of conformance and method of implementation for each requirement in this standard, identifying applicable in-house specifications used to comply with the requirement. It shall also describe the methods used to control compliance with these requirements by subcontractors and vendors. The Materials and Processes Selection, Control, and Implementation Plan, upon approval by the procuring activity shall become the Materials and Processes implementation document used for verification

The Materials and Processes Selection, Control, and Implementation Plan shall include the following:

4.1.1.1 Coordination, Approval, and Tracking

The Materials and Processes Selection, Control, and Implementation Plan shall identify the method of coordinating, approving, and tracking all engineering drawings, engineering orders, and other documents that establish or modify materials and/or processes usage.

NOTE: Per section 4.1.3: The use of materials and processes that do not comply with the technical requirements of this standard may be acceptable in the actual hardware applications. Material Usage Agreements (MUAs) shall be submitted for all materials and processes that are technically acceptable but do not meet the technical requirements of this standard, as implemented by the approved Materials and Processes Selection, Control, and Implementation Plan.

4.1.1.2 Approval Signature

The Materials and Processes Selection, Control, and Implementation Plan shall include a requirement that all design drawings and revisions contain a Materials and Processes approval block, or equivalent, to assure that the design has been reviewed and complies with the intent of this document. These drawings shall be signed by the responsible Materials and Processes authority prior to release.

4.1.1.3 Materials and Process Controls

All materials and processes shall be defined by standards and specifications and shall be identified directly on the appropriate engineering drawing. The Materials and Processes Selection, Control, and Implementation Plan shall identify those materials and process standards and specifications used to implement specific requirements in this document.

Standards and specifications shall be selected from Government, industry, and company specifications and standards. Rationale for the selection of company specifications over Government and industry voluntary consensus standards and specifications shall be documented in the Materials and Processes Selection, Control, and Implementation Plan. The rationale shall include an identification of the Government or industry specifications or standards examined and an explanation of why each was unacceptable. Company materials and process specifications shall be identified by revision letter in the Materials and Processes Selection, Control, and Implementation Plan.

All materials and process specifications used to produce flight hardware shall be made available to the responsible NASA Program or Project Office and Materials and Processes organization. Changes to materials and process standards and specifications identified in the Materials & Processes Selection, Control, and Implementation Plan shall require NASA Materials and Processes organization-approved MUAs in accordance with section 4.1.3 of this standard.

Process specifications shall adequately define process steps at a level of detail that ensures a repeatable/controlled process that produces a consistent and reliable product. Process qualification shall be conducted to demonstrate the repeatability of all processes where the quality of the product cannot be directly verified by subsequent monitoring or measurement.

Note: The process requirements in this standard do not provide the detailed process and quality assurance requirements that ensure a process is repeatable. Instead, they are intended as higher level documents which state minimum requirements and provide general directions for the design of hardware.

NOTE: Per section 4.1.3: The use of materials and processes that do not comply with the technical requirements of this standard may be acceptable in the actual hardware applications. Material Usage Agreements (MUAs) shall be submitted for all materials and processes that are technically acceptable but do not meet the technical requirements of this standard, as implemented by the approved Materials and Processes Selection, Control, and Implementation Plan.

4.1.1.3.1 Standard and Specification Obsolescence

During a long-term program, materials and process standards and specifications identified in this document or in contractor materials control plans could become obsolete. Continued use of obsolete standards and specifications is acceptable for manufacturing series or new-design hardware. Use of an updated, alternate, or new material or process standard or specification from those identified in the Materials and Processes Selection, Control, and Implementation Plan shall be implemented by either of the following means:

a. Updating the Materials and Processes Selection, Control, and Implementation Plan upon approval of a meets/exceeds analysis for process specification changes by the responsible NASA M&P organization and program or project office.

b. Processing a hardware-specific MUA demonstrating that the revised or alternative standard or specification does not adversely affect the functionality, reliability, and safety of the hardware.

Small changes to the chemical composition of nonmetallic materials may sometimes occur without affecting the materials specification. The Materials and Processes Selection, Control, and Implementation Plan shall identify materials where chemical fingerprinting is required to ensure the properties are controlled.

4.1.1.4 Commercial Off-The-Shelf (COTS) Hardware

A procedure shall be established to ensure that all vendor-designed, off-the-shelf, and vendor-furnished items are covered by the M&P requirements of this document. The procedure shall include special considerations for off-the-shelf hardware where detailed materials and processes information may not be available or it may be impractical to impose all the detailed requirements specified in this standard. The procedure shall include provisions for ensuring that this hardware is satisfactory from an overall materials and processes standpoint.

4.1.1.5 Materials and Processes Control Board

The prime contractor for each contract shall establish a materials and processes control board. The board charter and membership shall be described in the Materials and Processes Selection, Control, and Implementation Plan. The board shall be responsible for the planning, management, and coordination of the selection, application, procurement, control, and standardization of materials and processes for the contract. The board shall also be responsible for directing and dispositioning materials and processes problem resolution. The responsible

NOTE: Per section 4.1.3: The use of materials and processes that do not comply with the technical requirements of this standard may be acceptable in the actual hardware applications. Material Usage Agreements (MUAs) shall be submitted for all materials and processes that are technically acceptable but do not meet the technical requirements of this standard, as implemented by the approved Materials and Processes Selection, Control, and Implementation Plan.

NASA M&P organization shall be an active member of the board and shall have the right of disapproval of board decisions.

4.1.2 Materials and Processes Usage Documentation

Materials and processes usage shall be documented in an electronic searchable parts list or separate electronic searchable Materials Identification and Usage List (MIUL). The procedures and formats for documentation of materials and processes usage will depend upon specific hardware but shall cover the final design. The system used shall be an integral part of the engineering configuration control/release system. A copy of the stored data shall be provided to NASA in a form compatible with the Materials and Processes Technical Information System (MAPTIS), accessible via the Internet at http://maptis.nasa.gov.

The parts list or MIUL shall identify the following applicable information:

- Detail drawing and dash number
- Next assembly and dash number
- Change letter designation
- Drawing source
- Material form
- Material manufacturer
- Material manufacturer's designation
- Material specification
- Process specification
- Environment
- Weight
- Material code
- Standard/commercial part number
- Contractor
- System
- Subsystem
- Maximum temperature
- Minimum temperature
- Fluid type
- Surface area
- Associate contractor number
- Project
- Document title
- Criticality
- Line number

NOTE: Per section 4.1.3: The use of materials and processes that do not comply with the technical requirements of this standard may be acceptable in the actual hardware applications. Material Usage Agreements (MUAs) shall be submitted for all materials and processes that are technically acceptable but do not meet the technical requirements of this standard, as implemented by the approved Materials and Processes Selection, Control, and Implementation Plan.

- Overall evaluation
- Overall configuration test
- Maximum pressure
- Minimum pressure
- Test MUA document
- Cure codes
- Remarks (comments field)

The Materials and Processes Technical Information System (MAPTIS) shall be consulted to obtain material codes and ratings for materials, standard and commercial parts, and components. New material codes shall be assigned by NASA Marshall Space Flight Center (MSFC). Where batch/lot testing is required, traceability of specific test reports for batch/lot used shall be provided in the remarks field. Wire, cable, and exposed surfaces of connectors shall meet the requirements of this document and be reported on the MIUL. All other standard and nonstandard Eletrical, Electronic, and Electromechanical (EEE) parts shall be exempt from these requirements and reporting on the MIUL. Materials used in hermetically sealed electronic containers (maximum leak rate less than 1×10^{-4} cm^3/sec) are exempt from inclusion in the MIUL.

4.1.3 Materials Usage Agreements (MUAs)

The use of materials and processes that do not comply with the requirements of this standard may still be acceptable in the actual hardware applications. Material Usage Agreements (MUAs) shall be submitted for all materials and processes that are technically acceptable but do not meet the requirements of this standard, as implemented by the approved Materials and Processes Selection, Control, and Implementation Plan. The MUA shall include sufficient information to demonstrate that the application is technically acceptable. A typical MUA form is given in Appendix A, page A-1. A tiered MUA system with three categories shall be used.

4.1.3.1 Category I MUAs

Category I MUAs are those that involve M&P usage that could affect the safety of the mission, crew, or vehicle or affect the mission success, but must be used for functional reasons. Category I MUAs are delivered by the hardware developer, and approval by the responsible NASA Materials and Processes organization and the NASA Program/Project Office shall be required.

4.1.3.2 Category II MUAs

Category II MUAs are those that involve M&P usage that fails a screening of Material and Processes requirements and is not considered a hazard in its use application but for which no

NOTE: Per section 4.1.3: The use of materials and processes that do not comply with the technical requirements of this standard may be acceptable in the actual hardware applications. Material Usage Agreements (MUAs) shall be submitted for all materials and processes that are technically acceptable but do not meet the technical requirements of this standard, as implemented by the approved Materials and Processes Selection, Control, and Implementation Plan.

Category III rationale code exists. Category II MUAs are delivered by the hardware developer and approval by the responsible NASA Materials and Processes organization shall be required.

4.1.3.3 Category III MUAs

Category III MUAs are those that involve M&P that have not been shown to meet these requirements but have an approved rationale code listed in Appendix B. They are evaluated and determined to be acceptable at the configuration/part level

Approved category III MUAs shall be reported in the MIUL system or electronic data system utilizing the approved rationale codes in Appendix B. Category III MUAs are approved by the hardware developer and responsible Materials and Processes organization through acceptance of the MIUL. A key may be provided to correlate contractor Category III MUA database codes to the codes in Appendix B. No MUA form is submitted.

4.1.4 Manufacturing Planning

Materials and Processes organizations shall participate in manufacturing planning to ensure compliance with materials and process requirements. The degree of M&P involvement in manufacturing planning shall be defined in the Materials and Processes, Selection, Control, and Implementation Plan described in paragraph 4.1.1 of this standard.

4.1.5 Materials Certification and Traceability

All parts or materials shall be certified as to composition, properties, and requirements as identified by the procuring document. Parts and materials used in critical applications such as life-limited materials, and/or safety- and fracture-critical parts shall be traceable through all critical processing steps and the end-item application; processing records shall be retained for the life of the hardware.

4.1.6 Material Design Allowables

Values for allowable mechanical properties of structural materials (A, B, or S) in their design environment shall be taken from MMPDS-01, *Metallic Materials Properties Development and Standardization* or MIL-HDBK-17. When high-strength metallic materials are heat treated, the adequacy of the heat treatment process shall be verified by test (see section 4.2.2 of this standard).

Material "B" allowable values shall not be used except in redundant structure in which the failure of a component would result in a safe redistribution of applied load-carrying members.

NOTE: Per section 4.1.3: The use of materials and processes that do not comply with the technical requirements of this standard may be acceptable in the actual hardware applications. Material Usage Agreements (MUAs) shall be submitted for all materials and processes that are technically acceptable but do not meet the technical requirements of this standard, as implemented by the approved Materials and Processes Selection, Control, and Implementation Plan.

MMPDS-01 material ”S” allowables may be used in non-critical applications; the use of “S” allowables in primary structure or fracture-critical hardware requires an approved materials usage agreement.

When design allowables for mechanical properties of new or existing structural materials are not available, they shall be determined by analytical methods described in MMPDS-01 or MIL-HDBK-17. The hardware developer shall develop a plan describing its philosophy on how it will determine what material design properties will be used, and if those properties do not exist, how they will be developed including, but not limited to the statistical approaches to be employed. All mechanical and physical property data shall be provided to the responsible NASA Materials and Processes organization.

4.2 Detailed Requirements

4.2.1 Flammability, Offgassing, and Compatibility Requirements

Materials shall meet the requirements of NASA-STD-6001, *Flammability, Odor, Offgassing, and Compatibility Requirements and Test Procedures for Materials in Environments That Support Combustion*, as described below.

4.2.1.1 Flammability Control

Materials that are nonflammable or self-extinguishing in their use configuration as defined by NASA-STD-6001, Test 1, shall be used for flammability control. Material flammability ratings and tests based on NASA-STD-6001 for many materials are found in the MAPTIS database.

Additional acceptable materials or methods are the following:

a. The use of ceramics, metal oxides, and inorganic glasses is accepted without test.

b. When a material is sufficiently chemically and physically similar to a material found to be acceptable by testing per NASA-STD-6001, the use of this material without testing may be justified on an approved MUA.

c. Materials tested and A-rated under more severe conditions with respect to the use environment will be acceptable (considered A-rated) without test, as in the following examples:.

(1) Materials used in an environment with an oxygen concentration lower than the test level are accepted without test, whereas materials used in an environment where the concentration is greater than the test level shall be tested or considered

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flammable by default. Materials that are considered flammable by default may still be accepted through the MUA approval process.

(2) If a material passes the flammability test on a metal substrate, it shall be used on metal substrates of the same thickness or greater. If the material is used on a thinner or non-heat-sinking substrate (or on no substrate at all), it shall be retested or considered flammable by default.

Many situations arise where flammable materials are used in an acceptable manner without test, using mitigation practices and the MUA approval system. Guidelines for hardware flammability assessment and mitigation can be found in JSC 29353, *Flammability Configuration Analysis for Spacecraft Applications.*

4.2.1.2 Toxic Offgassing

All materials used in habitable flight compartments shall meet the offgassing requirements of Test 7 of NASA-STD-6001, using one of the following methodologies:

a. Offgassing is tested as an assembled article

Summation of Toxic Hazard Index (T) values (total concentration in mg/m^3 /Spacecraft Maximum Allowable Concentration (SMAC) in mg/m^3) of all offgassed constituent products shall not exceed 0.5.

b. Hardware components evaluated on a materials basis

Individual materials used to make up a component shall be evaluated based on the actual or estimated mass of the material used in the hardware component. The total T value for all materials used to make up the component shall be less than 0.5.

c. More than one hardware component or assembly

If a single hardware component is tested or evaluated for toxicity, but more than one will be flown, the T value obtained for one unit times the number of flight units shall be less than 0.5.

d. Bulk materials and other materials not inside a container

All materials shall be evaluated individually using the ratings in the MAPTIS database. The maximum quantity and associated rating is specified for each material code.

NOTE: Per section 4.1.3: The use of materials and processes that do not comply with the technical requirements of this standard may be acceptable in the actual hardware applications. Material Usage Agreements (MUAs) shall be submitted for all materials and processes that are technically acceptable but do not meet the technical requirements of this standard, as implemented by the approved Materials and Processes Selection, Control, and Implementation Plan.

The analytical technique used to identify and quantify offgassed products in the NASA-STD-6001 standard test shall be capable of detecting formaldehyde concentrations of 0.05 parts per million. Offgassing testing is not required for metallic materials or for ceramics and metal oxides. SMAC values shall be obtained from JSC 20584, *Spacecraft Maximum Allowable Concentrations for Airborne Contaminants*. For compounds for which no SMAC values are found in JSC 20584, the values in MAPTIS shall be used.

NASA-STD-6001 Test 6, Odor Assessment is not required.

4.2.1.3 Fluid Compatibility (Fluids Other Than Oxygen)

Materials exposed to hazardous fluids[1] shall be evaluated or tested for compatibility. NASA-STD-6001, Test 15 is a screening test for short-term exposure to fuels and oxidizers. Appropriate long-term tests shall be conducted for materials with long-term exposure to fuels, oxidizers, and other hazardous fluids. The test conditions shall simulate the worst-case use environment that would enhance reactions or degradation of the material or fluid. Materials degradation in long-term tests shall be characterized by post-test analyses of the material and fluid to determine the extent of changes in chemical and physical characteristics, including mechanical properties. The effect of material condition (for example, parent versus weld metal or heat-affected zone) shall be addressed in the compatibility determination.

4.2.1.4 Oxygen Compatibility

Liquid and gaseous oxygen (LOX/GOX) systems shall use materials that are nonflammable in their worst case use configuration, as defined by NASA-STD-6001, Test 13 for mechanical impact (for LOX or GOX) and Test 17 for upward flammability in GOX (or Test 1 for materials used in oxygen pressures that are less than 50 psia (350 kPa)). Material flammability ratings and tests based on NASA-STD-6001 for many materials are found in the MAPTIS database.

When a material in an oxygen system is determined to be flammable by the above tests, a hazard analysis shall be conducted and the system safety rationale shall be documented in an MUA. The hazard analysis shall clearly state the level of failure tolerance considered and what level of risk is considered acceptable and thereby needing no mitigation. The hazard analysis shall use

[1] For the purpose of this standard, the definition of hazardous fluids includes gaseous oxygen, liquid oxygen, fuels, oxidizers, and other fluids that could cause corrosion, chemically or physically degrade materials in the system, or cause an exothermic reaction.

the evaluation methodology described in NASA Technical Memorandum (TM) 104823, *Guide for Oxygen Hazard Analyses on Components and Systems.*

When a material in an oxygen system fails either test at its maximum use condition and the hazard analysis shows the risk is above an acceptable level, then configurational testing shall be conducted to support the hazard analysis. The configurational testing shall exercise the ignition mechanism in question using an accepted test method. The configurational test method and acceptance criteria shall be reviewed and approved as part of the MUA process described in paragraph 4.1.3.

The as-built configuration shall be verified against the hazard analysis to assure that mitigation methods identified in the report were incorporated into the final hardware design and build.

The need for an oxygen hazard analysis shall be addressed in the Materials & Processes Selection, Control, and Implementation Plan for compressed air systems and systems containing enriched oxygen. Such systems are inherently less hazardous than systems containing pure oxygen; the hazard increases with oxygen concentration and pressure.

Guidelines on the design of safe oxygen systems are contained in ASTM MNL 36, *Safe Use of Oxygen and Oxygen Systems: Guidelines for Oxygen System Design, Materials Selection, Operations, Storage, and Transportation*; ASTM Standard G88-90, *Standard Guide for Designing Systems for Oxygen Service*; ASTM G63-99, *Standard Guide for Evaluating Nonmetallic Materials for Oxygen Service*; and ASTM G94-92, *Standard Guide for Evaluating Metals for Oxygen Service*.

4.2.1.4.1 Oxygen Component Acceptance Test

Oxygen and enriched air system components that operate at pressures above 265 psia (1.83 MPa) shall undergo oxygen compatibility acceptance testing at maximum design pressure for a minimum of ten cycles to ensure that all oxygen system flight hardware is exposed to oxygen prior to launch. Components shall be retested if post-test actions (such as rework, repair, or interfacing with hardware having uncontrolled cleanliness) invalidate the acceptance test.

4.2.1.5 Electrical Wire Insulation Materials

Electrical wire insulation materials shall be evaluated for flammability in accordance with NASA-STD-6001 Test 4.

Arc tracking shall be evaluated in accordance with NASA-STD-6001 Test 18 or a generally accepted voluntary consensus standard aerospace wiring arc tracking test (such as MIL-STD-

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2223 method 3007). Testing is not required for polytetrafluoroethylene (PTFE), PTFE laminate, ethylene tetrafluoroethlyene (ETFE), or silicone-insulated wires since the resistance of these materials to arc tracking has already been established.

4.2.2 Metals

MSFC-STD-3029, *Guidelines for Selection of Metallic Materials for Stress-Corrosion-Cracking Resistance in Sodium Chloride Environments*, shall be used to select metallic materials to control stress corrosion cracking of metallic materials in sea and air environments. Additional information regarding metallic materials can be found in MAPTIS.

4.2.2.1 Aluminum

Aluminum alloys used in structural applications shall be resistant to general corrosion, pitting, intergranular corrosion, and stress corrosion cracking. 5000-series alloys containing more than 3 percent magnesium shall not be used in applications where the temperature exceeds 150° F (66° C) because grain boundary precipitation above this temperature can create stress-corrosion sensitivity.

Heat treatment of aluminum alloy parts shall meet the requirements of SAE-AMS 2772, *Heat Treatment of Aluminum Alloy Raw Materials*, SAE-AMS 2770, *Heat Treatment of Wrought Aluminum Alloy Parts*, or SAE-AMS 2771, *Heat Treatment of Aluminum Alloy Castings*. When aluminum alloys are solution heat treated, process-control tensile-test coupons to verify the adequacy of the heat treatment process shall be taken from the production part (or from the same material lot and processed identically to the production part). The requirement for process control coupons shall be specified on the engineering drawing for the part

4.2.2.2 Steel

Carbon and low alloy steels heat-treated to strength levels at or above 180 ksi (1240 MPa) UTS are sensitive to stress corrosion and shall not be used without an approved MUA. Note: Many applications are covered by Category III MUA rationale code 506 (see Appendix B).

4.2.2.2.1 Heat Treatment of Steels

Steel parts shall be heat treated to meet the requirements of SAE-AMS-H-6875, *Heat Treatment of Steel Raw Materials*, or SAE-AMS 2759, *Heat Treatment of Steel Parts, General Requirements*. When high-strength steels (>200 ksi (1380 MPa) UTS), tool steels, and maraging steel alloys are heat treated to high strength levels, process-control tensile-test coupons to verify the adequacy of the heat treatment process shall be taken from the production part (or from the same material lot and processed identically to the production part). The requirement for process

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control coupons shall be specified on the engineering drawing for the part. For all other steels (including alloy steels), the adequacy of the heat treatment process shall be verified by hardness measurements.

When acid cleaning baths or plating processes are used, the part shall be baked in accordance with SAE-AMS 2759/9, *Hydrogen Embrittlement Relief (Baking) of Steel Parts*, to alleviate potential hydrogen embrittlement problems.

4.2.2.2.2 Drilling and Grinding of High Strength Steel

The drilling of holes, including beveling and spot facing, in martensitic steel hardened to 180 ksi (1340 MPa) UTS or above, shall be avoided. When such drilling, machining, reaming, or grinding is unavoidable, carbide-tipped tooling and other techniques necessary to avoid formation of untempered martensite shall be used. Micro-hardness and metallurgical examination of test specimens typical of the part shall be used to verify that martensite areas have not been formed as a result of drilling or grinding operations, or temper etch actual hardware in lieu of destructive test. The surface roughness of finished holes shall not be greater than 63 roughness-height-ratio, and the edges of the holes shall be deburred by a method which has been demonstrated not to cause untempered martensite.

4.2.2.2.3 Corrosion Resistant Steel

Unstabilized, austenitic steels shall not be used above 700° F (371° C). Welded assemblies shall be solution heat-treated and quenched after welding except for the stabilized or low carbon grades such as 321, 347, 316L, and 304L. Service-related corrosion issues are common for free-machining alloys such as 303, and these alloys shall not be used in applications where they can get wet.

4.2.2.3 Titanium

4.2.2.3.1 Heat Treatment

Heat treatment of titanium and titanium alloy parts shall meet the requirements of SAE-AMS-H-81200, *Heat Treatment of Titanium and Titanium Alloys*. When titanium alloys are heat treated, process-control tensile-test coupons to verify the adequacy of the heat treatment process shall be taken from the production part (or from the same material lot and processed identically to the production part). The requirement for process control coupons shall be specified on the engineering drawing for the part.

4.2.2.3.2 Titanium Contamination

All cleaning fluids and other chemicals used during manufacturing and processing of titanium hardware shall be verified to be compatible and not detrimental to performance before use. Hydrochloric acid, chlorinated solvents, chlorinated cutting fluids, fluorinated hydrocarbons, and anhydrous methyl alcohol can all produce stress corrosion cracking. Mercury, cadmium, silver, and gold have been shown to cause liquid-metal-induced embrittlement and/or solid-metal-induced embrittlement in titanium and its alloys. Liquid-metal-induced embrittlement of titanium alloys by cadmium can occur as low as 300° F (149° C), and solid- metal-induced embrittlement of titanium alloys by cadmium can occur as low as room temperature.

The surfaces of titanium and titanium alloy mill products shall be 100 percent machined, chemically milled, or pickled to a sufficient depth to remove all contaminated zones and layers formed while the material was at elevated temperature. This includes contamination as a result of mill processing, heat treating, and elevated temperature forming operations.

4.2.2.3.3 Titanium Wear

Titanium and its alloys exhibit very poor resistance to wear. Fretting that occurs at interfaces with titanium and its alloys has often contributed to crack initiation, especially fatigue initiation. The preferred policy is a design that avoids fretting and/or wear with titanium and its alloys. If fretting and/or wear is unavoidable, the subject region shall be anodized per SAE-AMS 2488, *Anodic Treatment – Titanium and Titanium Alloys Solution, pH 13 or Higher*, or hard coated utilizing a wear-resistance material such as tungsten carbide/cobalt thermal spray.

4.2.2.3.4 Titanium Welding

Titanium and its alloys shall be welded with alloy-matching fillers or autogenously. Extra Low Interstitial (ELI) filler wires shall be used for cryogenic applications and are preferred for general applications. Commercially Pure (CP) titanium filler shall not be used on 6-4 titanium or other alloyed base material; hydride formation can occur in the weld, which can produce a brittle, catastrophic failure.

A great deal of care needs to be exercised to ensure complete inert gas (argon or helium) coverage during welding. Nitrogen, hydrogen, carbon dioxide, and mixtures containing these gases shall not be used in welding titanium and its alloys. The inert gas shall have a dew point of -76º F (-60º C) or lower.

Welded alpha and alpha plus beta alloys shall be stress relieved in a vacuum or inert gas environment (Ar or He). Beta alloys that are welded shall be evaluated on a case-by-case basis with respect to stress relief.

4.2.2.3.5 Titanium Flammability

Titanium alloys shall not be used with Liquid Oxygen (LOX) or Gaseous Oxygen (GOX) at any pressure or with air at oxygen partial pressures above 5 psia (35 kPa). Titanium alloys shall not be machined inside spacecraft modules during ground processing or in flight, because machining operations can ignite titanium turnings and cause fire.

4.2.2.4 Magnesium

Magnesium alloys shall not be used except in areas where minimal exposure to corrosive environments can be expected and protection systems can be maintained with ease and high reliability. Magnesium alloys shall not be used in primary structure or in other areas subject to wear, abuse, foreign object damage, abrasion, erosion, or at any location where fluid or moisture entrapment is possible. Magnesium alloys shall not be machined inside spacecraft modules during ground processing or in flight, because machining operations can ignite magnesium turnings and cause fire.

4.2.2.5 Beryllium

Beryllium shall not be used for primary structural applications. Beryllium is allowed as an alloying constituent up to 4 percent by weight. Beryllium alloys containing more than 4 percent beryllium by weight shall not be used for any application within spacecraft crew compartments unless suitably protected to prevent erosion or formation of salts or oxides. Design of beryllium parts shall include consideration of its low impact resistance and notch sensitivity, particularly at low temperatures, and its directional material properties (anisotropy) and sensitivity to surface finish requirements. All beryllium parts shall be processed to assure complete removal of the damaged layer (twins and microcracks) produced by surface-metal-working operations such as machining and grinding. Chemical/milling and etching are recognized successful processes. Beryllium alloys and oxides of beryllium shall not be machined inside spacecraft crew compartments at any stage of manufacturing, assembly, testing, modification, or operation.

All beryllium parts shall be penetrant inspected for crack-like flaws with a high-sensitivity fluorescent penetrant in accordance with section 4.2.5.

4.2.2.6 Cadmium

Cadmium shall not be used in crew environments. Cadmium shall not be used in vacuum environments at temperatures exceeding 212° F (100° C). Cadmium-plated tools shall not be used in the manufacture of flight hardware.

4.2.2.7 Zinc

Zinc shall not be used in vacuum environments where the temperature/pressure environment could cause contamination of optical surfaces or electrical devices. Due to zinc's ability to grow whiskers, zinc plating shall not be used.

4.2.2.8 Mercury

Owing to its potential for causing liquid metal embrittlement, equipment containing mercury shall not be used where the mercury could come in contact with the spacecraft or spaceflight equipment during manufacturing, assembly, test, checkout, and flight. Flight hardware (including fluorescent lamps) containing mercury shall have three levels of containment to prevent mercury leakage. The bulbs of non-flight lamps containing mercury, such as those used in hardware ground processing and fluorescent penetrant inspection of flight parts, shall be protected by a non-shatterable, leak-proof outer container.

4.2.2.9 Refractory Metals

Since engineering data on refractory alloys (alloys with a melting point above 3600° F (2000°C), plus osmium and iridium) are limited, especially under extreme environmental conditions of spacecraft, an MUA is required for all applications of such alloys. Appropriate tests shall be performed to characterize the material for the intended application and the data documented in the MUA.

4.2.2.10 Superalloys (Nickel-Based and Cobalt-Based)

High nickel content alloys are susceptible to sulfur embrittlement; therefore, any foreign material which could contain sulfur, such as oils, grease, and cutting lubricants, shall be removed by suitable means prior to heat treatment, welding, or high temperature service. Some of the precipitation-hardening superalloys are susceptible to alloying element depletion at the surface in a high temperature, oxidizing environment. This effect shall be carefully evaluated when a thin sheet is used, since a slight amount of depletion could involve a considerable proportion of the effective cross section of the material.

4.2.2.10.1 Heat Treatment of Nickel- and Cobalt-Based Alloys

Heat treatment of nickel- and cobalt-based alloy parts shall meet the requirements of SAE-AMS 2774, *Heat Treatment, Wrought Nickel Alloy and Cobalt Alloy Parts*. When nickel- and cobalt-based alloys are work strengthened before age hardening, resulting in age-hardened tensile strengths greater than 150 ksi (1030 MPa) UTS, process-control tensile-test coupons to verify the adequacy of the heat treatment process shall be taken from the production part (or from the same material lot and processed identically to the production part). The requirement for process control coupons shall be specified on the engineering drawing for the part. When tensile test coupons are not required, the adequacy of the heat treatment process shall be verified by hardness measurements.

4.2.2.11 Tin

Tin and tin plating shall not be used in any applications unless the tin is alloyed with at least 3 percent lead to prevent tin whisker growth. The presence of at least 3 percent lead shall be verified by lot sampling.

4.2.3 Nonmetallic Materials

4.2.3.1 Elastomeric Materials

Elastomeric materials shall be selected to operate within design parameters for the life of the vehicle after a storage time of 5 years. Elastomeric materials shall be cure dated for tracking purposes. Room Temperature Vulcanizing (RTV) silicones which liberate acetic acid during cure shall not be used since they can cause corrosion. When rubbers or elastomers are used at low temperatures, the ability of these materials to maintain and provide required elastomeric properties shall be verified. Natural rubber materials shall not be used.

4.2.3.2 Polyvinylchloride

Use of polyvinylchloride on flight hardware shall be limited to applications in pressurized areas where temperatures do not exceed 120° F (49° C). Polyvinylchloride shall not be used in a vacuum.

4.2.3.3 Composite Materials

Materials used in composite structures shall be developed and qualified in accordance with the guidelines in MIL-HDBK-17. Material property design allowables for composites shall be developed using the methodology described in MIL-HDBK-17. Defects resulting from the manufacturing process shall be assessed through the proper application of nondestructive inspection (NDI) techniques.

4.2.3.4 Lubricants

NASA-TM-86556, *Lubrication Handbook For the Space Industry, Part A: Solid Lubricants, Part B: Liquid Lubricants*, shall be used in the evaluation and selection of lubricants for space flight systems and components. Lubricants are not restricted to those listed in NASA-TM-86556; guidelines on additional lubricants are contained in NASA/CR-2005-213424, *Lubrication for Space Applications*. Long life performance shall be considered in lubricant selection. Lubricants containing chloro-fluoro components shall not be used with aluminum or magnesium if shear stresses can be imposed. Hardware with lubricants containing chloro-fluoro components shall not be heated above the maximum rated temperature of the lubricant, because decomposition/ reaction products can attack metallic materials.

4.2.3.5 Limited-Life Items

All materials shall be selected to meet the useful life (to include storage life, installed life in a non-operating mode, and operational service life) of the hardware with no maintenance. Materials which are not expected to meet the design life requirements but must be used for functional reasons shall be identified as limited-life items, requiring maintainability.

4.2.3.6 Thermal Vacuum Stability

Nonmetallic materials which are exposed to space vacuum shall be tested using the technique of ASTM-E595, *Total Mass Loss and Collected Volatile Condensable Materials From Outgassing in a Vacuum Environment, Test Method for*, with acceptance criteria of ≤0.1 percent collected volatile condensable materials (CVCM) and ≤1.0 percent total mass loss (TML). A TML greater than 1.0 percent is permitted if this mass loss has no effect on the functionality of the material itself and no effect on the functionality of any materials, components, or systems that could be adversely affected by the subject mass loss. Materials that are line of sight to contamination-sensitive surfaces on the spacecraft or attached vehicles shall have a ≤0.01 percent CVCM. Contamination-sensitive surfaces include windows, lenses, star trackers, solar arrays, radiators, and other surfaces with highly controlled optical properties.

A hardware item (component, assembly, etc.) containing materials that fail the CVCM requirement and/or having unidentified materials, may be vacuum baked at a temperature of 257º F (125º C) until the outgassing condensation rate, as measured by a quartz crystal microbalance at 77º F (25º C), is less than 1×10^{-9} g cm^{-2} s^{-1}. The test chamber shall be verified to have a background outgassing condensation rate less than 6×10^{-10} g cm^{-2} s^{-1} before hardware exposure and the test pressure shall

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be less than 5 x 10^{-5} torr. When a vacuum-bake temperature of 257º F (125º C) could damage flight hardware, lower temperatures may be used with an approved MUA. A hardware functionality bench test shall be performed to reverify performance after baking.

4.2.3.7 External Environment Survivability

Materials exposed in the spacecraft external environment shall be selected to perform in that environment for their intended life cycle exposure. The critical properties of the material shall survive exposure to the environments of atomic oxygen, solar ultraviolet (UV) radiation, ionizing radiation, plasma, vacuum, thermal cycling, and contamination. Critical properties shall survive exposure to applicable planetary environments, such as dust and planetary atmospheres. Meteoroids and orbital debris shall also be considered in the analysis of long-term degradation.

4.2.3.8 Fungus Resistance

Organic materials used in the pressurized environment shall be evaluated for fungus resistance prior to selection and qualification. Materials which are non-nutrient to fungi shall be used, as identified in MIL-STD-454, *General Guidelines for Electronic Equipment, Requirement 4, Fungus-Inert Materials*, Table 4-I, Group I, except when one of the following criteria is met:

a. Material has been tested to demonstrate acceptability per MIL-STD-810, *Department of Defense Test Method Standard for Environmental Engineering Considerations and Laboratory Tests*, Method 508.
b. Materials are used in crew areas, where fungus would be visible and easily removed.
c. Materials are used inside environmentally sealed containers with internal container humidity less than 60 percent relative humidity (RH) at ambient conditions.
d. Materials are used inside electrical boxes where the temperature is always greater than or equal to the ambient cabin temperature.
e. Materials have edge exposure only.
f. Materials are normally stowed with no risk of condensation in stowage locations.
g. Materials are used on noncritical, off-the-shelf electrical/electronic hardware that is stowed and/or used in crew areas.
h. Materials are fluorocarbon polymers (including ETFE) or silicones.
i. Materials are used in crew clothing items.

When fungus-nutrient materials shall be used, they shall be treated to prevent fungus growth. Materials not meeting this requirement shall be identified including any action required such as inspection, maintenance, or replacement periods. Fungus treatment shall not adversely affect unit performance or service life or constitute a health hazard to higher order life. Materials so treated shall be protected from environments that would be sufficient to leach out the protective agent.

4.2.3.9 Glycols

When solutions containing ethylene glycol are used aboard spacecraft which have electrical or electronic circuits containing silver or silver-coated copper, a silver chelating agent such as benzotriazole (BZT) shall be added to the solution to prevent spontaneous ignition from the reaction of silver with ethylene glycol. When solutions containing other glycols (aliphatic dihydric alcohols) are used in these conditions, testing shall be conducted to determine if the same spontaneous ignition reaction can occur as with ethylene glycol, and a silver chelating agent shall be added to the solution if ignition can occur.

4.2.3.10 Etching Fluorocarbons

The etching of fluorocarbons shall meet the requirements of SAE-AMS 2491, *Surface Treatment of Polytetrafluoroethylene, Preparation for Bonding*. Etched surfaces must be processed within 24 hours or packaged per SAE-AMS 2491. Etched surfaces packaged per AMS 2491 shall be processed within 1 year. Electrical wire or cable insulated or coated with fluorocarbons shall be etched prior to potting to ensure mechanical bond strength and environmental seal. When etching of wire insulation is required to provide satisfactory bonding to potting materials, the open end of the wire shall not be exposed to the etchant.

4.2.4 Processes

4.2.4.1 Forging

Because mechanical properties are optimum in the direction of material flow during forging, forging techniques shall be used that produce an internal grain-flow pattern such that the direction of flow is essentially parallel to the principal stresses. The forging pattern shall be essentially free from re-entrant and sharply folded flow lines. After the forging technique, including degree of working, is established, the first production forging shall be sectioned to show the grain-flow patterns and to determine mechanical properties at control areas. The procedure shall be repeated after any change in the forging technique. The information gained from this effort shall be utilized to redesign the forging as necessary. These data and results of tests on the redesign shall be retained and be made available for review by the procuring activity.

Where forgings are used in critical applications first-article (preproduction) approval is obtained from the procuring authority; first-article approval and the controls to be exercised in producing subsequent production forgings shall be in accordance with AMS 2375, *Control of Forgings*

Requiring First Article Approval. In addition, trim ring or protrusion specimens shall be obtained for each forging and shall be tested for required minimum mechanical properties; surface and volumetric nondestructive inspection shall also be performed.

4.2.4.2 Castings

Castings shall meet the requirements of SAE-AMS-2175, *Castings, Classification and Inspection of.*

4.2.4.3 Adhesive Bonding

Structural adhesive bonding shall meet MSFC-SPEC-445A, *Adhesive Bonding, Process, and Inspection, Requirements for*. Retesting of adhesives used for production parts is not required if they are within shelf life. The sensitivity of structural adhesive bonds to contamination is of particular concern. Structural adhesive bonding processes shall be controlled to prevent contamination that would cause structural failure which could affect the safety of the mission, crew, or vehicle or affect mission success. Bond sensitivity studies shall be conducted to verify the required adhesive properties are maintained after exposure to potential contaminant species and concentrations. Adequate in-process cleanliness inspections shall be conducted as part of the bonding process. Bonded primary structural joints shall demonstrate cohesive failure modes in shear.

4.2.4.4 Welding

The design selection of parent materials and weld methods shall be based on consideration of the weldments, including adjacent heat-affected zones, as they affect operational capability of the parts concerned. Welding procedures shall be selected to provide the required weld quality, minimum weld energy input, and protection of the heated metal from contamination. The suitability of the equipment, processes, welding supplies, and supplementary treatments selected shall be demonstrated through qualification testing of welded specimens representing the materials and joint configuration of production parts.

The processing and quality assurance requirements for manual, automatic, and semiautomatic fusion welding for space flight applications shall meet the requirements of NASA-STD-5006, *General Fusion Welding Requirements for Aerospace Materials Used in Flight Hardware*.

4.2.4.5 Brazing

Brazing shall be conducted in accordance with AWS C-3.3, *Design, Manufacture, and Inspection of Critical Brazed Components, Recommended Practices for*. Brazing of aluminum alloys shall meet the requirements of AWS C-3.7, *Aluminum Brazing*. Torch, induction, and furnace brazing shall meet the requirements of AWS C-3.4, AWS C-3.5, and AWS C-3.6, respectively. Subsequent fusion-welding operations in the vicinity of brazed joints or other operations involving high temperatures which might affect the brazed joint shall be prohibited unless it can be demonstrated that the fixturing, processes, methods, and/or procedures employed will preclude degradation of the braze joint.

Brazed joints shall be designed for shear loading and shall not be relied upon for strength in axial loading for structural parts. The shear strength of brazed joints shall be evaluated in accordance with AWS C3.2, *Standard Method for Evaluating the Strength of Brazed Joints*.

For furnace brazing of complex configurations, such as heat exchangers and cold plates, destructive testing shall be conducted on pre-production brazed joints to verify that the braze layer that extends beyond the fillet area is continuous and forms a uniform phase.

4.2.4.6 Structural Soldering

Soldering shall not be used for structural applications.

4.2.4.7 Electrical Discharge Machining and Laser Machining

The electrical discharge machining (EDM) and laser machining (LM) processes shall be controlled to limit the depth of the oxide layer, the recast layer, and the heat-affected zone. The oxide layer shall be removed from the surface. In addition, the recast layer and the heat-affected zone shall be removed from bearing, wear, fatigue or fracture-critical surfaces, and from crack- or notch-sensitive materials. The recast layer and heat-affected zone may be left on a part if an engineering evaluation shows that they are not of consequence to the required performance of the part. EDM/LM schedules shall be qualified to determine the maximum thickness of the affected layers when the depth of the affected material must be known for removal or analysis.

4.2.5 Material Nondestructive Inspection

4.2.5.1 Nondestructive Evaluation (NDE) Plan

The NDE Plan shall address the process for establishment, implementation, execution, and control of NDE through design, manufacturing, operations, and maintenance of flight hardware. The plan shall meet the intent of MIL-HDBK-6870A, *Inspection Program Requirements, Nondestructive for Aircraft and Missile Materials and Parts* and the requirements of NASA-STD(I)-5009, *Nondestructive Evaluation Requirements for Fracture Critical Metallic Components*. In case of conflict between the requirements of the two standards, the requirements of NASA-STD(I)-5009 are applicable. Qualification and certification of personnel involved in

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nondestructive testing shall comply with NAS 410, *NAS Certification & Qualification of Nondestructive Test Personnel*.

4.2.5.2 NDE Etching

All metallic fracture-critical parts shall be NDE etched prior to dye penetrant inspection. (**Note:** All machined or otherwise mechanically disturbed surfaces which are to be penetrant inspected must be adequately etched to assure removal of smeared, masking material prior to penetrant application on fracture-critical parts.)

4.2.6 Special Materials Requirements

4.2.6.1 Residual Stresses

Residual tensile stresses are induced into manufactured parts as a result of forging, machining, heat treating, welding, special metal-removal processes, or the straightening of warped parts. Stress equalization is a low-temperature heat treatment used to balance stresses in cold-worked material without an appreciable decrease in the mechanical strength produced by cold working. Residual stresses may be harmful in structural applications when the part is subjected to fatigue loading, operation stresses, or corrosive environments. Residual stresses shall be controlled or minimized during the fabrication sequence by special treatments such as annealing and stress relieving. The use of stress equalization and the straightening of warped parts shall require an approved MUA.

4.2.6.2 Sandwich Assemblies

Sandwich assemblies shall be designed to prevent the entrance and entrapment of water vapor or other contaminants into the core structure. Honeycomb sandwich assemblies that will be subjected to heating shall use a metallic or glass-reinforced core to minimize the absorption of moisture. Perforated and moisture-absorbing cores shall not be used in sandwich assemblies. Test methods for sandwich constructions and core materials shall meet the requirements of SAE-AMS-STD-401, *Sandwich Constructions and Core Materials: General Test Methods*.

4.2.6.3 Corrosion Prevention and Control

All parts, assemblies, and equipment, including spares, shall be finished to provide protection from corrosion in accordance with the requirements of MSFC-SPEC-250, *Protective Finishes for Space Vehicle Structures and Associated Flight Equipment, General Specification for*. Corrosion control of galvanic couples shall be in accordance with MIL-STD-889, *Dissimilar*

Metals. Galvanic couples for alloy combinations not listed in MIL-STD-889 shall not exceed 0.25 volts.

The following additional requirements shall be implemented for manned spacecraft hardware:

a. Faying surfaces of metal alloys shall be sealed for Class I, II, & III protective finish classes.
b. All contacts between graphite-based composites and metallic materials shall be treated as dissimilar metal couples and sealed per MSFC-SPEC-250.
c. All electrical bonding connections shall be faying-surface sealed, except for nickel-plated surfaces utilized in Class III applications.

For hardware in the mild corrosive environment of standard habitable spacecraft volumes where condensation is precluded, the following changes may be made:

d. Exposed aluminum surfaces may have anodic coatings instead of organic coatings specified in MSFC-SPEC-250.
e. Conversion coatings may be used as the sole corrosion protection for 5000 and 6000 series corrosion-resistant aluminum alloys. They are not acceptable as the sole corrosion protection for 2000 and 7000 series aluminum alloys.

For manned spacecraft hardware, corrosion prevention and control techniques shall be implemented to protect the hardware from corrosion as a result of exposure to manufacturing, storage, installation, and service environments. These techniques shall include the rigorous application of engineering design and analysis, quality assurance, nondestructive inspection, manufacturing, operations, and support technologies used to prevent the initiation of corrosion, avoid functional impairment due to corrosion, and provide processes for the tracking and repair of corrosion. Specific corrosion prevention and control techniques shall be defined in the Materials and Processes Selection, Control, and Implementation Plan.

4.2.6.3.1 Passivation

Corrosion-resistant steels shall be passivated after machining.

4.2.6.3.2 Sealing

Removable panels and access doors in exterior or interior corrosive environments shall be sealed either by mechanical seals or by separable, faying-surface sealing.

4.2.6.4 Hydrogen Embrittlement

When designing liquid or gaseous hydrogen systems, the degradation of metallic materials properties by hydrogen embrittlement shall be addressed in the Materials & Processes Selection, Control, and Implementation Plan. Overall, hydrogen embrittlement of materials is not very well understood and there are only limited materials property data generated and reported in MAPTIS. An MUA shall be written rationalizing the selection of metallic materials to preclude cracking and to ensure system reliability and safety. Test data may have to be generated in a simulated environment to support the rationale. Guidelines for the design of safe hydrogen systems are contained in ANSI/AIAA G-095-2004, *Guide to Safety of Hydrogen and Hydrogen Systems*.

Hydrogen embrittlement of metallic materials can also be caused by electrochemical processes or exposure to acids or bases during manufacturing or processing. Such processes shall be controlled to prevent hydrogen embrittlement or embrittlement relief treatment shall be performed promptly after processing (see section 4.2.2.2.1).

4.2.6.5 Fastener Installation

Self-locking fastener reuse shall be allowed when the running torque prior to clamp up remains between the maximum self-locking torque and the minimum breakaway torque. Wet installation of fasteners, using a corrosion-resistant sealant and installing the fastener while the sealant is still wet, is required in aqueous corrosive environments and applications where condensation can occur. Fastener management and control policy, responsibilities, and practices for structural fasteners, fracture-critical fasteners, and safety-critical fasteners that are procured, received, tested, inventoried, or installed for space flight shall meet the requirements of NASA-STD(I)-6008, *NASA Fastener Management and Control Practices*. The installation of titanium fasteners and associated parts shall meet the requirements of MSFC-STD-557, *Threaded Fasteners, 6Al-4V Titanium Alloy, Usage Criteria for Spacecraft Applications*.

4.2.6.5.1 Liquid Locking Compound

Liquid locking compounds shall not be used as secondary locking features on safety-critical fasteners[2]. Liquid locking compounds used as a secondary locking feature in non-safety-critical applications shall require a validated process specified on the engineering drawing.

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[2] For the purposes of this requirement, "safety-critical" fasteners are defined as
(a) All primary or secondary structural fasteners used in the exterior and interior of flight modules.
(b) All non-structural fasteners used exterior to flight modules, which may pose a foreign object debris (FOD) risk to vehicle operations and which have not been vibration tested during qualification or acceptance of the hardware.

4.2.6.5.2 Silver-Plated Fasteners

Silver reacts rapidly with atomic oxygen to generate a loose, friable, black oxide that can cause contamination and affect the operation of mechanisms. Silver-plated fasteners shall not be used in external applications where the silver plating is directly exposed to atomic oxygen.

4.2.6.6 Contamination Control

A contamination control plan shall be generated in accordance with the guidelines of ASTM E1548, *Standard Practice for Preparation of Aerospace Contamination Control Plans*. The plan shall include controls on contamination-sensitive manufacturing processes such as adhesive bonding, controls on packaging for shipment and storage, and a foreign-object-debris (FOD) prevention program.

The FOD prevention program shall be established for all ground operations of mechanical and electrical systems of flight hardware including the design, development, manufacturing, assembly, repair, processing, testing, maintenance, operation, and check out of the equipment to ensure the highest practical level of cleanliness. It shall conform to NAS 412, *Foreign Object Damage/ Foreign Object Debris (FOD) Prevention*.

Cleanliness levels for all hardware shall be identified on the engineering drawings.

4.2.6.7 Packaging

Packaging shall protect hardware from corrosion and contamination during shipping and storage.

4.3 Verification

Verification of compliance with the requirements of this document shall consist of the following steps as a minimum:

a. NASA approval of the contractor Materials and Processes Selection, Implementation, and Control Plan and other applicable materials data requirements documents such as the Contamination Control Plan and NDE Plan

b. Contractor M&P signature on engineering drawings to verify compliance with the requirements of this document or the Materials and Processes Selection, Implementation, and Control Plan

c. NASA audits of contractor M&P activities relating to hardware design and manufacturing

NOTE: Per section 4.1.3: The use of materials and processes that do not comply with the technical requirements of this standard may be acceptable in the actual hardware applications. Material Usage Agreements (MUAs) shall be submitted for all materials and processes that are technically acceptable but do not meet the technical requirements of this standard, as implemented by the approved Materials and Processes Selection, Control, and Implementation Plan.

d. Establishment and operation of the materials and processes control board in accordance with section 4.1.1.5 of this standard

e. NASA approval of MUAs

f. NASA approval of MIULs

NOTE: Per section 4.1.3: The use of materials and processes that do not comply with the technical requirements of this standard may be acceptable in the actual hardware applications. Material Usage Agreements (MUAs) shall be submitted for all materials and processes that are technically acceptable but do not meet the technical requirements of this standard, as implemented by the approved Materials and Processes Selection, Control, and Implementation Plan.

5. GUIDANCE

5.1 Reference Documents

The documents in this paragraph are provided as reference material for background information only. In case of conflict, this document shall take precedence.

ANSI/AIAA G-095-2004 Reference 4.1.5	Guide to Safety of Hydrogen and Hydrogen Systems
ASTM-E1548-03 Reference 4.6.5	Standard Practice for Preparation of Aerospace Contamination Control Plans
ASTM MNL36 (2000) Reference 4.1.4	Safe Use of Oxygen and Oxygen Systems – Guidelines for Oxygen System Design, Materials Selection, Operations, Storage, and Transportation
ASTM-G63-99 Reference 4.1.4	Standard Guide for Evaluating Nonmetallic Materials for Oxygen Service
ASTM-G88-90 Reference 4.1.4	Standard Guide for Designing Systems for Oxygen Service
ASTM-G94-92	Standard Guide for Evaluating Metals for Oxygen Service Reference 4.1.4
JSC 29353 Reference 4.1.1	Flammability Configuration Analysis for Spacecraft Applications
MIL-STD-2223 Change Notice 1 (1994) Reference 4.1.6	Test Methods for Insulated Electrical Wire
NASA/CR-2005-213424 Reference 4.3.4	Lubrication for Space Applications

APPENDIX A
MUA FORM

MATERIAL USAGE AGREEMENT	C	USAGE AGREEMENT NO.	REV	PAGE OF
PROJECT:	SYSTEM:	CATEGORY:	ORIGINATOR:	ORGANIZATION/CONTRACTOR:

PART NUMBER(S):	USING ASSEMBLY(S):	ITEM DESCRIPTION:	ISSUE:
MATERIAL DESIGNATION:	MANUFACTURER:	SPECIFICATION:	PROPOSED EFFECTIVITY:

MATERIAL CODE:			LOCATION:	ENVIRONMENT:		
THICKNESS:	WEIGHT:	EXPOSED AREA	HABITABLE ☐	PRESSURE PSIA:	TEMP.F:	MEDIA:
			NONHABITABLE ☐			

APPLICATION:

RATIONALE: (use second page if required.)

MATERIAL USAGE AGREEMENT DISPOSITION

CONTRACTOR TIER 1	CONTRACTOR PRIME	NASA PROJECT MGR.	NASA M & P

	DATE	APPROVE	REJECT	DEFER	
					MEMO NO.:
					EFFECTIVITY:
					ORIGINATING CONTRACTOR

APPENDIX B

CATEGORY III MUA RATIONALE CODES
FLAMMABILITY RATIONALE CODES

CODE	RATIONALE
101	Approved Materials Usage Agreement (MUA) Category I.
102	Approved Materials Usage Agreement (MUA) Category II.
103	Materials passed requirements when tested in configuration.
104	Unexposed, overcoated, or sandwiched between non-flammable materials and no ignition source or propagation path.
105	Minor usage (less than 0.1 lb (45 g) mass and 2 in^2 (13 cm^2) surface area); no propagation path or ignition source.
106	Material is used in hermetically sealed container.
107	Passes test No. 8 of NHB 8060.1, Flammability Test for Materials in Vented Containers, by test or analysis.
108	Off-the-shelf equipment having material acceptable in configuration; no ignition source or propagation path.
109	Material not exposed; totally immersed in fluid; evaluated for fluid compatibility only.
110	Material is acceptable when used on a metal substrate that provides a good heat sink. Material considered noncombustible in this configuration by test or analysis.
111	Material not A-rated for flammability is sandwiched between non-flammable materials with edges only exposed and is more than 2 in (5 cm) from an ignition source or more than 12 in (30 cm) from other materials not A-rated.
112	Material not A-rated for flammability is unexposed or is overcoated with a non-flammable material.
113	Material (less than 0.010 in (.25 mm) thickness) not A-rated for flammability is sprayed or bonded to a metallic surface greater than 0.062 in (1.6 mm) thick.
114	Material not A-rated for flammability is used in "small amounts" and is more than 2 in (5 cm) from and ignition source or more than 12 in (30.5 cm) from other materials not A-rated for flammability. "Small amounts" for flammability may be quantified as follows: total weight less than 0.1 lb(45 g) and less than 2.0 in^2 (13 cm^2) surface area.

TOXICITY (OFFGASSING) RATIONALE CODES

CODE	RATIONALE
201	Approved Material Usage Agreement (MUA) Category I.
202	Meets toxicity requirements with performed cure.
203	T value for material/component in usage weight is <0.5 in for manned flight compartment volume.
204	Materials usage in hermetically sealed container.

FLUID SYSTEM COMPATIBILITY RATIONALE CODES

CODE	RATIONALE
301	Approved Material Usage Agreement (MUA) Category I.
302	Passes requirements in configuration.
303	B-rated material passed batch lot test.
304	Approved Material Usage Agreement (MUA) Category II.

THERMAL VACUUM STABILITY RATIONALE CODES

CODE	RATIONALE
401	Approved Material Usage Agreement (MUA) Category I.
402	Approved Material Usage Agreement (MUA) Category II.
403	C-rated material; exposed area is less than 2 in^2 (13 cm^2) and not near a critical surface.
404	X-rated material; exposed area is less than 0.25 in^2 (1.6 cm^2).
405	Unexposed, overcoated, or encapsulated with approved material.
406	B-rated material cured to meet the requirements of an A-rating.
407	Meets thermal vacuum stability requirements in configuration.
408	Materials usage in hermetically sealed container.
409	Material not A-rated for thermal vacuum stability is enclosed in a sealed container (maximum leak rate less than 1 x 10-4 cm3/sec).

STRESS CORROSION CRACKING RATIONALE CODES

CODE	RATIONALE
501	Approved Material Usage Agreement (MUA) Category I.
502	Approved Material Usage Agreement (MUA) Category II.
503	Maximum tensile stress <50% of yield strength for part on electrical/electronic assemblies.
504	Martensitic or PH stainless steels used in ball bearing, race, or similar applications where the primary loading is compressive.
505	Metal not A-rated for stress corrosion cracking is not exposed to a corrosive environment after final assembly through end item use.
506	Carbon & low alloy high strength steels greater than180 ksi (1240 MPa) used in ball bearings, springs, or similar applications where primary loading is compressive, low tensile stresses, or history of satisfactory performance.

CORROSION RATIONALE CODES

CODE	RATIONALE
601	Approved Material Usage Agreement (MUA) Category I.
602	Approved Material Usage Agreement (MUA) Category II.
603	Adequately finished for corrosion protection.
604	Acceptable in use environment.
606	Electrical grounding required, cladding plus conversion coating adequate.
607	Thermal conductance and electrical bonding requirements preclude painting. Conversion coating is adequate (for aluminum only).
608	Finished on a higher assembly.
609	Laminated shim - minimum exposure of corrosion resistant material.
610	Surface of a metal not A-rated for corrosion is treated or coated in a manner which meets or exceeds the requirements of MSFC-SPEC-250A. Actual surface treatment shall be listed.
611	Metal not A-rated for corrosion is not exposed to a corrosive environment after final assembly through end item use.
612	Welding of titanium alloy-to-alloy or commercially pure-to-alloy using commercially pure filler metal in mixed alloy welds where hydrogen embrittlement is not predicted in service.

GENERAL CODES

CODE	RATIONALE
702	Generic materials controlled by military or industry specification using MAPTIS averages for ratings or test results. Material codes for generic material shall be used.
703	Military specification or industry specification allowing several material options where all options have acceptable ratings.

APPENDIX C
RECOMMENDED DATA REQUIREMENTS DOCUMENTS

Recommended Data Requirements Documents (DRDs) are as follows:

- Materials and Processes (M&P) Selection, Implementation, & Control Plan
- Material Usage Agreements (MUA)
- Materials and Processes Identification and Usage List (MIUL)
- Contamination Control Plan (CCP)
- Nondestructive Evaluation Plan (NDE)

Examples of DRD content are provided on the following pages. However, the specific DRDs and the content of those DRDs should be tailored to each manned spacecraft program and additional DRDs may be appropriate.

DATA REQUIREMENTS DESCRIPTION (DRD)

1. **PROGRAM**:
2. **DRD NO.**: XXXX
3. **DATA TYPE**: 1
4. **DATE REVISED**:
5. **PAGE**: 1
6. **TITLE**: Materials & Processes Selection, Control, and Implementation Plan

7. **DESCRIPTION/USE**:
This plan shall document the degree of conformance and method of implementation for each requirement in this standard, identifying applicable in-house specifications used to comply with the requirement. It shall also describe the methods used to control compliance with these requirements by subcontractors and vendors. The Materials and Processes Selection, Control, and Implementation Plan , upon approval by the procuring activity shall become the Materials and Processes implementation document used for verification.

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

9. **INITIAL SUBMISSION**: SRR

10. **SUBMISSION FREQUENCY**: Final at SDR

11. **REMARKS**:

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

13. **DATA PREPARATION INFORMATION**:

13.1 **SCOPE**:
The Materials and Processes Selection, Control, and Implementation Plan shall describe the hardware developer's activities involved in the identification, evaluation, documentation, and reporting of materials and processes usage in space flight hardware, support hardware and ground support equipment.

13.2 **APPLICABLE DOCUMENTS**:
NASA-STD-6016, Standard Manned Spacecraft Requirements for Materials and Processes

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

Conformance – The Plan shall address each applicable paragraph of NASA-STD-6016 and describe the method of implementation and degree of conformance for each applicable requirement. If tailoring of the requirements is planned or necessary, alternate approaches to NASA-STD-6016 may be submitted in this plan, which meet or exceed the stated requirements. This tailoring approach will allow for NASA approval of alternate requirements.

Hardware Developer's Organization - Authority shall be assigned to an individual or group who shall be responsible for review and approval of all M&P specified prior to release of engineering documentation.

Materials and Processes Identification - Identification and documentation of the M&P used, both in the original design and in any changes shall be contained in the Material and Process Identification and Usage List DRD.

Testing - Logic, procedures and data documentation for any proposed test program to support materials screening and verification testing. Any material/process testing to be performed by the hardware developer shall require prior NASA approval.

Materials Usage Agreement (MUA) Procedures - Logic, procedures and documentation involved in documenting and approving materials/processes as indicated in NASA-STD-6016 shall be defined, including those that do not meet the established requirements, but are proposed for use due to lack of replacement materials/processes or other considerations and shall be contained in the Materials Usage Agreement DRD.

Material Design Properties – The plan shall contain the philosophy describing how material properties will be determined, and if those properties do not exist, how the material properties will be developed including, but not limited to the statistical approaches to be employed.

Process Controls – The plan shall identify all process specifications used to implement specific requirements in NASA-STD-6016. All materials processes used in manufacturing shall be documented in process specifications and all applicable process specifications shall be identified on the engineering drawing. Each processing step in the process specification shall be identified in a level of detail that ensures the process is repeatable.

13.4 **FORMAT**: Electronic, Word-compatible document or Adobe PDF. For each paragraph in sections 4 and 5 of NASA-STD-6016, the plan shall state the requirement from NASA-STD-6016, identify the degree of conformance under the subheading “Degree of Conformance,” and identify the method of implementation under the subheading “Method of Implementation.”

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

DATA REQUIREMENTS DESCRIPTION (DRD)

1. **PROGRAM**:
2. **DRD NO.**: XXXX
3. **DATA TYPE**: 1 (Category I and II MUAs)
   2 (Category III MUAs)
4. **DATE REVISED**:
5. **PAGE**: 1

6. **TITLE**: Materials Usage Agreements (MUA)

8. **DESCRIPTION/USE**:
MUAs shall be submitted for all materials and processes that are technically acceptable but do not meet the technical requirements of NASA-STD-6016, as implemented by the approved Materials and Processes Selection, Control, and Implementation Plan. [The use of materials and processes that do not comply with the technical requirements of this standard may be technically acceptable if hardware reliability and vehicle safety are not affected.]

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

9. **INITIAL SUBMISSION**: PDR.

10. **SUBMISSION FREQUENCY**: At PDR and as the need for new MUAs is identified during the detailed design process. MUAs shall be revised and resubmitted whenever design modifications affect the part numbers identified on the MUA or the MUA rationale.

11. **REMARKS**:

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

13. **DATA PREPARATION INFORMATION**:

13.1 **<u>SCOPE</u>**:
MUAs shall be submitted as described below.

Category I MUAs – Category I MUAs are those that involve material/processes usage that could affect the safety of the mission, crew, or vehicle or affect the mission success, but **must** be used for functional reasons. Approval by the responsible NASA Materials and Processes organization and the NASA Program/Project Office shall be required.

Category II MUAs - Category II MUAs are those that involve material/processes usage that fails a screening of Material and Processes requirements and is not considered a hazard in its use application but for which no Category III rationale code exists. Approval by the responsible NASA Materials and Processes organization shall be required.

Category III MUAs - Category III MUAs are those that involve materials or processes that have not been shown to meet these requirements but have an approved rationale code listed in Appendix B of NASA-STD-6016. They are evaluated and determined to be acceptable at the configuration/part level. Category III MUAs shall be reported in the Materials Identification and Usage List (MIUL) system or electronic data system utilizing the approved rationale codes in Appendix B. A key may be provided to correlate contractor Category III MUA database codes to the codes in Appendix B. No MUA form is submitted. [Category III MUAs are identified here for completeness, but are not required until after PDR.]

13.2 **<u>APPLICABLE DOCUMENTS</u>**:
NASA-STD-6016, Standard Manned Spacecraft Requirements for Materials and Processes
MSFC-STD-3029, Guidelines for the Selection of Metallic Materials for Stress Corrosion Cracking Resistance in Sodium Chloride Environments

13.3 **CONTENTS**:
The MUA package shall include all technical information required to justify the application. MUAs for stress corrosion shall include a Stress Corrosion Cracking Evaluation Form per MSFC-STD-3029 (see NASA-STD-6016) and a stress analysis.

13.4 **FORMAT**: Electronic. A sample MUA form is provided in NASA-STD-6016; however, Contractor format is acceptable. The complete MUA package shall be provided in Adobe PDF format; the MUA form shall also be provided in a format that is compatible with the NASA Materials and Processes Technical Information System (MAPTIS) database.

13.5 **MAINTENANCE**: Contractor updates to the Category I and Category II MUAs shall be submitted to NASA for approval. Complete re-issue of the MUA is required.

DATA REQUIREMENTS DESCRIPTION (DRD)

1. **PROGRAM**:
2. **DRD NO.**: XXXX
3. **DATA TYPE**: 2
4. **DATE REVISED**:
5. **PAGE**: 1
6. **TITLE**: Materials Identification and Usage List (MIUL)

9. **DESCRIPTION/USE**:
The MIUL is an electronic searchable parts list or separate electronic searchable materials identification and usage list. The MIUL identifies all Material and Processes (M&P) usages contained in the end item, excluding piece part electronics, for evaluation of the acceptability of M&P selected and utilized.

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

9. **INITIAL SUBMISSION**: PDR

10. **SUBMISSION FREQUENCY**: As-designed MIUL – at Hardware Acceptance Review
As-built MIUL updates – prior to FRR

11. **REMARKS**:

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

13. **DATA PREPARATION INFORMATION**:

13.1 **<u>SCOPE</u>**:
Materials and processes usage shall be documented in an electronic searchable parts list or separate electronic searchable Materials Identification and Usage List (MIUL). The procedures and formats for documentation of materials and processes usage will depend upon specific hardware but shall cover the final design. The system used shall be an integral part of the engineering configuration control/release system. A copy of the stored data shall be provided to NASA in a form compatible with the Materials and Processes Technical Information System (MAPTIS).

13.2 **<u>APPLICABLE DOCUMENTS</u>**:
NASA-STD-6016, Standard Manned Spacecraft Requirements for Materials and Processes

13.3 **<u>CONTENTS</u>**:
The parts list or MIUL shall identify the following applicable information:

- Detail drawing and dash number
- Next assembly and dash number
- Change letter designation
- Drawing source (contractor or vendor)
- Material form
- Material manufacturer
- Material manufacturer's designation
- Material specification
- Process specification
- Environment
- Weight
- Material code
- Standard/commercial part number
- Contractor
- System
- Subsystem
- Maximum temperature
- Minimum temperature

- Fluid type
- Surface Area
- Associate contractor number
- Project
- Document title
- Criticality
- Line number
- Overall evaluation
- Overall Configuration test
- Maximum pressure
- Minimum pressure
- Test MUA Document
- Cure codes

13.4 **FORMAT**: Contractor format is acceptable. However, Contractor format for electronic submittal of MIUL data shall be compatible with the NASA Materials and Processes Technical Information System (MAPTIS) database.

13.5 **MAINTENANCE**: Contractor updates to the MIUL shall be submitted to NASA for approval. Complete re-issue of the document is not required.

DATA REQUIREMENTS DESCRIPTION (DRD)

1. **PROGRAM**:
2. **DRD NO.**: XXXX
3. **DATA TYPE**: 2
4. **DATE REVISED**:
5. **PAGE**: 1
6. **TITLE**: Contamination Control Plan (CCP)

10. **DESCRIPTION/USE**:
The contamination control plan defines implementation measures to control contamination of flight hardware and fluid systems during manufacturing, assembly, test, transportation, launch site processing, and post-flight refurbishment.

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

9. **INITIAL SUBMISSION**: PDR

10. **SUBMISSION FREQUENCY**: The contractor may submit updates/revisions at any time. Final submission shall be at CDR.

11. **REMARKS**:

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

13. **DATA PREPARATION INFORMATION**:

13.1 **SCOPE**:
The contamination control plan shall be generated in accordance with the guidelines of ASTM E1548, Standard Practice for Preparation of Aerospace Contamination Control Plans (as specified by NASA-STD-6016) and shall include:

a. a FOD control plan to prevent damage to flight hardware and injury to the flight crew by foreign object debris (FOD) during manufacture, assembly, test, transportation, launch site processing, operation, repair, modification, refurbishment and maintenance. The FOD prevention program shall conform to NAS 412, Foreign Object Damage/ Foreign Object Debris (FOD) Prevention, as specified by NASA-STD-6016.

b. Definition of cleanliness level acceptance limits and verification methods for fluid systems, and for general flight hardware internal and external surfaces. The plan shall also contain a list identifying all system fluids, together with the fluid specifications (for procurement or custom mixing) and the required cleanliness levels for the fluid system.

13.2 **APPLICABLE DOCUMENTS**:
NASA-STD-6016, Standard Manned Spacecraft Requirements for Materials and Processes
NAS 412, Foreign Object Damage/ Foreign Object Debris (FOD) Prevention

13.3 **CONTENTS**:
The FOD control plan shall address the following elements:

a. Identification of probable FOD sources
b. Early design considerations for FOD prevention, resistance to damage, foreign object entrapment, etc
c. Manufacturing planning for minimizing FOD generation and cleaning up whatever FOD is generated
d. FOD control methods
e. FOD Awareness and Prevention Training.
f. Metrics - Measuring techniques for analysis, trending, and feedback.
g. Incident investigation/reporting, "lessons learned."
h. Awareness/Employee Feedback.

The contractor shall define cleanliness level acceptance limits and verification methods for fluid systems, and for general flight hardware internal and external surfaces. The contractor shall also provide a list identifying all system fluids, together with the fluid specifications (for procurement or custom mixing) and the required cleanliness levels for the fluid system.

13.4 **FORMAT**: Electronic, Word-compatible document or Adobe PDF.

13.5 **MAINTENANCE**:

NASA-STD-(I)-6016

DATA REQUIREMENTS DESCRIPTION (DRD)

1. **PROGRAM**:
2. **DRD NO.**: XXXX
3. **DATA TYPE**: 2
4. **DATE REVISED**:
5. **PAGE**: 1
6. **TITLE**: Nondestructive Evaluation Plan

11. **DESCRIPTION/USE**:
This plan shall identify all Nondestructive Evaluation (NDE) and nondestructive testing procedures and specifications employed in the inspection of materials.

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

9. **INITIAL SUBMISSION**: PDR

10. **SUBMISSION FREQUENCY**: The contractor may submit updates/revisions at any time. Final submission shall be at CDR.

11. **REMARKS**:

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

13. **DATA PREPARATION INFORMATION**:

13.1 **SCOPE**:
The NDE Plan shall describe the process for establishment, implementation, execution and control of NDE. The plan shall meet the intent of MIL-HDBK-6870, Inspection Program Requirements, Nondestructive for Aircraft and Missile Materials and Parts and MSFC-STD-1249, Standard NDE Guidelines and Requirements for Fracture Control Programs, as specified by NASA-STD-6016.

13.2 **APPLICABLE DOCUMENTS**:
NASA-STD-6016, Standard Manned Spacecraft Requirements for Materials and Processes
MIL-HDBK-6870, Inspection Program Requirements, Nondestructive for Aircraft and Missile Materials and Parts
MSFC-STD-1249, Standard NDE Guidelines and Requirements for Fracture Control Programs

13.3 **CONTENTS**:
The plan shall define NDT planning and requirements to include the following:

Hardware Design -- The NDE plan shall define the system to assure all designs are reviewed to establish appropriate NDE inspection requirements and acceptance criteria and that final hardware design approval signifies agreement that the part is producible and inspectable or is subject to process controls.

Manufacturing Planning -- The NDE plan shall identify the process used to ensure that NDE inspection requirements are properly defined and are sequenced in the specific manufacturing process to optimizing inspection reliability and early flaw detection before unnecessary processing costs are incurred and/or processes are performed that may significantly reduce flaw detection capability.

Personnel Training -- The NDE plan shall identify formal training and certification requirements for flaw detection NDT Inspection

NDE Reliability Requirements for Fracture Critical Parts -- Demonstration of reliability is required when the inspection method differs from standard industry and government practices described in the MIL-HDBK-5870 or MSFC-STD-1249. Application of NDE methods for detection of cracks or crack like flaws smaller than those defined in MSFC-STD-1249 shall require a reliability demonstration. Such NDE methods are referred to as "Special NDE".

NDE Reporting – The NDE plan shall describe the NDE reporting system, including the means of coordinating design requirements such as critical crack size and NDT capabilities; means of implementing NDT specifications and procedures, including personnel and facilities certification; and the means of coordinating NDT procedures and specifications with NASA.

13.4 **FORMAT**: Electronic, Word-compatible document or Adobe PDF.

13.5 **MAINTENANCE**: