JSC 27301H

Materials and Processes Selection, Control, and Implementation Plan for JSC Flight Hardware

Engineering Directorate

Structural Engineering Division

National Aeronautics and
Space Administration

Lyndon B. Johnson Space Center

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PREFACE

This Materials and Processes Selection, Control, and Implementation Plan defines the implementation of the materials and processes (M&P) requirements for all new flight hardware developed by the NASA Johnson Space Center (JSC). Space Shuttle GFE, International Space Station GFE, Constellation Program GFE, and JSC-developed payload hardware are to be designed and manufactured in accordance with this plan. The plan describes the implementation of the M&P requirements in NASA-STD-6016, Standard Materials and Processes Requirements for Spacecraft; SSP 30233, Space Station Requirements for Materials and Processes; and JPR 8080.5A, JSC Design and Procedural Standards.

This plan defines the responsibilities of the JSC Materials & Processes Branch and JSC contractors for flight hardware M&P requirements implementation and verification, and includes modifications of Space Shuttle, ISS, and Constellation Program requirements for flight hardware. The contents of this document are consistent with the tasks performed for the ISS as defined in SSP 41000, System Specification for the International Space Station.

This flight hardware Materials and Processes Selection, Control, and Implementation Plan shall be implemented on all new contracts for the procurement of JSC flight hardware, and shall be included in existing contracts through contract changes. This document is under the control of the JSC Structural Engineering Division (JSC Code ES), and any changes or revisions shall be approved by the same organization.

MATERIALS AND PROCESSES SELECTION, CONTROL, AND IMPLEMENTATION PLAN FOR JSC FLIGHT HARDWARE

Prepared By: MICHAEL PEDLEY Digitally signed by MICHAEL PEDLEY Date: 2024.02.08 13:34:12 -06'00'

ES4/Michael D. Pedley

Approved By: Ronald Lewis Digitally signed by Ronald Lewis Date: 2024.02.08 15:11:37 -06'00'

ES4 /Ronald K. Lewis
Chief, Materials and Processes Branch

REVISIONS		
VERSION	CHANGES	DATE
Baseline	Original version (Materials Control Plan for JSC Space station Government-Furnished Equipment)	3/96
A	Retitled and revised to address all JSC flight hardware; numerous minor technical revisions, including reference document updates	7/16/99
B	Added requirement for oxygen system hardware exposure to pressurized oxygen before flight (Section 5.1.4.1)	3/9/00
C	Added ISS alcohol usage control (VUAs); added requirements for precision-cleaned hardware; revised author; incorporated administrative changes for division reorganization; numerous minor technical revisions, including reference document updates	1/29/02
D	Clarified requirement on low earth orbit environment survivability (Section 5.3.7); added related requirement on external use of silver-plated fasteners (Section 5.6.5.2)	2/26/02
E	Revised and retitled document to make compliant with JSC 49774A, Standard Manned Spacecraft Requirements for Materials and Processes	11/05
F	Revised document to make compliant with NASA-STD-6016, Standard Materials and Processes Requirements for Spacecraft. NASA-STD-6016 replaces JSC 49774A, which is cancelled.	8/09
G	Revised document to make compliant with new revision, NASA-STD-6016A, Standard Materials and Processes Requirements for Spacecraft, and to address JSC Class 1-E hardware.	6/18
H	Revised document to make compliant with NASA-STD-6016C Change 1, Standard Materials and Processes Requirements for Spacecraft, and ISS OB siloxane policy letter. Revised requirements on Composite Materials and Sandwich Assemblies to exceed those in NASA-STD-6016. Identified error in JSC 29353. Other minor changes.	2/24

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APPENDICES

1.0 INTRODUCTION

This plan documents the methods by which the NASA Johnson Space Center (JSC) will implement materials and processes control for flight hardware developed by JSC, including International Space Station GFE, Orion Multi-Purpose Crew Vehicle (MPCV) Program GFE, Gateway Program GFE, Human lander System (HLS) Program GFE, Human Lander System (HLS) GFE, and payload hardware. The plan addresses the detailed requirements in NASA-STD-6016, Standard Materials and Processes Requirements for Spacecraft. The plan does not apply to program hardware developed by a program contractor as contractor-furnished equipment (CFE) or to hardware developed by commercial providers unless it is specified in the commercial provider Materials And Processes Selection, Control, and Implementation plan or M&P alternate standard.

This plan also implements for JSC flight hardware the Materials and Processes (M&P) requirements contained in SSP 30233, Space Station Requirements for Materials and Processes. The M&P requirements for MPCV, Gateway, and HLS Program hardware are contained in NASA-STD-6016; compliance with NASA-STD-6016 ensures compliance with MPCV, Gateway, and HLS Program M&P requirements. The plan tailors the requirements in NASA-STD-6016 and SSP 30233 for JSC in-house hardware; in the event of a conflict between these three documents and this implementation plan, this plan takes precedence. The plan also addresses the M&P requirements in JSC 08080.2B, JSC Design and Procedural Standards.

Note: Exceptions to NASA-STD-6016 are identified in Appendix F.

a. Flight hardware under JSC control shall be designed and fabricated in accordance with this plan.

b. This plan shall be incorporated as a general materials control specification in end-item specifications for JSC flight hardware procurements.

c. This plan shall be implemented on all new contracts for procurement of JSC flight hardware and shall be included in existing contracts through contract changes.

d. Ground Support Equipment (GSE) supplied as JSC-controlled hardware shall comply with this plan where GSE hardware can adversely affect flight hardware.

Note: *This plan does not address fracture control. Fracture control for JSC flight hardware structures, including pressure vessels, is implemented in accordance with NASA-STD-5019, Fracture Control Requirements for Spaceflight Hardware, and JSC 25863, Fracture Control Plan for JSC Flight Hardware. However, the Materials and Fracture Control Certification generated to verify compliance with this plan (see Section 4.6) includes certification of compliance with fracture control requirements and any flight limitations determined by the fracture control analysis.*

2.0 DOCUMENTS

The following documents include specifications, standards, handbooks, and other special publications. They are applicable to the extent specified herein.

In the event of a conflict between these documents and this plan, this plan shall take precedence.

2.1 APPLICABLE DOCUMENTS

2.1.1 VOLUNTARY CONSENSUS STANDARDS

DOCUMENT NO.	TITLE
AIAA/NAS NAS410 (2020)	NAS Certification and Qualification of Nondestructive Test Personnel
Reference	5.5.1
AIAA/NAS NAS412 (2023)	Foreign Object Damage/Foreign Object Debris (FOD) Prevention
Reference	5.6.7
ASTM-E595-15	Total Mass Loss and Collected Volatile Condensable Materials from Outgassing in a Vacuum Environment
Reference	5.3.6
AWS C3.2M/C3.2:2019	Standard Method for Evaluating the Strength of Brazed Joints
Reference	5.4.7
AWS C3.3:2008	Recommended Practices for the Design, Manufacture, and Inspection of Critical Brazed Components,
Reference	5.4.7
AWS C3.4M/C3.4:2016	Specification for Torch Brazing
Reference	5.4.7
AWS C3.5M/C3.5:2017	Specification for Induction Brazing
Reference	5.4.7

AWS C3.6M/C3.6:2022	Specification for Furnace Brazing
Reference	5.4.7
AWS C3.7M/C3.7:2011	Specification for Aluminum Brazing
Reference	5.4.7
AWS D17.1/D17.1M:2018	Specification for Fusion Welding for Aerospace Applications
References	5.4.6, 5.4.6.1
Battelle MMPDS Volume 1 (2023) and Volume 2 (2024)	Metallic Materials Properties Development and Standardization (MMPDS)
References	4.1.10.1, 4.1.10.3, 4.1.10.3, 5.4.1
ESD S20.20 (2021)	Development of an Electrostatic Discharge Control Program: Protection of Electrical and Electronic Parts, Assemblies and Equipment (Excluding Electrically Initiated Explosive Devices)
Reference	5.7.10
IPC-CM-770E (2004)	Component Mounting Guidelines For Printed Boards.
Reference	5.7.6.2
IPC-2221B (2012)	Generic Standard on Printed Board Design
Reference	5.7.5
IPC-2222B (2020)	Sectional Design Standard for Rigid Organic Printed Boards
Reference	5.7.5
IPC-6011 (1996)	Generic Performance Specification for Printed Boards
Reference	5.7.5
IPC-6012F (2023)	Qualification and Performance Specification for Rigid Printed Boards
Reference	5.7.5

IPC-J-STD-001H (2020)	Requirements for soldered electrical and electronic assemblies
References	5.7.6.2, 5.7.7
IPC-J-STD-001FS	Space Applications Electronic Hardware Addendum to IPC-J-STD-001F
References	5.7.6.2, 5.7.7
SAE-AMS-H-6875C (2020)	Heat Treatment of Steel Raw Materials
Reference	5.4.1
SAE-AMS-STD-401 (1999)	Sandwich Constructions and Core Materials; General Test Methods
Reference	5.6.2
SAE-AMS2175A (2010)	Castings, Classification and Inspection Of
Reference	5.4.3
SAE-AMS2375D (2007, Reaffirmed 2012)	Control of Forgings Requiring First Article Approval
Reference	5.4.2
SAE-AMS2403R (2021)	Plating, Nickel General Purpose
Reference	5.4.10
SAE-AMS2404J (2018)	Plating, Electroless Nickel
Reference	5.4.10
SAE-AMS2423F (2022)	Plating, Nickel Hard Deposit
Reference	5.4.10
SAE-AMS2488E (2019) or Higher	Anodic Treatment - Titanium & Titanium Alloys, Solution pH 13
Reference	5.2.3.2

SAE-AMS2491G (2022)	Surface Treatment, Polytetrafluoroethylene, Preparation for Bonding
Reference	5.3.10
SAE-AMS2759G (2019)	Heat Treatment of Steel Parts, General Requirements
Reference	5.4.1
SAE-AMS2759/9E (2018)	Hydrogen Embrittlement Relief (Baking) of Steel Parts
Reference	5.6.4
SAE-AMS2770R (2020)	Heat Treatment of Wrought Aluminum Alloy Parts
Reference	5.4.1
SAE-AMS2771F (2017)	Heat Treatment of Aluminum Alloy Castings
Reference	5.4.1
SAE-AMS2772H (2023)	Heat Treatment of Aluminum Alloy Raw Materials
Reference	5.4.1
SAE-AMS2773F (2022)	Heat Treatment, Cast Nickel Alloy and Cobalt Alloy Parts
Reference	5.4.1
SAE-AMS 2774G (2020)	Heat Treatment, Wrought Nickel Alloy and Cobalt Alloy Parts
Reference	5.4.1
SAE-AMS-H-81200D (2014)	Heat Treatment of Titanium and Titanium Alloys.
Reference	5.4.1
SAE-AS7928C (2019)	Terminals, Lug: Splices, Conductors: Crimp Style, Copper, General Specification For
Reference	5.7.8

SAE CMH-17-1H (2022)	Composite Materials Handbook Volume 1. Polymer Matrix Composites Guidelines for Characterization of Structural Materials
Reference	4.1.10.1
SAE CMH-17-2H (2018)	Composite Materials Handbook Volume 2. Polymer Matrix Composites Materials Properties
Reference	4.1.10.1
SAE CMH-17-3G (2012)	Composite Materials Handbook Volume 3. Polymer Matrix Composites Materials Usage, Design, and Analysis
Reference	4.1.10.1
SAE CMH-17-4B (2013)	Composite Materials Handbook Volume 4. Metal Matrix Composites
Reference	4.1.10.1
SAE CMH-17-5A (2017)	Volume 5. Ceramic Matrix Composites
Reference	4.1.10.1
SAE CMH-17-6 (2013)	Composite Materials Handbook Volume 6. Structural Sandwich Composites
Reference	4.1.10.1

2.1.2 GOVERNMENT AND MILITARY STANDARDS

DOCUMENT NO.	**TITLE**
MIL-HDBK-6870B (2012)	Nondestructive Inspection Program Requirements for Aircraft and Missile Materials and Parts
Reference	5.5.1
MIL-HDBK-454C (2021)	General Guidelines for Electronic Equipment
Reference	5.3.8
MIL-STD-810H (2022)	Department of Defense Test Method Standard for Environmental Engineering Considerations and Laboratory Tests
Reference	5.3.8

2.1.3 NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

DOCUMENT NO.	TITLE
GSDO-RQMT-1080 (2013)	Cross-Program Contamination Control Requirements
Reference	5.4.12
NASA-STD-5006A	General Fusion Welding Requirements for Aerospace Materials Used in Flight Hardware
Reference	5.4.6
NASA-STD-5009C	Nondestructive Evaluation Requirements for Fracture-Critical Metallic Components
Reference	5.5.1, 5.5.2
NASA-STD-6001B	Flammability, Offgassing, and Compatibility Requirements and Test Procedures
References	5.1, 5.1.1, 5.1.2, 5.1.3, 5.1.4, 5.1.5
NASA-STD-6012A	Corrosion Protection for Space Flight Hardware
Reference 5.6.3	
NASA-STD-6016C	Standard Materials and Processes Requirements for Spacecraft
References	1.0, 3.1.1, 3.5, 4.1.1, 4.1.2, Appendix E, Appendix F
NASA-STD-6030	Additive Manufacturing Requirements for Spaceflight Systems
Reference:	5.4.11
NASA-STD-8739.1B	Workmanship Standard for Polymeric Application on Electronic Assemblies
References	5.7.6.1, 5.7.6.2
NASA-STD-8739.4A	Crimping, Interconnecting Cables, Harnesses, and Wiring
References	5.7.3, 5.7.8, 5.7.9

NASA-STD-8739.5A	Fiber Optic Terminations, Cable Assemblies, and Installation
References	5.7.4

2.1.4 JOHNSON SPACE CENTER / SPACE STATION PROGRAM

The latest revision of all JSC documents shall be used.

DOCUMENT NO.	**TITLE**
JSC 20584	Spacecraft Maximum Allowable Concentrations for Airborne Contaminants
Reference	5.1.2
JSC 25863	Fracture Control Plan for JSC Flight Hardware
Reference	1.0
JPR 8080.5	JSC Design and Procedural Standards Manual
Reference	1.0
JPR 8500.4	Engineering Drawing System Manual: Drawing Format, Requirements, and Procedures
References	3.0, 3.6, 4.1.2
JPR 8730.12	Electrostatic Discharge Control Requirements for the Protection of Electrical and Electronic Parts, Assemblies, and Equipment (Excluding Electrically Initiated Devices)
Reference	5.7.10
SSP 30233	Space Station Requirements for Materials and Processes
References	1.0, 3.1.1, 3.4, 3.5
SSP 30234	Failure Modes and Effects Analysis and Critical Items List Requirements for Space Station
References	3.2.1, 3.2.2
SSP 50431	Space Station Program Requirements for Payloads
References	3.2.1, 3.2.2

2.1.5 MARSHALL SPACE FLIGHT CENTER

DOCUMENT NO.	TITLE
MSFC-SPEC-445A (1990)	Adhesive Bonding, Process and Inspection, Requirements for
Reference	5.4.5
MSFC-STD-3029A (2005)	Guidelines for Selection of Metallic Materials for Stress-Corrosion-Cracking Resistance in Sodium Chloride Environments
Reference	5.2

2.1.6 JOHNSON SPACE CENTER MATERIALS AND PROCESSES BRANCH

The latest revision of all JSC Materials and Processes Branch documents shall be used.

PRC-0001	Manual Arc Welding of Aluminum Alloy Hardware
Reference	5.4.6
PRC-0002	Manual Arc Welding of Titanium Alloy Flight Hardware, Process Specification for
Reference	5.4.6
PRC-0005	Manual Arc Welding of Steel and Nickel Alloy Flight Hardware
Reference	5.4.6
PRC-0007	Process Specification for the Manual Arc Welding of Developmental and Experimental Hardware
Reference	5.4.6
PRC-0009	Resistance Spot Welding of Battery and Electronic Assemblies
Reference	5.4.6
PRC-0010	Automatic and Machine Arc Welding of Steel and Nickel Alloy Hardware
Reference	5.4.6

PRC-0011	Semi-Automatic and Machine Stud Welding of Non Flight Hardware
Reference	5.4.6
PRC-0014	Friction Stir-Welding
Reference	5.4.6
PRC-0015	Process Specification for Automatic and Machine Arc Welding of Titanium and Titanium Alloy Hardware
Reference	5.4.6
PRC-1001	Process Specification for Adhesive Bonding
Reference	5.4.5
PRC-2001	Heat Treatment of Steel Alloys
Reference	5.4.1
PRC-2002	Heat Treatment of Aluminum Alloys
Reference	5.4.1
PRC-2003	Heat Treatment of Nickel Alloys
Reference	5.4.1
PRC-4002	Application of Thermal and Corrosion Control Paints and Coatings
Reference	5.6.3
PRC-4004	Sealing of Joints and Faying Surfaces
Reference	5.6.3
PRC-5001	Process Specification for Cleaning of Hardware
References	5.4.12, 5.4.12.3
PRC-5002	Passivation and Pickling of Metallic Materials
Reference	5.6.3.1

PRC-5005	Process Specification for the Chemical Conversion Coating of Aluminum Alloys
Reference	5.6.3
PRC-5006	Anodizing of Aluminum Alloys
Reference	5.6.3
PRC-5008	Specialty Anodizing of Aluminum Alloys to Control Optical Properties
Reference	5.6.3
PRC-5011	Polytetrafluoroethylene (PTFE) – Impregnated or Codeposited Surface Treatment of Aluminum Alloys
Reference	5.6.3
PRC-6001	Manufacture of Composite Laminate Prepreg. Parts
Reference	5.4.13
PRC-6002	Assembly of Sandwich Structures
Reference	5.4.13
PRC-6003	Trimming and Drilling of Composites
Reference	5.4.13
PRC-6501	Ultrasonic Inspection of Composites, Process Specification for the
Reference	5.5.1
PRC-6503	Radiographic Inspection
Reference	5.5.1
PRC-6504	Ultrasonic Inspection of Wrought Metals
Reference	5.5.1
PRC-6505	Magnetic Particle Inspection
Reference	5.5.1

PRC-6506	Liquid Penetrant Inspection
Reference	5.5.1
PRC-6509	Eddy Current Inspection
Reference	5.5.1
PRC-6510	Process Specification for Ultrasonic Inspection of Welds
Reference	5.5.1
PRC-7001	Soldering of Electrical Components
Reference	5.7.7
PRC-7002	Staking and Conformal Coating of Printed Wiring Boards and Electronic Assemblies
References	5.7.6.1 and 5.7.6.2
PRC-7003	Electrical Cables, Wiring, and Harnesses
Reference	5.7.3
PRC-9001	Installation of Solid and Blind Rivets
Reference	5.6.6
PRC-9004	Installation of Thin-Wall Screw Thread Inserts
Reference	5.6.6
PRC-9005	Lockwiring
Reference	5.6.6
PRC-9006	Installation of Key-Retained Screw Thread Inserts
Reference	5.6.6
PRC-9007	Installation of Threaded and Collared fasteners
Reference	5.6.6

PRC-9008	Installation of Helical Coil Inserts
Reference	5.6.6
ES SOP-004.5	Control of Weld and Braze Filler Materials, Electrodes, and Fluxing Materials
Reference	5.4.6, 5.4.7
ES SOP-007.5	Materials and Processes Drawing Approval
Reference	4.1.1.2, 4.2.1
ES SOP-007.6	Materials and Fracture Control Certification
Reference	4.1.6.1, 4.1.6.2, 4.1.7, 4.2
ES SOP 0009.86	Written Practice for Certification and Qualification of Nondestructive Evaluation Personnel
Reference	5.5.1

2.2 REFERENCE DOCUMENTS

DOCUMENT NO.	TITLE
ASTM G63	Standard Guide for Evaluating Nonmetallic Materials for Oxygen Service
Reference	5.1.4
ASTM G88	Standard Guide for Designing Systems for Oxygen Service
Reference	5.1.4
ASTM G94 (R 2014)	Standard Guide for Evaluating Metals for Oxygen Service
Reference	5.1.4
JPD 7120.9	Experimental Flight Hardware (Class 1-E) Development Policy
References	3.0, 3.6

JPR 7120.10	JSC Experimental Flight Hardware Class 1-E Procedural Requirements
Reference	4.2.1
GSFC Supplement S-312-P003	Process Specification for Rigid Printed Boards for Space Applications and Other High Reliability Uses,
Reference	5.7.5
JSC 29353	Flammability Configuration Analysis for Spacecraft Applications
Reference	5.1.1
MPCV 70059	Orion Multi-Purpose Crew Vehicle (MPCV) Program Safety and Mission Assurance (S&MA) Requirements
Reference	5.7
MSFC-SPEC-250A (1977)	Protective Finishes for Space Vehicle Structures and Associated Flight Equipment, General Specification for
Reference	Appendix E
NSTS 1700.7B (including ISS Addendum)	Safety Policy and Requirements for Payloads Using the Space Transportation System
References	3.4
NASA-TM-86556	Lubrication Handbook for the Space Industry, Part A: Solid Lubricants, Part B: Liquid Lubricants
Reference	5.3.4
SE-R-0006 (Retired)	Space Shuttle Program Requirements for Materials and Processes
Reference	3.4
SSP 51700 (Retired)	Payload Safety Policy and Requirements for the International Space Station
Reference	3.4

SSP 51721	ISS Safety Requirements Document
Reference	3.4, 3.5
SSP 57000	Pressurized Payloads Interface Requirements Document,
Reference	3.5
SSP 57003	External Payload Interface Requirements Document
Reference	3.5

3.0 <u>REQUIREMENTS IMPLEMENTATION RESPONSIBILITIES</u>

Primary responsibilities for implementing the requirements in this plan are divided between the JSC Materials & Processes Branch and JSC contractors as outlined in this section. These and other responsibilities are discussed in further detail in other sections of this document. JSC contractors are divided into in-house contractors that design and fabricate flight hardware at JSC, using the JSC engineering drawing release system per JPR 8500.4 (for Class 1-E hardware, as defined by JPD 7120.9, Experimental Flight Hardware (Class 1-E) Development Policy, other drawing release systems are permitted), and outside contractors that normally design and fabricate flight hardware for JSC in accordance with a contractor drawing release system (note that outside contractors can (and sometimes do) choose to use the JSC engineering drawing release system per JPR 8500.4).

3.1 "PLAN" AND "NON-PLAN" CONTRACTORS

The terms "plan" and "non-plan" JSC contractors are used only for the purposes of this plan, as follows:

3.1.1 "PLAN" CONTRACTOR

A "plan" flight hardware contractor is defined as a contractor that has a Materials and Processes Selection, Control, and Implementation Plan approved by the JSC Materials & Processes Branch as meeting the requirements of either this control plan or the applicable program materials and processes requirements document (such as SSP 30233 for ISS and NASA-STD-6016 for later programs). Only a few major contractors are required by contract by the JSC Materials & Processes Branch to provide a Materials and Processes Selection, Control, and Implementation Plan. (Refer to Section 4.1 of this plan for information on Materials and Processes Selection, Control, and Implementation Plans.) Plan contractors may choose to use the applicable program materials and processes requirements document without modification instead of generating a Materials and Processes Selection, Control, and Implementation Plan (plan contractors usually prefer to generate a plan as it allows for tailoring of requirements). Plan contractors (and not the JSC Materials & Processes Branch) are responsible for certifying their flight hardware for materials and processes to JSC requirements, unless otherwise specified in the Materials and Processes Selection, Control, and Implementation Plan, Materials and Processes Alternate Standard, and/or the contract.

3.1.2 "NON-PLAN" CONTRACTOR

A "non-plan" flight hardware contractor is defined as a contractor that neither has, nor is required by contract to develop, a Materials and Processes Selection, Control, and Implementation Plan approved by the JSC Materials & Processes Branch. Consequently, a non-plan contractor cannot provide final materials certification for JSC flight hardware.

The JSC Materials & Processes Branch shall provide Materials and Fracture Control Certification for JSC flight hardware provided by non-plan contractors.

Note: The contractor for the ISS Cargo Mission Contract (CMC) it not required by contract to develop, a Materials and Processes Selection, Control, and Implementation Plan and works directly to SSP 30233, hardware developed for ISS under this contract is considered to be CFE and is not covered by this document. The ISS CMC contractor is also providing hardware to other programs such as MPCV and HLS. This hardware is classed as GFE for these programs, but the same hardware certification process is used as for ISS CFE except that the hardware is certified to NASA-STD-6016.

3.2 NEW FLIGHT HARDWARE

Basic M&P responsibilities for new flight hardware are summarized in this section. Recertification of existing Space Shuttle and payload flight hardware provided to support ISS and recertification of existing Space Shuttle and ISS hardware for the Multipurpose Crew Vehicle (MPCV) program are addressed in section 3.4 of this plan. Further details on these and other M&P responsibilities are discussed in other sections of the plan.

3.2.1 JSC PLAN CONTRACTOR FLIGHT HARDWARE

JSC plan contractor flight hardware refers to flight hardware developed for JSC by a contractor with an approved Materials and Processes Selection, Control, and Implementation Plan (per Section 3.1.1).

The plan contractor shall perform the following basic M&P functions:

a. The plan contractor shall provide drawing review and approval for M&P

b. The plan contractor shall provide a Materials Identification and Usage List (MIUL) (or an electronic searchable parts list) for all Criticality category 1 ISS and MPCV flight hardware. (Criticality categories are as defined in SSP 30234.) Criticality categories 1R, 1S, 1SR and 1P are not included.

***Notes*:**

1. *The MIUL is required for payload criticality 1 hardware only if the payload is Class A or Class B per SSP 50431, Space Station Program Requirements for Payloads (or equivalent classes for other program payloads)*

2. *For selected plan contractors, additional MIUL requirements may be specified in the contract.*

c. The plan contractor shall generate and approve Materials Usage Agreements (MUAs) and water-soluble Volatile Organic Compound Usage Agreements (VUAs).

Final MUA/VUA approval will be by the JSC Materials and Processes Branch.

d. The plan contractor shall provide materials certification as specified in the Materials and Processes Selection, Control, and Implementation Plan and/or the contract.

3.2.2 JSC NON-PLAN CONTRACTOR FLIGHT HARDWARE (& FLIGHT HARDWARE DESIGNED BY JSC EMPLOYEES)

The above two types of flight hardware in the title are grouped together in this section because both types of flight hardware have M&P functions that are performed by the JSC Materials & Processes Branch, as shown below:

a. The JSC Materials & Processes Branch shall provide drawing review and approval for M&P.

This requirement applies to drawings generated by JSC employees, and to most of the non-plan contractors who generate drawings in the "JSC engineering drawing system", with the following two exceptions:

(a) Some non-plan contractors who generate flight hardware drawings in the JSC engineering drawing system have been selected by the JSC Materials & Processes Branch to sign their own JSC drawings for M&P (and also generate their own MIULs and MUAs).

(b) The JSC Materials & Processes Branch does not approve contractor drawings generated per a contractor's own engineering drawing system but does review such drawings to the extent necessary to ensure compliance with M&P requirements.

Note: JSC Materials & Processes Branch drawing review and approval may be conducted by civil servants or by in-house contractors.

b. The JSC Materials & Processes Branch shall provide a Materials Identification and Usage List (MIUL) (or an electronic searchable parts list) for Criticality category 1 flight hardware with the following exceptions:

(1) Electrical, electronic, and electromechanical (EEE) parts other than wire, cable, and exposed surfaces of connectors.

(2) Materials used in hermetically sealed electronic containers (maximum leak rate less than 1 x 10^{-4} cm^3/sec).

(3) Criticality category 1 Class 1-E hardware

Notes:

1. *The MIUL is required for payload criticality 1 hardware only if the payload is Class A or Class B per SSP 50431, Space Station Program Requirements for Payloads (or equivalent classes for other program payloads)*

2. *For selected plan contractors, additional MIUL requirements may be specified in the contract.*
3. *JSC Materials and Processes Branch functions may be performed by civil servants or in-house support contractors.*

c. The JSC Materials & Processes Branch shall provide assistance to flight hardware managers in the generation of Materials Usage Agreements (MUA)

d. The JSC Materials & Processes Branch shall approve MUAs

e. The JSC Materials & Processes Branch shall provide Materials and Fracture Control Certification.

3.3 MATERIALS AND PROCESSES RECIPROCAL AGREEMENTS

NASA Centers (or other space agencies) with reciprocal agreements for Materials and Processes with JSC shall generate MUAs and materials certifications on payload hardware that they manage or manufacture.

The reciprocal or intercenter agreements with other NASA Centers and other space agencies involve acceptance of each other's materials certifications and MUAs.

Currently, NASA Centers that have reciprocal agreements with JSC include Glenn Research Center, Marshall Space Flight Center, Jet Propulsion Laboratory, and Goddard Space Flight Center. NASA also has M&P reciprocal agreements with the European Space Agency (ESA), the Japan Aerospace Exploration Agency (JAXA), and the Russian space companies, Energia and Khrunichev; these agreements cover stowed cargo as well as payloads.

Copies of these agreements can be obtained from the JSC Materials & Processes Branch.

3.4 PREVIOUSLY CERTIFIED GFE FOR ISS AND MPCV

JSC GFE hardware certified prior to the baseline release of JSC 27301 is certified by the JSC Materials & Processes Branch as meeting the requirements of SE-R-0006, Space Shuttle Program Requirements for Materials and Processes, and NSTS 1700.7, Safety Policy and Requirements for Payloads Using the Space Transportation System.

a. For previously approved hardware built to SE-R-0006 and NSTS 1700.7 and supplied as GFE to the ISS Program, Materials Usage Agreements (including Materials Stowage Codes) shall be reviewed by the JSC Materials & Processes Branch, or plan contractor, as applicable, to verify compliance with this plan.

All JSC GFE certified since the baseline release of JSC 27301 is certified by the JSC Materials & Processes Branch as meeting the requirements of SSP 30233, Space Station Requirements for Materials and Processes and NSTS 1700.7, SSP 51721, ISS Safety Requirements Document, or

SSP 51700, Payload Safety Policy and Requirements for the International Space Station (retired and replaced for payloads by SSP 51721.

b. For previously approved hardware built to SE-R-0006, NSTS 1700.7, SSP 30233, or previous releases of JSC 27301and subsequently supplied as GFE to other Programs for use in those Programs, toxic offgassing data shall be reevaluated by the JSC Materials & Processes Branch, or plan contractor, as applicable, to verify that they still meet requirements in the new vehicle volume if that volume is smaller than the vehicle volume for which offgassing was previously evaluated.

3.5 ISS GFE AS CARGO

Recertification of GFE delivered to ISS as cargo by Commercial Cargo vehicles and International Partner vehicles is not required. Recertification of GFE delivered to ISS as cargo by Commercial Crew vehicles is not required, provided that the cargo is sealed in nonporous bags and stowed in a nonflammable container until the vehicle has docked to ISS.

GFE delivered to ISS as cargo by Commercial Crew vehicles that is not sealed in bags and GFE that will be used during Commercial Crew vehicle free flight shall be reevaluated for toxic offgassing in the much smaller Commercial Crew vehicle internal free volume (11 m^3).

Except when specifically noted otherwise, all JSC GFE certified since this release of JSC 27301 (Rev. G) is certified by the JSC Materials & Processes Branch as meeting the requirements of NASA-STD-6016 as well as SSP 30233, SSP 51721,and SSP 57000, Pressurized Payloads Interface Requirements Document, SSP 57003, External Payload Interface Requirements Document, or both.

3.6 CLASS 1-E HARDWARE

JPD 7120.9, Experimental Flight Hardware (Class I-E) Development Policy, establishes a new classification of space flight hardware, Class 1-E, and directs JSC institutional organizations to change, as required, the Quality Management System processes and instructions to implement this policy directive. Class 1-E hardware does not provide mission critical functions, but all required safety processes are still followed. Although this class was initially established for experimental flight hardware, Commercial Off-the-Shelf and other non-complex, non-critical solutions may be processed as Class I-E.

Per JPD 7120.9, Class 1-E hardware is exempt from JSC Procedural Requirements (JPR) 8500.4, Engineering Drawing System Manual. At least one top assembly drawing is required but only a single authorizer is required for drawing release. With the exception of materials used in load-bearing structure and pressurized systems, materials traceability and certification of compliance (verifying that materials meet the required specifications for composition and properties) are not required. Alternate approaches to requiring materials traceability and *certification of compliance as part of verifying the acceptability of materials used in load-bearing structure and pressurized systems may be acceptable with JSC Structures concurrence.*

All general requirements in Section 4.0 and all detailed technical requirements in section 5.0 of JSC 27301except those required to ensure safety and ISS vehicle compatibility are deleted for Class 1-E hardware classed as GFE or payload hardware. Requirements to ensure safety and ISS vehicle compatibility are as follows:

- *Flammability*
- *Toxic offgassing*
- *Fluid compatibility*
- *Requirements on materials used in load-bearing structure and pressurized systems*
- *Vacuum outgassing (only for vacuum-exposed hardware)*
- *Requirements on water-soluble volatile organic compounds and siloxanes*

4.0 GENERAL REQUIREMENTS

Requirements for materials used in the fabrication and processing of spaceflight hardware are as follows:

a. Materials shall meet the worst-case useful-life requirements for the particular application.

The useful-life requirements include, but are not limited to, the following:

(1) Operational temperature limits.
(2) Loads.
(3) Contamination.
(4) Life expectancy.
(5) Moisture or other fluid media exposure.
(6) Vehicle-related induced and natural space environments.

Experimental spaceflight hardware and other hardware that do not provide mission-critical functions may have no useful-life requirements, provided that the safety of the crew, the space vehicle, or launch vehicle are not compromised.

Properties to be considered in material selection include, but are not limited to, the following:

(1) Mechanical properties.
(2) Fracture toughness.
(3) Flammability and offgassing characteristics.
(4) Corrosion.
(5) Stress corrosion.
(6) Thermal and mechanical fatigue properties.
(7) Glass-transition temperature.
(8) Coefficient of thermal expansion mismatch.
(9) Vacuum outgassing.
(10) Fluids compatibility.
(11) Microbial resistance.
(12) Moisture resistance.
(13) Fretting.
(14) Galling.
(15) Susceptibility to electrostatic discharge (ESD).
(16) Susceptibility to contamination.

b. M&P used in interfacing GSE, test equipment, hardware processing equipment, hardware packaging, and hardware shipment shall be controlled to prevent damage to or contamination of spaceflight hardware.

4.1 MATERIALS AND PROCESSES, SELECTION, CONTROL, AND IMPLEMENTATION PLAN

a. The contractor shall provide a Materials and Processes Selection, Control, and Implementation Plan when specified in the contract data requirements.

The contractor Materials and Processes Selection, Control, and Implementation Plan documents the degree of conformance and method of implementation for each requirement in this plan and identifies applicable in-house specifications used to comply with the requirement.

Other documents, such as contractor-specific M&P requirements documents and detailed requirements compliance matrices, can be used to form the basis of the Materials and Processes Selection, Control, and Implementation Plan, provided the content addresses the requirements.

b. The contractor Materials and Processes Selection, Control, and Implementation Plan shall also describe the methods used to control compliance with these requirements by subcontractors and vendors.

Prime contractors may require subcontractors and vendors to develop a tailored plan to comply with NASA-STD-6016 or a tailored plan to comply with the prime contractor's plan. Alternatively, prime contractors may flow down a limited subset of (or even no) requirements, with the prime making up the difference between the subset and materials control plan. Whichever approach is selected, prime contractors are responsible for ensuring that hardware designed and fabricated by their subcontractors meet this materials control plan or NASA-STD-6016.

c. Upon approval by the procuring activity, the contractor Materials and Processes Selection, Control, and Implementation Plan, shall become the M&P implementation document used for verification.

d. All JSC flight hardware contractors not required by their contract to provide a Materials and Processes Selection, Control, and Implementation Plan shall use this document as their Materials and Processes Selection, Control, and Implementation Plan instead of developing a separate contractor plan.

Only a few major contractors are required by contract to provide a Materials and Processes Selection, Control, and Implementation Plan.

e. The contractor Materials and Processes Selection, Control, and Implementation Plan shall address the content of sections 4 through 6 of this plan.

4.1.1 COORDINATION, APPROVAL, AND TRACKING

The contractor 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.

4.1.2 APPROVAL SIGNATURE

a. The contractor Materials and Processes Selection, Control, and Implementation Plan shall include a requirement that all hardware design drawings and revisions for spaceflight hardware that provides mission-critical functions contain an M&P approval block, or equivalent, to ensure that the design has been reviewed by the responsible M&P authority and complies with the intent of this document.

b. The M&P drawing approval process shall comply with ES SOP-007.5, Materials and Processes Drawing Approval.

c. For non-plan contractors, the JSC Materials & Processes Branch shall review drawings to the extent necessary to ensure compliance to M&P requirements.

4.1.3 MANUFACTURING PLANNING

Materials and Processes organizations shall participate in manufacturing and inspection/verification planning to the extent required to ensure that manufacturing operations comply with materials and process requirements.

For flight hardware manufactured in-house at JSC, this requirement is implemented through manufacturing process teams designated for identified areas or processes. Each team consists of a materials and processes engineer, a manufacturing engineer, an area/process expert and an area supervisor. The teams are responsible for creating and maintaining process specifications, detailed process instructions, work instructions, and any other documents required to ensure that manufacturing operations comply with requirements.

4.2 MATERIALS AND PROCESSES CONTROLS

a. All materials and processes for spaceflight hardware that provides mission-critical functions shall be defined by standards and specifications selected from government, industry, and company specifications and standards.

b. All materials and processes for spaceflight hardware that provides mission-critical functions shall be identified directly on the appropriate engineering drawing.

c. Contractor M&P specifications used to implement specific requirements in this document shall be identified by document number in the Materials and Processes Selection, Control, and Implementation Plans.

JSC M&P standards and specifications used to implement the requirements of NASA-STD-6016 are identified throughout this document.

d. All contractor M&P specifications used to produce spacecraft flight hardware that provides mission-critical functions shall be made available to the responsible NASA Program or Project Office and M&P organization.

e. Process specifications for spacecraft flight hardware that provides mission-critical functions shall define process steps at a level of detail that ensures a repeatable/controlled process that produces a consistent and reliable product.

f. Process qualification shall be conducted to demonstrate the repeatability of all processes for spacecraft flight hardware that provides mission-critical functions where the quality of the product cannot be directly verified by subsequent monitoring or measurement.

Note: *With the exception of the JSC in-house process specifications (PRC-xxxx), the process requirements in section 5.4 of this plan do not always define process steps at a level of detail that ensures a repeatable/controlled process that produces a consistent and reliable product, so it should not be assumed that they are suitable to be called out as process specifications on engineering drawings. They are intended as higher-level documents that state minimum requirements and provide general directions for the design of hardware. JSC in-house process specifications require preparation of either a Detailed Process Instruction (DPI) or a contractor-generated work instruction that is verified to result in a consistent and reliable product. For higher-level specifications, a process specification (complying with the minimum requirements and general directions of the higher-level document) equivalent to a JSC PRC (and requiring a verified detailed work instruction) should be generated.*

g. JSC in-house hardware (designed and fabricated using the JSC engineering drawing release system per JPR 8500.4) other than Class 1-E hardware shall be designed and fabricated in accordance with JSC internal process specifications approved by the Materials & Processes Branch unless an alternate process is approved by the JSC M&P engineering drawing signature.

These specifications (designated PRC-xxxx) are available at https://mmptdpublic.jsc.nasa.gov/prc/prclist.htm. Most (but not all) of these specifications are identified specifically in Section 5 of this document.

4.2.1 STANDARD AND SPECIFICATION OBSOLESCENCE

A process shall be established for ensuring that updated, alternate, or new material or process standards or specifications from those identified in the Materials and Processes Selection, Control, and Implementation Plan meet or exceed the technical requirements identified in the original material or process standards or specifications.

During a long-term program, M&P 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.

Although updated M&P standards or specifications usually meet or exceed earlier standards and specifications, their use can result in requirements creep so that new hardware no longer meets the original design requirements. JSC internal process specifications (PRC-xxxx) are controlled by JSC M&P to ensure that new revisions always meet/exceed the requirements of the previous release.

4.3 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, with the exception that M&P requirements for off-the-shelf hardware, Class 1-E hardware, and other spaceflight hardware that does not provide mission-critical functions may be limited to those required to ensure safety of flight (for example, flammability, toxic offgassing) and vehicle compatibility (for example, vacuum outgassing).

4.4 M&P CONTROL PANEL

a. An M&P control panel shall be established by each contractor hardware provider with a Materials and Processes Selection, Control, and Implementation Plan (excluding subcontractors).

b. The M&P control panel's scope and membership shall be described in the Materials and Processes Selection, Control, and Implementation Plan.

The M&P control panel plans, manages, and coordinates the selection, application, procurement, control, and standardization of M&P for the contract.

The panel also resolves and dispositions M&P problems.

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

An M&P control panel is not required for contractor hardware providers with no Materials and Processes Selection, Control, and Implementation Plan other than this document.

4.5 MATERIALS AND PROCESSES USAGE DOCUMENTATION

a. M&P usage shall be documented in an electronic searchable parts list or separate electronic searchable Materials Identification and Usage List (MIUL) for hardware as specified in section 3.2.1 and 3.2.2 with the following exceptions:

(1) Electrical, electronic, and electromechanical (EEE) parts other than wire, cable, and exposed surfaces of connectors.

(2) Materials used in hermetically sealed electronic containers (maximum leak rate less than 1 x 10^{-4} cm^3/sec).

(3) Criticality category 1 Class 1-E hardware

b. The documentation of M&P usage depends upon specific hardware but shall cover the final design as delivered.

c. The documentation approach and MIUL content shall be defined in the Materials and Processes Selection, Control, and Implementation Plan.

Material codes and ratings for materials, standard and commercial parts, and components are available in the Materials and Processes Technical Information System (MAPTIS). When required, new material codes will be assigned by NASA's Marshall Space Flight Center (MSFC). In some cases, MAPTIS contains averages for ratings or test results for generic materials controlled by military or industry specifications; the material codes for the generic materials are used.

MAPTIS is accessible via the Internet at http://maptis.nasa.gov.

Note: Accessibility to MAPTIS is by registration only.

Note: For non-plan contractors, the JSC Materials & Processes Branch must be notified by CDR of all Criticality 1 flight hardware for which it is responsible for providing the MIUL and Materials and Fracture Control Certification (as well as any changes "to or from" a Criticality 1 status which might occur after CDR).

d. A periodic review of plan contractors shall be conducted by the JSC Materials & Processes Branch to ensure compliance with Material and Processes requirements.

4.5.1 MIUL CONTENT

When required, the parts list, or MIUL, should identify some or all of the following information:

(1) *Detail drawing and dash number.*
(2) *Next assembly and dash number.*
(3) *Change letter designation.*
(4) *Drawing source.*
(5) *Material form.*
(6) *Material manufacturer.*
(7) *Material manufacturer's designation.*
(8) *Material specification.*
(9) *Process specification.*

(10) Environment.
(11) (Reserved)
(12) MAPTIS material code (if data are to be provided in a form compatible with MAPTIS).
(13) Standard/commercial part number.
(14) Contractor.
(15) System.
(16) Subsystem.
(17) Maximum operating temperature.
(18) Minimum operating temperature.
(19) Fluid type.
(20) (Reserved)
(21) Associate contractor number.
(22) Project.
(23) Document title.
(24) Criticality.
(25) Line number.
(26) Overall evaluation.
(27) Overall configuration test.
(28) Maximum operating pressure.
(29) Minimum operating pressure.
(30) MUA number or rationale code.
(31) Cure codes.
(32) Materials rating.
(33) Remarks (comments field).

Ground Support Equipment is exempt from inclusion in the MIUL.

4.6 MATERIALS USAGE AGREEMENTS (MUA)

a. MUAs containing sufficient information to demonstrate that the application is acceptable shall be submitted for all M&P (including M&P for Class 1-E hardware) that are technically acceptable but do not meet the requirements of this plan or an approved contractor Materials and Processes Selection, Control, and Implementation Plan.

The use of M&P that do not comply with the requirements of this plan may still be acceptable in the actual hardware applications.

In most cases, the requirements in this document identify technical requirements for which deviations may be accepted through the MUA process. However, in some cases, MUAs are specifically identified as required for documentation of hardware acceptability.

For contractors with a Materials and Processes Selection, Control, and Implementation Plan, the MUA generation and approval system should be defined in the plan.

b. MUAs shall not be used to change the M&P requirements for a nonconforming product.

When the nonconformance is a deviation from M&P requirements and is acceptable for future series hardware, an MUA may be generated to provide technical support for a change to the product baseline.

A typical MUA form is given in Appendix D.

A tiered MUA system with three categories shall be used.

4.6.1 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 have to be used for functional reasons.

Category I flight hardware MUAs shall be approved by the hardware manager, the JSC Materials & Processes Branch Chief or the JSC GFE Materials Control Manager (or by alternates as specified in ES SOP-007.6), and the applicable Program Office.

4.6.2 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.

Category II MUAs shall be approved by the hardware manager and the JSC Materials & Processes Branch Chief or the JSC GFE Materials Control Manager (or by alternates as specified in ES SOP-007.6).

4.6.3 CATEGORY III MUAS

Contractors who want to use Category III rationale codes relevant to their hardware may do so through their Materials and Processes Selection, Control, and Implementation Plan. Category III MUAs are those that involve M&P that have not been shown to meet these requirements but have an appropriate rationale code listed in the Materials and Processes Selection, Control, and Implementation Plan. The rationale codes are approved as part of the overall Materials and Processes Selection, Control, and Implementation Plan approval. Category III rationale codes are evaluated and determined to be acceptable at the configuration/part level.

Note: The Category III MUA rationale codes in releases of this plan through Revision G have been retired, either because the acceptance rationale was deemed inadequate or because the application was made an exception to the requirement. Retired codes are listed in Appendix E, Retired Category III MUA Rationale Codes, for continuity purposes but should not be used for hardware designed to this JSC 27301 release unless they are listed as approved *rationale codes in the Materials and Processes Selection, Control, and Implementation Plan. Category III MUAs will not be used for JSC GFE hardware certified to this plan.*

4.7 VOLATILE ORGANIC COMPOUND USAGE AGREEMENTS

a. Volatile Organic Compound Usage Agreements (VUAs) shall be submitted for ISS and visiting vehicle hardware (including Class 1-E hardware) containing the following water-soluble volatile organic compounds (Section 5.3.11):

Methanol; ethanol; isopropyl alcohol; n-propyl alcohol; n-butyl alcohol; acetone; ethylene glycol; propylene glycol.

The restrictions on water-soluble volatile organic compounds apply only to hardware used in the ISS habitable environment and hardware used in visiting vehicles while docked to ISS with the hatch open. VUAs are not required for hardware used in the MPCV at this time. It is not known whether the ECLSS designs for Gateway and the HLS vehicles will require similar restrictions to those for ISS hardware. If such restrictions are required, they may also apply to MPCV vehicles that dock to Gateway or HLS.

b. A tiered VUA system with two categories shall be used.

Category II VUAs are for water-soluble volatile organic compound releases of 10 mg/day or below.

Category II VUAs shall be approved by the hardware manager and the JSC Materials & Processes Branch Chief (or by alternates as specified in ES SOP-007.6).

Category I VUAs are for water-soluble volatile organic compound releases greater than 10 mg/day.

Category I flight hardware VUAs shall be approved by the hardware manager, the NASA ISS M&P System Manager, the ISS ECLSS System Manager, the responsible ISS Office, and the ISS Alcohol Manager.

c. VUA forms shall be used for both categories.

The standard JSC VUA form is shown in Appendix D.

4.7.1 CATEGORY I VUAS

Category I VUAs are those that involve water-soluble volatile organic compound usage that exceeds 10 mg/day and could affect the safety of the ISS mission, crew, or vehicle or affect the mission success, but must be used for functional reasons. Category I VUAs are not normally approved for water-soluble volatile organic compound usage that exceeds 1.0 g/day

Category I flight hardware VUAs shall be approved by the hardware manager, the JSC Materials & Processes Branch Chief, the JSC GFE Materials Control Manager, or the NASA ISS M&P System Manager, the NASA ISS ECLSS System Manager and the ISS Increment Integration and Operations (OC) Alcohol Manager.

4.7.2 CATEGORY II VUAS

Category II VUAs are those that involve water-soluble volatile organic compound usage that is less than or equal to 10 mg/day and is not considered a hazard to ISS safety or mission success in its use application. Usage levels up to 10 mg/day do not raise the gas-phase water-soluble volatile organic compound generation rate significantly above the background level that results from normal materials offgassing.

Category II VUAs shall be approved by the hardware manager and the JSC GFE Materials Control Manager or the NASA ISS M&P System Manager.

4.7.3 VOLATILE ORGANIC COMPOUND USAGE AGREEMENT SUBMITTAL

a. Category I and II VUAs shall be submitted as appropriate for each usage of a water-soluble volatile organic compound that does not meet the requirements of this document.

b. Category I and II VUAs shall be signed by a member of the contractor M&P organization and approved as indicated in the categories above.

c. The information required on the VUA form shall be provided as specified in the contract data requirement for the category I and II MUAs and must include sufficient information to assess these usages.

A typical VUA form is shown in Appendix D page D-3.

d. The VUA shall be submitted separately from MUAs submitted for the same hardware.

Documentation of a VUA in an applicable MIUL is not required.

4.8 MATERIALS CERTIFICATION AND TRACEABILITY

a. All parts or materials used in manufacturing JSC spaceflight hardware that provides mission-critical functions shall be certified as to composition, properties, and requirements as identified by the procuring document.

b. With the exception of off-the-shelf parts, parts and materials used in critical applications such as life-limited materials and/or safety- and fracture-critical parts shall be traceable through all processing steps defined in the engineering drawing to the end-item application.

c. Distributors or other processors shall not heat treat, hot work, or cold work metal stock unless they take the responsibilities as the producer of the metal and produce a new certification.

Processing records should be retained for the life of the program.

4.9 MATERIAL DESIGN ALLOWABLES

In the design and analysis of aerospace hardware, the terms "material allowables," "design allowables," and "design values" are commonly used to address the design values used in structural analysis. The term "design values" is used throughout this document which encompasses both the material and design feature performance, whichever is used to support the structural certification.

4.9.1 REQUIREMENTS FOR DESIGN VALUES

a. A, B, or S-basis statistical values for mechanical properties of materials shall be utilized for the design and analysis of hardware for all applications where structural analysis is required.

Statistical design values are needed for any hardware where structural analysis is required in order to demonstrate positive margins of safety for the design loads and environments in combination with the factor of safety requirements.

Each distinct form of a material should be assumed to have unique design values unless testing and statistical analysis shows that design values are combinable. For example, rolled bar may have different design values than the same alloy in plate, forging, spin forming, extrusion, or casting. Different layups affect the properties of composite structures. Manufacturing methods, like welding, brazing, swaging, forming, diffusion bonding, adhesive bonding, and co-curing of sandwich alter the properties of the original materials. Design features, such as joints, ply-drops, and tapered ramps affect the design values of composites.

Design values are also required for other mechanical properties, such as dynamic properties like fatigue and fracture. The basis for these properties is not necessarily statistical, but the sampling is expected to be representative of the material, product form, and state used in the design. Some applications require lower bound, and others require typical properties. The specific requirement can be found in the governing specifications for the design, such as NASA-STD-5019, Fracture Control Requirements for Spaceflight Hardware, or NASA-STD-5012, Strength and Life Assessment Requirements for Liquid-Fueled Space Propulsion System Engines. See NASA-STD-6030 for requirements for design values for additively manufactured material.

b. The sampling for other mechanical properties, such as dynamic properties like fatigue and fracture, and verification of design values shall be representative of the material, product form, and state used in the design.

The statistical basis for fatigue and fracture properties should be consistent with the governing specification. Fatigue data provided in MMPDS requires further analysis to derive a bounded design curve.

c. A, B, or S-basis statistical methods shall be defined by, and values for mechanical properties in their design environment taken from MMPDS, Metallic Materials Properties Development and Standardization, or SAE CMH-17, Composite Materials Handbook.

Design values from MMPDS, Volume 2, may only be used if the production facility substantiates that its material and process controls produce repeatable and reliable results that support the published design value. This substantiation needs to be reviewed by NASA.

S-basis statistical values apply to metallic structures only. Although SAE CMH-17 does use the term "S-basis," it is used only for screening composite materials and such values may not be used in design.

Design values in CMH-17 Volume 2 may be used only if each production facility substantiates that its material and process controls produce repeatable and reliable results that support the published design value. "Equivalency" test methods such as those outlined in DOT/FAA/AR-03/19, Material Qualification and Equivalency for Polymer Matrix Composite Material Systems: Updated Procedure, are acceptable.

d. For metallic materials, the alloy, heat treatment, product specification, product form, and thickness shall match the alloy, heat treatment, product specification, product form, and thickness in MMPDS.

Since the testing to develop design values is specific to alloy, heat treatment, specification and form, the statistical relationship is relevant only to that same combination. Thickness affects strength of metal because of metallurgical factors that influence strength, like heat transfer during heat treatment and variability of reduction during metal working.

SAE CMH-17 is composed of six volumes: SAE CMH-17-1G, Volume 1 – Polymer Matrix Composites Guidelines for Characterization of Structural Materials; SAE CMH-17-2G, Volume 2 – Polymer Matrix Composites Materials Properties; SAE CMH-17-3G, Volume 3 – Polymer Matrix Composites Materials Usage, Design, and Analysis; SAE CMH-17-4B, Volume 4 – Metal Matrix Composites; SAE CMH-17-5, Volume 5 – Ceramic Matrix Composites; and SAE CMH-17-6, Volume 6 – Structural Sandwich Composites.

Notes:

(1) *Design values of structural materials listed in later versions of MMPDS or SAE CMH-17 than those specified in section 2 may be used provided the methodology used to develop the allowable mechanical properties is at least as conservative.*

(2) *Published properties need to be appropriate for the design environment. For example, published properties at ambient temperature are not typically appropriate for applications in high-temperature environments.*

(3) *Design Values calculated based on regression analysis according to SAE CMH-17 (Volume 1, section 8.3.7) are acceptable.*

(4) *Caution is warranted for material properties that significantly exceed minimum specification values. Sensitivity to stress corrosion cracking, loss of ductility and fracture toughness, and degraded mechanical properties at cryogenic temperatures, may result in some alloys that are over-strengthened. For example, for quenched and tempered alloy steels, precipitation hardened steels, heat treatable aluminums etc., the durability and behavior in service environments may be adversely affected when they are strengthened significantly beyond their minimum strength requirements.*

(5) *Section 5.4.1 of this document contains requirements for test verification of the adequacy of the heat treatment process when metallic materials are user heat treated.*

(6) *For composite structures, "pristine" A and B-basis design values may not be appropriate as they can be compromised by manufacturing defects, mishandling, impacts, etc. Such damage is commonly in the form of subsurface delaminations that cannot be seen by visual inspection or detected by a practical NDE program. Degraded design values that take into account damage tolerance may be substantially lower than pristine design values and may be required in accordance with NASA-STD-5019, Fracture Control Requirements for Spaceflight Hardware.*

e. When statistical design values for new or existing structural materials are not available, they shall be determined by methods described in MMPDS or SAE CMH-17 and a report documenting the derivation of the new design values be made available to NASA for review.

Design values for polymeric materials other than composites are covered by this requirement but are not addressed by MMPDS or SAE CMH-17. The methods described in SAE CMH-17 are appropriate for such materials.

It is recognized that the development of statistical design values may, at times, be impractical for materials in extreme environments given project resource limitations. In such cases, the contractor should develop a tailored approach to adequately substantiate the design values for the environment and submit the approach and design values for approval via an MUA.

f. The implementation of an approach for generating statistical design values that deviates from the sampling methodology and statistical methods in MMPDS or SAE CMH-17 and the use of design values that deviate from those published in MMPDS or SAE CMH-17 shall be approved with an MUA.

At a minimum, the following should be should be addressed in the MUA documenting the rationale for use of the alternative approach for generating statistical design values that deviate from the guidance in MMPDS or SAE CMH-17.

(1) Description of the statistical approach.

(2) Description of the number of test specimens, number of lots, heats, and/or production units, e.g., weld panels, castings, parts.

(3) Description of the range of relevant process parameters.

(4) Verification that the test specimens are representative of the product specification and product form used in the design (for metallic materials, the heat treatment and thickness also need to be verified as representative).

T*he following should be addressed in the MUA documenting the rationale for use of the alternative design values:*

(1) How the design values have been derived.

(2) How future material lots will be verified for performance.

(3) *Justification for use of the alternate statistical methods or the use of engineering reduction factors.*

For new or modified production methods, consistency with the original qualification testing and the associated design values should be demonstrated at an appropriate structural scale.

g. All contractor-developed mechanical and physical property data shall be made available to the responsible NASA M&P organization.

4.9.2 DESIGN VALUE IMPLEMENTATION IN DESIGN

a. Material “B” design values shall not be used except in redundant structure in which the failure of a component would result in a safe redistribution of applied loads to other load-carrying members.

Material "B" or "B-basis" design values are specified to assure reliability for redundant structures, which are typically components or structural elements with a redundant load path. Material "A" or "A-basis" design values may be used in lieu of Material "B" or "B-basis" because they are derived using a more conservative statistical method.

Note: For nonmetallic structures, this requirement applies only to pristine material "B" design values. For fracture-critical nonmetallic structures, B-basis design values should be used in accordance with the methods outlined in NASA-STD-5019. B-basis design values developed for intentionally damaged structure as part of damage tolerance assessment may be acceptable for *non-redundant structure. As strength and life verification of composites requires empirical testing, it may become necessary to first develop design values representing the intrinsic material constitutive properties, and then separately establish design values for discrete design features which cannot be adequately correlated via traditional stress analysis. Examples may include complex ply-drop scenarios, discontinuities, composite/metallic interfaces, sandwich ramps, or unique bonded/bolted joints. In such cases, strictly using "material" design values rather than establishing design values specific to the design feature may result in an inadequately designed structure.*

[Composite damage tolerance is outside the scope of this plan; NASA-STD-5019 contains requirements on this subject.]

b. Minimum property acceptance values in material specifications (specification minimums) not explicitly published as "S" design values in MMPDS, Volume 1, shall require an approved MUA for use as design values.

S-basis values published in MMPDS, Volume, 2 require an MUA for use as design values.

MMPDS Volume 1 requires three distinct lots of metal be tested and the data statistically analyzed and tested before the "S" design values are published in the handbook.

To minimize MUA activity, a process or set of standardized criteria can be defined in the Materials and Process Control Plan to allow the use of specification minimums for design without MUAs for traditionally produced material. Approaches could include extra lot testing, proof testing, substantiating the "S" basis over time, high margin applications, or the use of substantiated engineering reduction factors. Process intensive material (such as additive manufacturing) should not use this minimized MUA activity.

4.9.3 STRUCTURAL FASTENER DESIGN VALUES

Structural fastener design values shall be defined by minimum load test requirements in the applicable part and/or procurement specification (government, aerospace industry consensus, company-specific, or custom specification).

MMPDS design values are not transferrable to fasteners, because raw material used to make fasteners is reprocessed using various metallurgical practices such as hot heading, thread rolling, and heat treating. These processes change the strength of the metal from the original bar stock. NASA has chosen to adopt lot tested design strength defined in the specific fastener part and procurement specifications as the design value instead of the certifications of the original bar stock.

Other structural fastener requirements are identified in section 5.6.6.

4.10 MATERIALS AND FRACTURE CONTROL CERTIFICATION PROCESS

Materials and Fracture Control Certification is required to document that hardware has been evaluated for compliance with the M&P requirements of this document. The Materials and Fracture Control Certification process includes drawing review and approval, and issuance of a Materials and Fracture Control Certification.

a. The Materials and Fracture Control Certification process shall comply with ES SOP-007.6, Materials and Fracture Control Certification.

b. A Materials and Fracture Control Certification shall be issued by the JSC Materials & Processes Branch or plan contractor, as applicable, after satisfactory completion of required materials analysis and/or testing, drawing review, fracture control analysis, MUAs, and VUAs.

c. The Materials and Fracture Control Certification shall identify any MUAs or VUAs applying to the hardware and the reason for each MUA (use of flammable materials, stress corrosion sensitive materials, etc.).

d. The Materials and Fracture Control Certification shall identify the vehicle locations (environments) for which the hardware is approved and any flight limitations.

Formal Materials and Fracture Control Certification is not required for crew preference hardware that is manifested outside the standard JSC flight hardware certification process, for items in the crew personal hygiene kit, or for medical supplies. These items are required to be evaluated for acceptability by JSC M&P, but approval is documented by e-mail. [Additional details are in 5.1.2.1 and 5.1.2.2.]

Use of this hardware in a different application (even in the same environment) may require different materials to be used and/or a new Materials and Fracture Control Certification.

A copy of the JSC Materials & Processes Branch Materials and Fracture Control Certification form is shown in Appendix C.

Plan contractors may use their own form, with the following information shown as a minimum:

(a) Top assembly drawing number

(b) Applicable M&P requirements documents

(c) Location / environment certified for

(d) Any MUAs or VUAs

(e) Any flight, EVA, or other limitations

4.10.1 M&P DRAWING APPROVAL

With the exception of spaceflight hardware built to JSC Class 1-E requirements, M&P approval is required for JSC spaceflight hardware drawings, either by the JSC Materials & Processes Branch, or the plan contractor, as applicable.

JSC requirements for JSC Experimental Flight Hardware (Class 1-E) are specified in JPR 7120.10, JSC Experimental Flight Hardware Class 1-E Procedural Requirements, which does not require formal drawing release. Class 1-E drawings, are required only to have the Class 1-E Project Manager's formal approval.

With the exception of spaceflight hardware built to JSC Class 1-E requirements, the M&P drawing approval process shall comply with ES SOP-007.5, Materials and Processes Drawing Approval.

The JSC Materials & Processes Branch signature on drawings provides only "preliminary approval" for fabrication, pending the resolution of any open issues, such as toxic offgassing, vacuum outgassing, or flammability testing, MUA approval, fracture control analysis, etc. (Contractors may choose to withhold their M&P signature until all materials issues have been resolved.) The JSC Materials & Processes Branch signature on drawings does not constitute Materials and Fracture Control Certification or final materials approval of the hardware. This is accomplished only through a formal Materials and Fracture Control Certification.

The list of personnel approved to sign JSC Engineering Drawings for M&P is maintained and controlled by the JSC Materials & Processes Branch. In-house contractors and other personnel may be authorized by the Materials & Processes Branch to sign for M&P. Authorization will be in accordance with ES SOP-007.5.

4.10.2 CERTIFICATION OF NEW FLIGHT HARDWARE

a. For new flight hardware, a Materials and Fracture Control Certification issued by the JSC Materials & Processes Branch, or plan contractor, as applicable, shall include all top assembly part numbers and their dash numbers.

b. Parts classified as subassemblies shall not be identified in the certification.

4.10.3 CERTIFICATION OF MODIFIED FLIGHT HARDWARE

a. JSC hardware that is modified by drawing change notices (DCNs) that do not change the top assembly dash number shall be approved by a Materials signature on the DCN; the Materials and Fracture Control Certification shall not be revised.

b. When drawing changes result in the top assembly dash number being changed, a new Materials and Fracture Control Certification shall be issued.

When drawing changes result in the part number being changed or the dash number being rolled, but the changes have no effect on the rationale for MUAs applicable to the hardware, the revised part number may be redlined into the MUA, and the MUA will not be formally revised.

4.10.4 CERTIFICATION OF OFF-THE-SHELF (OTS) HARDWARE

a. The statement of work and/or procurement request for OTS spaceflight hardware shall require identification of materials contained in off-the-shelf hardware, wherever practical and cost effective.

b. When detailed materials information for OTS spaceflight hardware is not available, the hardware shall be evaluated by sufficient analysis and/or testing in configuration as required to provide for Materials and Fracture Control Certification.

c. Criticality 3 OTS and Class 1-E spaceflight hardware shall be evaluated only for compliance with M&P safety requirements (flammability, toxic offgassing, etc.) and for compatibility with the flight vehicle (normally limited to vacuum outgassing contamination).

5.0 DETAILED REQUIREMENTS

Deviations from the detailed requirements in this section require an approved MUA documenting the rationale for acceptability in the specific application.

Note: Materials and processes selection requires a tradeoff between the strengths and weaknesses of candidate materials. Materials and processes that deviate from the detailed requirements in this section are frequently the best overall choice for an application, provided that the deviations are acceptable in that application. In general, materials and processes that do not meet these detailed requirements are unacceptable for an application only if the deviations are unacceptable in that application.

5.1 FLAMMABILITY, OFFGASSING, AND COMPATIBILITY REQUIREMENTS

Materials shall meet the requirements of NASA-STD-6001, Flammability, Odor, Offgassing, and Compatibility Requirements and Test Procedures as described below.

5.1.1 FLAMMABILITY CONTROL

a. Materials that are nonflammable or self-extinguishing in their use configuration as defined by NASA-STD-6001, Test 1 or an appropriate configurational flammability test per NASA-STD-6001 shall be used for flammability control.
with the following exceptions:

a. Ceramics, metal oxides, and inorganic glasses are exempt.

b. Materials that are designed to ignite and burn in their use application (for example, pyrotechnic materials) are exempted from flammability requirements, provided that systems/experiments using such materials are designed so that the burning materials cannot act as an ignition source for other hardware.

c. Materials used in minor quantities (dimensions controlled so the potential fire propagation path is less than 15 linear cm (6 linear inches) and the surface area is no more than 80 cm^2 (12 square in)) in crew environments and 30 linear cm (12 linear inches) for external materials) with no propagation path or ignition source.

d. Materials used in sealed containers are exempt because insufficient oxygen is available to maintain combustion.

e. Materials within vented electronics packages with metallic cases and no forced air convection are exempt because of the self-extinguishing effect of expanding combustion gases in a constrained volume.

f. Materials that have been shown by test to meet the requirements of NASA-STD-6001 may be used in an environment with an oxygen concentration lower than the test level without further testing (provided that the oxygen partial pressure is no greater than the partial pressure at the test level or general test data exist to demonstrate that the higher oxygen partial pressure is outweighed by the lower percentage concentration for the environments in question).

g. Materials are acceptable when used on a metal substrate that provides an adequate heat sink. A heat sink is considered adequate in the use configuration by test or analysis. When testing is conducted, materials passing the flammability test on a metal substrate are acceptable on metal substrates of the same thickness or greater. Materials that are flammable but have a thickness less than 0.25 mm (0.010 in) and are attached to a metallic surface greater than 1.6 mm (0.062 in) thick are acceptable by analysis.

MAPTIS flammability test data showing a material meets flammability requirements when tested on a metallic substrate should not be used to accept the use of that material on a nonmetallic substrate or on no substrate.

h. Materials are unexposed, overcoated with a verified fire-blocking material, or no more than 1/4 inch thick and sandwiched between nonflammable materials with only the edges exposed.

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. When released, NASA-HDBK-5028, Flammability Configuration Analysis for Spacecraft Applications, should be used in place of JSC 29353.

Note: JSC 29353, Flammability Configuration Analysis for Spacecraft Applications, states that NASA testing has shown that solid materials (excluding materials with a finely divided flock on the surface, such as moleskin and some medical dressings) in an atmosphere containing 34 percent oxygen at 15 psia cannot be ignited by electrical powers of around 25 watts. This threshold value of 25 watts is incorrect and unconservative. It should no longer be used as an acceptance rationale for the absence of credible ignition sources. A more accurate threshold number is not available at this time.

i. Flammability configuration analysis in accordance with JSC 29353 or NASA-HDBK-5028 shows hardware configuration to be self-extinguishing.

Material flammability ratings and tests based on NASA-STD-6001B for many materials are found in the MAPTIS database. MAPTIS data showing that a material meets flammability requirements on a metallic substrate should not be used to justify use of that material on no substrate or on nonmetallic substrates.

When a material is sufficiently chemically and physically similar to a material found to be acceptable by testing per NASA-STD-6001B, the use of this material without testing may be justified on an approved MUA. All such data are from testing in Earth gravity

j. For applications in lunar and Martian gravity, the effects of reduced gravity on materials flammability shall be evaluated to ensure that the data from NASA-STD-6001 testing are adequately conservative.

Limited partial gravity testing in drop towers has shown that materials may be more flammable in partial gravity environments than in Earth gravity.

If flammable materials must be used, they should, if possible, be protected by covering with nonflammable materials, such as nonflammable tape, coatings, shrink tubing, and sleeving (the effectiveness of the covering material must be verified by test). Flammable hardware that is normally stowed in a locker or a nonflammable container may be acceptable (refer to next section on stowed hardware). The absence of ignition sources is not normally sufficient justification in itself for accepting flammable materials but may be used as supporting rationale for acceptance.

5.1.1.1 Stowed Flammable Hardware

For ISS, operational controls have been put in place for flammable spacecraft hardware that is normally stowed. These controls are documented in the ISS Operational Control Agreement Database (OCAD) system. The standard OCAD language for control of such hardware is as follows:

> *When not in use, flammable items will be stowed in non-flammable stowage containers or compartments.*
>
> *Non-flammable stowage containers include: CTBs, JSBs, other bags or containers made of non-flammable material, ZSR/RSR compartments, and designated stowage areas in payload or other racks.*
>
> *When deployed in the open cabin for use, flammable items will be kept away from rack power outlets, utility outlet panels (UOPs) and power strips (a.k.a. Junction boxes). A guideline of approximately 6" between the flammable item and power sources will be provided in crew training. Measurement in real time is not required.*
>
> *This operational control applies to the list of items below. This list is not all inclusive.*
>
> - *Plastic or Trash Bags (Ziplocs, waste bags, food packaging, etc)*
> - *Fabric and Foam (clothing, towels, Velcro, foam packing material, etc)*
> - *Off-the-shelf plastics (camcorders, mp3 players, inflatable globe, etc) (not laptops)*
> - *Paper (procedure books, wipes, reading materials, pictures, post-its, etc)*
> - *Bungees*
> - *Rolls of Gray tape and antistatic tape (Kapton is non-flammable) (lengths of tape applied to hardware don't require special controls for this OCAD)*

A generic flammability OCAD using this language is used for hardware that would not otherwise require operational controls. If hardware-specific operational controls exist, the applicable flammability control language should be included in the OCAD for the other operational controls. Flammable spacecraft hardware is acceptable for use on ISS if it complies with these controls.

Similar controls are being placed on flammable MPCV hardware. However, instead of a single generic flammability OCAD, multiple flammability control OCADs exist with items that have a common purpose (such as all types of hearing protection) kitted together for stowage and a flammability OCAD generated at the "kit" level.

Similar controls will be needed for the Gateway and HLS Programs. The approach is not yet baselined but will likely be similar to that for MPCV.

5.1.1.2 Spacing of Hook and Loop Fasteners

Hook and loop fasteners in habitable areas, whether applied on the ground or on orbit, shall not exceed the following restrictions:

(a) Maximum size - 4 square inches

(b) Maximum length - 4 inches

(c) Minimum separation - 2 inches

5.1.2 TOXIC OFFGASSING

a. With the following exemptions, all nonmetallic materials used in habitable flight compartments, shall meet the offgassing requirements of NASA-STD-6001B.

For ISS, if the total mass of polymeric materials in an end item, or a system with multiple end items (such as a set of CubeSats with deployer) is less than 20 lb, it is exempt from offgas testing or evaluation unless it contains one of the following excluded materials:

- *COTS end items that include uncured adhesives, lubricants, cleaning wipes, markers, pens, other items with uncontained liquids or gels, and hardware used for uncontained on-orbit processing of materials at elevated temperatures (such as 3D printers) are not exempt.*

- *Custom end items that include the materials listed above or foams and foamed fluorocarbons (cables) are not exempt.*

- *If excluded materials are present or the total mass of polymeric materials exceeds 20 lb, an offgassing test could be required or an offgassing evaluation could be conducted to verify that all excluded materials and major use polymeric materials are used in quantities less than the ISS maximum limit weight in the MAPTIS database.*

The same constraints apply for polymeric materials in Commercial Crew Program, MPCV, and Gateway hardware, except that the mass limitation is 0.5 lb, not 20 lb. Similar exemptions will exist for the HLS Program, but they are not yet defined and will be vehicle specific with vehicle volume the key factor.

b. Spacecraft maximum allowable concentration (SMAC) values shall be obtained from JSC 20584, Spacecraft Maximum Allowable Concentrations for Airborne Contaminants, or from MAPTIS for compounds for which no SMAC values are found in JSC 20584.

5.1.2.1 Personal Hygiene Kit (PHK) Materials

Each astronaut is able to select basic generic off-the-shelf personal hygiene items, such as toothpaste, deodorant, makeup, etc. without an offgas test being required for each new item. The JSC Materials & Processes Branch, in conjunction with the JSC Medical Sciences Division Toxicology Group, consider that personal hygiene products sold in the United States (with exceptions cited below) do not present a significant toxic offgassing hazard in manned flight compartments.

Note: *Personal Hygiene Kit items used on ISS or on the Space Shuttle orbiter or Orion CEV while it is docked to ISS shall also comply with Section 5.3.11, with the exception that a VUA is not required if any of the 8 controlled water-soluble volatile organic compounds are present at levels that will release 10 mg/day or less.*

The following rules apply for Astronaut Personal Hygiene Kit items:

a. Products that contain a restricted alcohol listed as one of their first four ingredients shall not be used unless a VUA has been approved for the application.

Products that contain siloxanes should be avoided wherever possible for ISS or other programs where siloxanes can degrade water recovery system hardware. Products containing siloxanes can also degrade the EMU space suit water separator.

b. The use of products that contain siloxanes shall comply with memo OB-20-019, Methods of Control of Volatile Methyl Siloxanes in the International Space Station (ISS) From Crew Provisions.

Unscented products are recommended but are not mandatory.

c. Aerosol and pump sprays shall not be used.

d. Products manufactured in foreign countries and not sold in the U.S. shall be evaluated on a case-by-case basis.

e. Custom items that are not available commercially shall be evaluated on a case-by-case basis.

5.1.2.2 Medical Materials

Emergency medical kit supplies that are used only for medical emergencies are exempt from toxic offgassing and other M&P requirements, provided they remain stowed when nor in use. Emergency medical kit supplies (that are used only for medical emergencies) used on ISS, or commercial crew vehicles, while they are docked to ISS are exempted from the requirements in Section 5.3.11. A VUA is not required if any of the 8 controlled water-soluble volatile organic compounds are present.

Note: These exemptions do not apply to non-emergency items that are manifested in the emergency medical kit.

Prescription and nonprescription medications are exempted from toxic offgassing and other M&P requirements, provided they remain stowed when not in use. They are not exempted from the requirements in Section 5.3.11 except that a VUA is not required if any of the 8 controlled water-soluble volatile organic compounds are present at levels that will release 10 mg/day or less. The siloxane requirements in 5.1.2.1 and OB-20-019 also apply although siloxanes are not normally found in medications.

A list of ingredients of prescription and nonprescription medications shall be provided to JSC M&P for approval before each flight

Medications containing any of the 8 controlled water-soluble volatile organic compounds should be avoided wherever possible (propylene glycol and ethyl alcohol are the only ones likely to be present). If any of the 8 controlled water-soluble volatile organic compounds are present, M&P will evaluate the likely release, given the specifics of the medication and the way it is used. A VUA will be required if the likely release is deemed excessive.

5.1.3 FLUID COMPATIBILITY (FLUIDS OTHER THAN OXYGEN)

a. An MUA shall be written rationalizing the selection of materials if any of the following conditions apply:

(1) If a material is exposed directly to a hazardous fluid[1].
(2) If a material is exposed directly to a hazardous fluid vapor.
(3) If a material is exposed to a hazardous fluid liquid or a vapor by failure of a single barrier seal.
(4) If a material is exposed to a hazardous fluid liquid or a vapor by leakage or permeation through a single or multiple seals.

The number of seals to be considered for hazardous fluid exposure by leakage or permeation will be dictated by the system criticality and imposed fault tolerance.

[1] For the purpose of this NASA Technical Standard, the definition of hazardous fluids includes gaseous oxygen (GOX), liquid oxygen (LOX), fuels, oxidizers, and other fluids that are critical or catastrophic hazards due to chemical or physical degradation of the materials in the system, corrosion (with the exception of general corrosion covered by NASA-STD-6012) or causing an exothermic reaction.

The MUA is always required for hardware acceptability and needs to document how new or historical test data demonstrate materials acceptability of all exposed materials at worst-case operating conditions. When historical data are referenced, the references need to be included. Potential effects of reactions between the hazardous fluids and external environments need to be considered.

NASA-STD-6001B, Test 15, is a 48-hour screening test for short-term exposure to fuels and oxidizers.

b. Appropriate long-term tests to simulate the worst-case use environment that would enhance reactions or degradation shall be conducted for materials with long-term exposure to liquid fuels, oxidizers, and other hazardous liquids.

The test program needs to demonstrate that materials will not degrade sufficiently to affect hardware performance before, during, and after the actual time of hazardous fluid exposure, including ground processing prior to flight, flight exposure, dormant periods, post-flight processing prior to decontamination, and the decontamination process. It also needs to demonstrate that otherwise acceptable materials do not cause unacceptable degradation of the fluid or unacceptable release of gases/vapors. Use of elevated temperatures to accelerate the test and/or extrapolation of minor degradation from the test duration to the actual time of hazardous fluid exposure are acceptable approaches. The rationale behind the acceleration/extrapolation parameters needs to be explained in the MUA.

NASA-STD-6001B, Supplemental Test A.7, identifies changes resulting from incidental exposure (minor amounts, such as a splash) to fuels or oxidizers.

c. 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.

d. The effect of material condition (for example, parent versus weld metal or heat-affected zone) shall be addressed in the compatibility determination.

e. Materials used in nitrogen tetroxide systems shall be evaluated for flammability in nitrogen tetroxide using promoted combustion tests similar to NASA-STD-6001B, Test 17, for metallic materials used in oxygen systems and Test 1 for polymeric materials.

(1) When materials are determined to be flammable, a nitrogen tetroxide compatibility assessment shall be conducted using the methodology described for oxygen systems in NASA-STD-6001B and the system safety rationale of this assessment documented in an MUA.

f. Materials used in other oxidizer systems shall be evaluated for potential ignition.

5.1.4 OXYGEN COMPATIBILITY

a. Materials and components, and systems used in liquid oxygen (LOX) and gaseous oxygen (GOX) environments, compressed air systems, and pressurized systems containing enriched oxygen shall be evaluated for oxygen compatibility in accordance with NASA-STD-6001B.

Material flammability ratings and tests based on NASA-STD-6001B for many materials are found in the MAPTIS database.

b. When materials in such systems are determined to be flammable, an oxygen compatibility assessment shall be conducted as described in NASA-STD-6001B and the system safety rationale of this assessment documented in an MUA.

As described in NASA-STD-6001B, material/component configurational testing may be required to support the compatibility assessment.

Compressed air systems and pressurized systems containing enriched oxygen 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: Handbook for Design, Operation, and Maintenance; ASTM G88, Standard Guide for Designing Systems for Oxygen Service; ASTM G63, Standard Guide for Evaluating Nonmetallic Materials for Oxygen Service; ASTM G94, Standard Guide for Evaluating Metals for Oxygen Service; and NASA/TM-2007-213740, Guide for Oxygen Compatibility Assessments on Oxygen Components and Systems.

Note: With a few exceptions, such as Monel alloys, common structural metallic materials are flammable in oxygen at modest pressures. However, most metals can be used safely in oxygen provided that the system is designed to eliminate potential ignition sources. Titanium alloys are extremely flammable and should be used only in exceptional circumstances and at very low pressures (never above 100 psia). Aluminum alloys are also highly flammable, but can be used for static components, such as pressure vessels, at pressures up to 3,000 psia; aluminum valves, regulators, etc. should not be used at pressures above 100 psia. Stainless steel and Inconel alloys are flammable at pressures above 500 psia, but, with careful design to eliminate ignition sources, can be used safety at pressures as high as 10,000 psia.

5.1.4.1 Oxygen Component Acceptance Test

a. GOX and enriched air system components that operate at pressures above 1.83 MPa (265 psia), with the exception of items identified in Table 5-1 as not requiring testing, shall undergo oxygen component acceptance testing for a minimum of ten cycles from ambient pressure to maximum design pressure within 100 milliseconds to ensure that all oxygen system spaceflight hardware is exposed to oxygen prior to launch.

b. Oxygen system components shall be exposed to oxygen at maximum design pressure (MDP).

c. Functional tests, other than leakage, shall be conducted while the component is pressurized with oxygen at MDP (functional tests include opening and closing a valve, connecting and disconnecting a quick disconnect, etc.).

d. Cleanliness shall be maintained to the level specified in the component specification.

e. For components exposed to non-oxygen-compatible solvents as an assembly, hydrocarbon detection analysis shall be performed prior to the oxygen compatibility acceptance test; after a 24-hour "lock-up" of the component, the solvent concentration in "lock-up" gas samples shall not exceed 18 parts per million when measured as methane.

The 24-hour "lock-up" is required to ensure that enough time is provided for contaminant solvent to volatilize, thus achieving concentration equilibrium so that gas sampling will provide an accurate reflection of the residual solvent concentration.

f. The component shall be maintained at MDP for at least 30 seconds following each oxygen pressurization cycle.

g. Each component shall be subjected to oxygen flow in both the forward and reverse flow directions, where reversible flow is within the operational capability of the component.

h. Visual inspection shall be performed after conduct of the oxygen compatibility acceptance test and shall be verified to the level specified in the component specification.

i. If disassembly of the component occurs after the oxygen compatibility acceptance test, the test must be repeated.

j. All functional and leak tests required in the component specification shall be conducted (or repeated) after the oxygen compatibility acceptance test.

5.1.5 ELECTRICAL WIRE INSULATION MATERIALS

a. Electrical wire insulation materials shall be evaluated for flammability in accordance with NASA-STD-6001B Test 4 or Test 1.

Test 4 should be used for insulation on electrical power wiring where the maximum current passing through the wiring can raise the temperature above 49 °C (120 °F). Either test can be used for signal/data wiring and other wiring where the current is too small to raise the temperature above this value.

b. Arc tracking shall be evaluated in accordance with NASA-STD-6001B Test 18, for all wire insulation constructions except polytetrafluoroethylene (PTFE), PTFE/polyimide insulation conforming to SAE AS22759C, Wire, Electrical, Fluoropolymer-Insulated, Copper or Copper

Alloy, and used in conditions bounded by the dry arc-tracking test specified by SAE AS22759C, ethylene tetrafluoroethylene (ETFE), and silicone-insulated wires (the resistance of these materials to arc tracking has already been established). Polyvinyl chloride-insulated COTS wiring is also exempt.

Table 5–1. Oxygen Components Requiring Acceptance Testing

Component	Testing Required
Hard Line (rigid metal tubing)	
Metal Flex Hose	
Metal Flex Hose (>/=3,000 psia)	X
Metal Fluid Fitting with all metal seals	
Self–Sealing Quick Disconnect	X
Valve	X
Pressure Relief Valve	X
Temperature Sensor	X
Pressure Sensor	X
Nonmetal Lining Flex Hose	X
Fluid Fitting with nonmetal seals	X
Pressure Regulator	X
Metallic Pressure Vessels (including composite-overwrapped pressure vessels with metallic liners)	

b. Arc tracking shall be evaluated in accordance with NASA-STD-6001B Test 18, for all wire insulation constructions except polytetrafluoroethylene (PTFE), PTFE/polyimide insulation conforming to SAE AS22759C, Wire, Electrical, Fluoropolymer-Insulated, Copper or Copper Alloy, and used in conditions bounded by the dry arc-tracking test specified by SAE AS22759C, ethylene tetrafluoroethylene (ETFE), and silicone-insulated wires (the resistance of these materials to arc tracking has already been established). Polyvinyl chloride-insulated COTS wiring is also exempt.

5.2 METALS

a. Metallic materials shall not be used in spaceflight hardware that provides mission-critical functions outside the limits of their procurement specification, heat treat specification, or MMPDS specification.

Procurement specifications, heat treat specifications, and MMPDS all limit product size of metal stock to ensure full consolidation of cast structure, product uniformity, and consistent mechanical properties.

b. MSFC-STD-3029A, Guidelines for the 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, with the exception that an MUA is not required for the following conditions:

(1) Parts in electrical/electronic assemblies with maximum sustained tensile stress less than 50 percent of the yield strength.

(2) Martensitic or precipitation-hardening (PH) stainless steels used in ball bearing or roller bearings where the loading is compressive.

This exception cannot be used for ball-bearing races for which the primary loading is tensile.

(3) Carbon and low alloy high-strength steels with strength greater than 1240 MPa (180 ksi) used in ball bearings or similar applications where the loading is compressive and there is a history of satisfactory performance at equivalent (or more severe) stress and environmental exposure.

(4) Hardware provides no mission-critical functions.

MAPTIS contains several stress corrosion ratings in addition to those in MSFC-STD-3029A. These ratings are not acceptable for JSC flight hardware.

5.2.1 ALUMINUM

Aluminum alloys used in structural applications should 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 in spaceflight hardware that provides mission-critical functions where the temperature exceeds 66 °C (150 °F)

Grain boundary precipitation above 66 °C (150 °F) can create stress-corrosion sensitivity.

5.2.2 STEEL

5.2.2.1 Drilling and Grinding of High Strength Steel

When performing drilling, grinding, reaming, or machining of steels, low-stress machining techniques with coolant should be used. Uncontrolled high-stress machining used without coolant is detrimental to the steel microstructure. Untempered martensite is formed that leads to cracking. Overheating can soften the steel due to overtempering or decarburization. Low-stress machining practices, such as those in SAE AMS2453, Low Stress Grinding of Steel Parts Heat

Treated to 180 ksi or Over, and Low Stress Grinding of Chrome Plating Applied to Steel Parts Heat Treated to 180 ksi or Over, should be used to prevent damage to the microstructure.

a. When drilling, grinding, reaming, or machining is performed on high-strength steels that can form martensite and are used in spaceflight hardware that provides mission-critical functions, a validated process for machining shall be used.

b. The absence of machining damage for high-strength steels used in spaceflight hardware that provides mission-critical functions shall be verified by microexamination of production parts (such as Nital etch inspection) or by a microhardness and metallurgical examination of sample parts for either of the following situations:

(1) When the material has very low toughness (such as martensitic steel above 200 ksi) and the part has low stress margins or is fatigue driven.

(2) When the surface condition of the part is critical to the design (such as its ability to withstand hertzian stresses or remain perfectly flat).

5.2.2.2 Corrosion Resistant Steel

a. Unstabilized, austenitic steels shall not be processed or used above 371 °C (700 °F) in spaceflight hardware that provides mission-critical functions.

b. Welded assemblies used in spaceflight hardware that provides mission-critical functions shall be solution heat-treated and quenched after welding except for the stabilized or low carbon grades such as 321, 347, 316L, 304L.

c. Service-related corrosion issues are common for free-machining alloys such as 303, and these alloys shall not be used in spaceflight hardware that provides mission-critical functions when they can be exposed to moisture other than transient condensation, or to nitrogen tetroxide.

5.2.2.3 Ductile-Brittle Transition Temperature

Steels shall not be used in tension below their ductile-brittle transition temperature.

Alloy and carbon steels, as well as ferritic, martensitic, and duplex steels tend to become brittle as the temperature is reduced. Balls in ball bearings are generally acceptable because they are in compression.

5.2.3 TITANIUM

5.2.3.1 Titanium Contamination

a. All cleaning fluids and other chemicals used during manufacturing and processing of titanium spaceflight hardware that provides mission-critical functions 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 149 °C (300 ºF) and solid-metal-induced embrittlement of titanium alloys by cadmium can occur as low as room temperature.

b. The surfaces of titanium and titanium alloy mill products used for spaceflight hardware that provides mission-critical functions 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.

Contaminated zones and layers may be formed as a result of mill processing, heat treating, and elevated temperature-forming operations.

5.2.3.2 Titanium Wear

Titanium and its alloys exhibit very poor resistance to wear. Fretting that occurs at interfaces with titanium and its alloys have 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. Bolted joints are not considered to fret.

All regions of titanium alloys for spaceflight hardware that provides mission-critical functions that are subject to fretting or wear 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.

5.2.3.3 Titanium Flammability

a. 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 35 kPa (5 psia).

b. 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.

5.2.4 MAGNESIUM

a. Magnesium alloys shall not be used in primary structure or in other areas of spaceflight hardware that provides mission-critical functions that are subject to wear, abuse, foreign object damage, abrasion, erosion, or where fluid or moisture entrapment is possible.

b. 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.

5.2.5 BERYLLIUM

Beryllium alloys are exceptionally lightweight but are not often used because of the extreme toxicity of beryllium salts and oxides, and because it is unusually susceptible to damage. Alloys containing up to 4 percent beryllium by weight are not an issue, provided they are not machined inside spacecraft crew compartments.

a. Alloys containing more than 4 percent beryllium by weight shall not be used for primary structural applications.

b. 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.

c. Design of beryllium parts for spaceflight hardware that provides mission-critical functions shall address its low-impact resistance and notch sensitivity, particularly at low temperatures, and its directional material properties (anisotropy) and sensitivity to surface finish requirements.

d. All beryllium parts used in spaceflight hardware that provides mission-critical functions shall be processed to ensure 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 for removal of the damaged layer.

e. Beryllium-containing alloys (including alloys containing less than 4 percent beryllium by weight) and oxides of beryllium shall not be machined inside spacecraft crew compartments at any stage of manufacturing, assembly, testing, modification, or operation.

Stripping, crimping, and cutting electrical wire are not considered to be machining operations.

f. All beryllium parts used in spaceflight hardware that provides mission-critical functions shall be penetrant-inspected for crack-like flaws with a high-sensitivity fluorescent dye penetrant in accordance with section 5.5.

5.2.6 CADMIUM

Cadmium is highly toxic, can sublime and cause outgassing contamination at elevated temperatures in vacuum, and can cause liquid metal embrittlement of titanium and some steel alloys. Cadmium plating can spontaneously form cadmium whiskers.

a. Cadmium shall not be used in crew or vacuum environments.

b. Cadmium-plated tools and other hardware shall not be used in the manufacture or testing of spaceflight hardware that provides mission-critical functions.

5.2.7 ZINC

Owing to zinc's ability to grow whiskers, zinc plating other than black zinc-nickel plating shall not be used in spaceflight hardware that provides mission-critical functions.

Metallic zinc is less volatile than cadmium but should not be used in vacuum environments where the temperature/pressure environment could cause contamination of optical surfaces or electrical devices.

5.2.8 MERCURY

a. 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.

Mercury has the potential for causing liquid-metal embrittlement.

b. Spaceflight hardware (including fluorescent lamps) containing mercury shall have three levels of containment to prevent mercury leakage.

Non-flight lamps containing mercury, such as those used in hardware ground processing and fluorescent dye penetrant inspection of flight parts, are acceptable, provided that the bulbs are protected by a non-shatterable, leak-proof outer container.

5.2.9 REFRACTORY METALS

For refractory alloys (alloys with a melting point above 2000 °C (3600 °F), plus osmium and iridium) used in mission-critical applications, tests shall be performed to characterize the material for the intended application and the data documented in an MUA.

Engineering data on refractory alloys are limited, especially under extreme environmental conditions of spacecraft.

5.2.10 SUPERALLOYS (NICKEL-BASED AND COBALT-BASED)

In these requirements, a superalloy refers to a nickel- or cobalt- based alloy that retains all or most of its strength at usage temperatures approaching 538 °C (1000 °F) and higher. Examples include both wrought products such as Inconel 718 and castings such as Mar-M-247 and Inconel 625.

a. High nickel content alloys are susceptible to sulfur embrittlement; therefore, for spaceflight hardware that provides mission-critical functions, 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. Nickel-based superalloys are susceptible to grain boundary cracking phenomena at elevated temperatures, such as Stress Assisted Grain Boundary Oxidation Embrittlement (SAGBOE), and to stress rupture during heat treatment.

b. The reduction to design properties of alloying element depletion shall be evaluated when a thin sheet of one of these alloys is used for spaceflight hardware that provides mission-critical functions, since a slight amount of depletion could involve a considerable proportion of the effective cross section of the material.

Hot Corrosion is a complex process involving both sulfidation and oxidation.

5.2.11 TIN

High-purity tin and tin plating are susceptible to two degradation phenomena: tin whisker growth and tin pest (sometimes known as tin plague). The following requirements for tin whisker mitigation may not be adequate to prevent tin pest from occurring:

a. For spaceflight hardware that provides mission-critical functions, tin and tin plating shall be alloyed with at least 3 percent lead by weight or other proven alloying element(s) to prevent tin whisker growth.

b. Tin and tin plating alloyed with less than 3 percent lead by weight and used in electrical/electronic applications shall comply with GEIA-STD-0005-1A, Performance Standard for Aerospace and High Performance Electronic Systems Containing Lead-Free Solder, and Control Level 2C requirements of GEIA-STD-0005-2A, Standard for Mitigating the Effects of Tin Whiskers in Aerospace and High Performance Electronic Systems, with the following exceptions:

(1) Solder alloy Sn96.3Ag3.7 (Sn96) used for high-temperature applications.

(2) Solder alloy Au80Sn20 used as a die attach material or as a package sealing material.

(3) Tin alloys containing less than 20 percent tin by weight.

c. When high-purity tin and tin plating are used for spaceflight hardware that provides mission-critical functions and will also be exposed to temperatures below 13 ˚C for periods longer than 6 months, the method for preventing tin pest formation shall be documented in the materials control plan.

At this time, insufficient data exist to define hard requirements for controlling tin pest. Alloying with more than 5 percent lead or smaller quantities of antimony or bismuth significantly slows tin pest formation but may not eliminate it completely. Alloying recommendations based on weight percentage are:

(1) Not less than 5 percent lead.
(2) Not less than 0.3 percent bismuth.
(3) Not less than 0.5 percent antimony.
(4) Not less than 3.5 percent silver.

d. Tin plating shall not be used for contacts in electrical interconnects (connectors, sockets, switches, etc.) for spaceflight hardware that provides mission-critical functions.

Tin plating has been demonstrated to have oxidation, wear, cold-weld, fretting, and tin whisker issues that reduce performance and reliability. Tin plating may be accepted through the MUA process, provided appropriate controls (contact lubricant, stabilant, etc.) are used to mitigate the performance and/or reliability risk.

5.3 NONMETALLIC MATERIALS

5.3.1 ELASTOMERIC MATERIALS

a. Elastomeric materials used in spaceflight hardware that provides mission-critical functions shall be selected to operate within design parameters for the useful life of the hardware.

b. Elastomeric materials used in spaceflight hardware that provides mission-critical functions, other than those used in off-the-shelf parts, such as cable clamps, shall be cure dated for tracking purposes.

c. Room temperature vulcanizing (RTV) silicones that liberate acetic acid during cure shall not be used because they can cause corrosion.

d. When rubbers or elastomers are used at low temperatures in spaceflight hardware that provides mission-critical functions, the ability of these materials to maintain and provide required elastomeric properties shall be verified.

Elastomers do not seal effectively below their glass-transition temperature, and the ability of elastomers to seal decreases significantly as the glass-transition temperature is approached. The high glass-transition temperature of Viton® rubbers was a major contributor to the loss of the Space Shuttle Challenger, and other elastomers may struggle to retain sealing performance at spacecraft temperatures.

5.3.2 POLYVINYL CHLORIDE

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

Polyvinyl chloride offgasses unacceptably at temperatures above 49 °C (120 °F). It is also normally flammable in pressurized areas of spacecraft; so, when it is used, its flammability has to be controlled in accordance with section 4.2.1.1.

Polyvinyl chloride is not vacuum-compatible.

Rigid polyvinyl chloride tubing is not acceptable for pressurized gas applications, because it can have a brittle failure when used for pressurized gas transport.

5.3.3 COMPOSITE MATERIALS

Requirements and guidance on materials design values for polymer matrix, ceramic matrix, and metal matrix composites are in section 4.1.10. Requirements on sandwich assemblies are in section 5.6.2.

Composite manufacturing is sensitive to both material and manufacturing process variability. Qualified materials control specifications should include appropriate batch-lot acceptance testing. Process control specifications should include conservative constraints to contamination, bonding surface preparation time, cumulative out-time for pre-preg materials, thermoset mix vs application/cure time, temperature/time exposure before and during cure, etc.

a. Each flight-production composite part classified as “fracture critical” or “non fracture critical low-risk” in accordance with NASA-STD-5019 shall incorporate witness panels that are extracted from cut-outs within the part acreage or from prolongations intentionally designed into the flight part.

Witness panels are used to verify critical properties, which should include mechanical properties (e.g. laminate interlaminar shear, compression, sandwich flatwise tension), porosity, and glass transition temperature. Witness panels should be extracted directly from the production part, in *locations on the production part tooling that represent the thermal profile experienced during cure. In extraneous circumstances, manufacturing of a separate "traveler" witness panel that directly tracks the part production in parallel (on separate tooling) may be accepted by the procuring authority with substantiation.*

b. Witness panels shall be tested and evaluated against a statistically based pass/fail criterion established from prior testing and dispositioned by the Material Control Panel where the specified criteria are not met.

5.3.4 LUBRICANTS

NASA-TM-86556, Lubrication Handbook for the Space Industry, Part A: Solid Lubricants, Part B: Liquid Lubricants, provides guidance on the evaluation and selection of lubricants for spaceflight systems and components. Guidelines on additional lubricants not listed in NASA-TM-86556 are contained in NASA/CR-2005-213424, Lubrication for Space Applications. Lubricants containing chloro-fluoro components may react with newly exposed rubbing surfaces of aluminum, magnesium or titanium alloys, especially at elevated temperatures.

5.3.5 LIMITED-LIFE ITEMS

All materials shall be selected to meet the useful life of the hardware with no maintenance or be identified as limited-life items requiring maintainability.

5.3.6 VACUUM OUTGASSING

a. Nonmetallic materials that are exposed to space vacuum, with the exception of ceramics, metal oxides, inorganic glasses, and cetyl alcohol lubricants used on fasteners outside closed compartments, shall be tested using the technique of ASTM-E595, Total Mass Loss and Collected Volatile Condensable Materials from Outgassing in a Vacuum Environment, Standard Test Method for, with acceptance criteria as follows:

(1) ≤0.1 percent Collected Volatile Condensable Materials (CVCM)

(2) ≤1.0 percent Total Mass Loss (TML) less Water Vapor Recovery (WVR), except that a higher mass loss 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.

Many materials contain absorbed water, but the loss of absorbed water does not normally affect functionality; so the WVR (a measure of the total water vapor lost in the ASTM E595 test) is subtracted from the TML.

More stringent requirements may be needed for materials that are line of sight to contamination-sensitive surfaces on spacecraft or attached vehicles. Contamination-sensitive surfaces include

ISS and other vehicle windows, lenses, star trackers, solar arrays, radiators, and other surfaces with highly controlled optical properties. The approach taken depends on the specific program needs but may include lowering the CVCM requirement to ≤0.01 percent CVCM, use of optical surfaces in testing to characterize the effects of deposition, or measurement of outgassing deposition rates as functions of source and target temperature (the standard test method is ASTM E1559, Standard Test Method for Contamination Outgassing Characteristics of Spacecraft Materials) and calculating deposition on critical surfaces using an integrated vehicle model (this approach is used for ISS external contamination, but the requirements and implementation are the responsibility of ISS Environments and are not addressed by the materials control program, which implements only the above requirements). Spacecraft with cryogenic optics may be sensitive to water vapor deposition; in such cases, the WVR would not be subtracted from the TML.

b. With the following exceptions, hardware items (components, assemblies, etc.) containing materials that fail the CVCM requirement and/or having unidentified materials shall be vacuum baked at the maximum tolerable temperature of the component, 10 ºC above the maximum predicted operating temperature, or an alternate temperature agreed with NASA JSC M&P, to meet the program/project acceptance outgassing criteria:

(1) Materials that are not near a critical surface and have a CVCM between 0.1 and 1.0 percent and an exposed surface area less than 13 cm^2 (2 in^2) are exempt.

(2) Materials with an exposed surface area less than 1.6 cm^2 (0.25 in^2) are exempt.

(3) Materials that are unexposed, overcoated, or encapsulated with approved materials are exempt.

(4) Materials enclosed in a sealed container (maximum leak rate less than 1×10^{-4} cm^3/sec) are exempt.

Determination of acceptable molecular outgassing limits, selection of the bakeout method and temperature, and determination of the specific bakeout completion criteria are the responsibility of JSC M&P. ASTM E2900, Standard Practice for Spacecraft Hardware Thermal Vacuum Bakeout, is recommended as a guide for performing thermal vacuum bakeout.

A vacuum-bake temperature of 125 ºC (257 ºF) (the ASTM E595 screening temperature) may damage some spaceflight hardware. Temperature requirements for hardware thermal vacuum bakeout should be adjusted to prevent damage to components. Because bakeout time and efficiency are dependent on temperature, the chosen temperature should be the highest possible without damage to hardware.

A hardware functionality bench test should be performed to re-verify performance after baking.

5.3.7 EXTERNAL ENVIRONMENT SURVIVABILITY

a. The critical properties of materials exposed in the spacecraft external environment shall meet operational requirements for their intended life cycle exposure.

Applicable space environments include atomic oxygen, solar ultraviolet (UV) radiation, ionizing radiation, plasma/spacecraft charging, vacuum, thermal cycling, and contamination. Applicable planetary environments, such as dust and planetary atmospheres, may also apply. Meteoroids and orbital debris should also be considered in the analysis of long-term degradation.

Evaluation is not required for contingency tools and materials that are normally protected from the environment and exposed only temporarily as a result of removal of the protective covering (blankets, shrouds, etc.) during maintenance or assembly operations.

5.3.8 MOISTURE AND FUNGUS RESISTANCE

Materials that 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, shall be used in launch vehicles and pressurized spaceflight compartments, except when one of the following criteria is met.

a. Materials have 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% 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 have to be used (and none of the above exception criteria are met) and an MUA is submitted for approval, supporting rationale should include how materials are treated to prevent fungus growth, using a fungus treatment that does not adversely affect unit performance or service life, does not constitute a health hazard to higher order life, and is not leached out by the use environment.

5.3.9 GLYCOLS

When solutions containing glycols (aliphatic dihydric alcohols) are used aboard spacecraft that 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 the glycol.

This reaction is known to occur for ethylene and propylene glycol. Solutions containing other glycols may be exempted if testing is conducted to demonstrate that the spontaneous ignition reaction does not occur.

5.3.10 ETCHING FLUOROCARBONS

a. The etching of PTFE, perfluoroalkoxy (PFA), and fluorinated ethylene propylene (FEP) shall meet the requirements of SAE-AMS 2491, Surface Treatment of Polytetrafluoroethylene, Preparation for Bonding, when adhesion to the fluorocarbon surface is required, except that for insulated wire or cable a pull test on co-produced specimens may be performed in lieu of the tensile and shear strength tests in AMS2491, section 3.5.2.

Adhesion to the fluorocarbon surface is required for electrical wire or cable insulated or coated with fluorocarbons intended for potting if mechanical bond strength and environmental sealing are a design requirement.

b. Etched surfaces shall be processed within 24 hours or within 1 year if packaged per SAE-AMS 2491.

The open end of the wire should not be exposed to the etchant.

5.3.11 WATER-SOLUBLE VOLATILE ORGANIC COMPOUNDS

a. The following water-soluble volatile organic compounds shall not be released into the ISS habitable environment:

Methanol; ethanol; isopropyl alcohol; n-propyl alcohol; n-butyl alcohol; acetone; ethylene glycol; propylene glycol.

This requirement applies to hardware used in the ISS habitable environment and hardware used in commercial crew and cargo vehicles while docked to ISS with the hatch open

MPCV currently has no restrictions on water-soluble volatile organic compounds. It is not yet known whether Gateway or HLS will have such restrictions. If they do, those restrictions will likely also apply to MPCV when it is docked to these vehicles with the hatch open.

b. A VUA shall be processed in accordance with section 4.1.7 for all hardware containing such compounds, with the following exceptions:

- The release of these compounds by normal materials offgassing
- The water-soluble volatile organic compound is properly contained and released to the habitable environment only as a result of a single barrier failure (redundant containment is not required)
- All emergency surgery supplies are exempt

Note: Commercial personal hygiene items such as toothpaste and deodorant are acceptable if none of the 8 controlled water-soluble volatile organic compounds are listed as ingredients on the commercial container or packaging. Ethanol may be listed as "ethyl alcohol", "SD alcohol", or "Alcohol Denat."

5.4 PROCESSES

5.4.1 HEAT TREATMENT

a. Heat treatment of aluminum alloys used in spaceflight hardware that provides mission-critical functions shall meet the requirements of PRC-2002, Heat Treatment of Aluminum Alloys, SAE AMS2772, Heat Treatment of Aluminum Alloy Raw Materials; SAE AMS2770, Heat Treatment of Wrought Aluminum Alloy Parts; or SAE AMS2771, Heat Treatment of Aluminum Alloy Castings.

b. Heat treatment of steel alloys used in spaceflight hardware that provides mission-critical functions shall meet the requirements of PRC-2001, Heat Treatment of Steel Alloys, SAE AMS-H-6875, Heat Treatment of Steel Raw Materials, or SAE AMS2759, Heat Treatment of Steel Parts, General Requirements.

c. Heat treatment of titanium alloys used in spaceflight hardware that provides mission-critical functions shall meet the requirements of SAE AMS-H-81200, Heat Treatment of Titanium and Titanium Alloys, for raw stock and SAE AMS2801, Heat Treatment of Titanium Alloy Parts, for parts requiring heat treatment during fabrication.

d. Heat treatment of nickel- and cobalt-based alloy parts used in spaceflight hardware that provides mission-critical functions shall meet the requirements of PRC-2003, Heat Treatment of Nickel Alloys, SAE AMS2774, Heat Treatment, Wrought Nickel Alloy and Cobalt Alloy Parts, or SAE AMS2773, Heat Treatment, Cast Nickel Alloy and Cobalt Alloy Parts.

Care should be taken in design of heat treatment fixturing and in heat treatment procedures for nickel- and cobalt-based alloy parts to avoid cracking, dimensional distortion, oxidation and other problems. Important issues include:

- *Significant differences in thermal expansion coefficients between metallic alloys of the part and of the fixture. This issue can result in cracking and/or dimensional distortion.*

- *Thermal shock from excessive rapid heating. This can occur from placing a cold part into a very hot furnace. This issue often results in dimensional distortion.*

- *Pockets or restricted thermal flow regions (esp. sharp corners). Rapid cooling in one region with slow cooling in another region can produce unwanted residual tensile stresses, cracking, and/or dimensional distortion in critical locations.*

- *Abrupt changes in part thickness, especially with low toughness castings. Cracks can occur at thick-to-thin transition areas especially during cooling cycles.*

The AMS heat treatment specifications require hardness and/or conductivity measurements to verify the adequacy of the heat treatment process. In many cases, hardness tests are inadequate for spacecraft hardware; and testing of process-control tensile-test coupons is required.

e. For spaceflight hardware that provides mission-critical functions, process-control tensile-test coupons shall be taken from the production part (or from the same material lot, having the same thickness as and processed identically to the production part) to verify the adequacy of the heat treatment process for the following conditions:

(1) Aluminum alloys are solution heat-treated.

(2) Any quenched and tempered steel.

(1) A286 or MP35N alloys (or any alloy that has poor correlation between hardness and tensile strength) are heat treated.

(2) Titanium alloys are annealed or solution heat treated and aged.

(3) Nickel- and cobalt-based alloys are work strengthened before age hardening, resulting in age-hardened tensile strengths greater than 1030 MPa (150 ksi) UTS.

(4) Precipitation hardenable nickel- and cobalt-based alloys are re-solution heat treated other than by the mill.

Note: Representative tensile test coupons are preferred over hardness and conductivity measurements for aging of aluminum alloys.

f. When process-control tensile-test coupons are required, the requirement for the coupons shall be specified on the engineering drawing for the part.

g. If no tensile values are available in MMPDS for a specific alloy, tensile-test acceptance values shall be specified on the engineering drawing for the part.

h. Materials shall not be used in spaceflight hardware that provides mission-critical functions outside the limits of their procurement specification, heat treat specification, or MMPDS specification.

5.4.2 FORGING

Because mechanical properties are optimum in the direction of material flow during forging, forging techniques should be used that, whenever possible, produce an internal grain- flow pattern such that the direction of flow is essentially parallel to the principal stresses. If forging techniques do not allow for the direction of the flow to be parallel to the principal stresses, parts should be designed such that the weakest grain flow direction is not in line with the principal stresses. The forging pattern should be essentially free from re-entrant and sharply folded flow lines.

a. Where forgings are used in critical applications, first-article (preproduction) approval shall be obtained from the procuring authority.

b. First-article approval and the controls to be exercised in producing subsequent production forgings shall be in accordance with SAE-AMS 2375, Control of Forgings Requiring First Article Approval.

c. 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 and the trim ring/protrusion specimens (prolongations).

Mechanical properties testing requirements may include fracture, durability, or damage tolerance testing.

d. The mechanical properties of the trim ring/protrusion specimens (prolongations) for the first article shall be compared to the control coupons to show they are predictive of the properties in the body of the first article.

e. Sectioning to show the grain-flow patterns and to determine mechanical properties at control areas shall be repeated after any substantive change in the forging technique, as determined by M&P analysis.

The information gained from this effort is utilized to redesign the forging as necessary.

f. These data and results of tests on the redesign shall be retained and made available for review by the procuring activity.

g. Trim ring or protrusion specimens (prolongations) shall be obtained for each production forging used in safety-critical applications and tested for required minimum mechanical properties.

h. Surface and volumetric nondestructive inspection (NDI) shall be performed on all safety-critical forgings.

5.4.3 CASTINGS

a. Castings used in spaceflight hardware that provides mission-critical functions shall meet the requirements of SAE-AMS-STD-2175, Castings, Classification and Inspection of.

b. Where castings are used in mission-critical applications, pre-production castings shall be subjected to first-article inspection to verify proper material flow, proper material integrity, minimum required mechanical properties, proper grain size, and macro/microstructure.

c. The mechanical properties in trim ring/protrusion of the first article shall be compared to the control coupons to show they are predictive of the properties in the body of the first article.

Mechanical properties testing requirements may include fracture, durability, or damage tolerance testing.

d. The same casting practice and heat-treating procedure shall be used for the production castings as for the approved first-article castings.

e. For Class 1 and Class 2 castings (classes as defined by SAE AMS2175), mechanical property testing of integrally cast or excised tensile bars at critical locations shall be conducted to ensure foundry control of cast lots.

f. Periodic cut-ups or functional testing shall be conducted for Class 1 and Class 2 castings (classes as defined by SAE AMS2175).

g. Surface and volumetric nondestructive inspection shall be performed on all safety-critical castings.

5.4.4 FORMED PANELS

Barrel and gore panels with complex geometries and integral stiffeners are often formed by processes such as roll forming, brake forming, peen forming, stretch forming, and explosive forming and then heat treated. The mechanical and thermal forming processes can result in strength and toughness variations across the panel.

a. Where formed panels are used in mission-critical applications, pre-production panels shall be subjected to first-article inspection to verify proper material integrity, minimum required mechanical properties, proper grain size, and macro/microstructure.

b. The mechanical properties of the first production article shall be compared to control coupons to show they are predictive of the properties in the body of the first article.

Mechanical properties testing requirements may include fracture, durability, or damage tolerance testing.

c. The same forming practice and heat-treating procedure shall be used for the production formed panels as for the approved first-article panels.

d. Sectioning to determine mechanical properties at control areas shall be repeated after any substantive change in the forming technique, as determined by M&P analysis.

e. Surface and volumetric NDI shall be performed on all safety-critical formed panels.

Given the complexities of some formed panels, volumetric NDI may be performed as a raw stock inspection.

5.4.5 ADHESIVE BONDING

a. Structural adhesive bonding shall meet PRC-1001, Adhesive Bonding or MSFC-SPEC-445A, Adhesive Bonding, Process, and Inspection, Requirements For.

The Operator Certification Plan and the Adhesive Control Plan may be described in the implementing process specification in place of submittal to NASA for approval.
Retesting of adhesives used for production parts is not required if they are within shelf life.

b. Structural adhesive bonding processes shall be controlled to prevent contamination that would cause structural failure that could affect the safety of the mission, crew, or vehicle or affect mission success.

(1) The sensitivity of structural adhesive bonds to contamination is of particular concern. Bond sensitivity studies should be conducted to verify the required adhesive properties are maintained after exposure to potential contaminant species and concentrations and in-process cleanliness inspections should be conducted as part of the bonding process. Silicone contamination is a particular concern because it severely degrades adhesive performance.

c. Bonded primary structural joints shall demonstrate cohesive failure modes in shear.

5.4.6 WELDING

The design selection of parent materials and weld methods should be based on consideration of the weldments, including adjacent heat affected zones, as they affect operational capability of the parts concerned. Peaking and mismatch limits should be considered in the mechanical properties.

Welding procedures should 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 should be demonstrated through qualification testing of welded specimens representing the materials and joint configuration of production parts.

Working with the responsible Technical Authority and NASA M&P organization, Programs/Projects will assess if it is more beneficial to directly use welding specifications cited in this section or develop alternatives. The requirements in this section provide compliance with NASA-STD-5006, General Welding Requirements for Aerospace Materials. If the requirements in this section are met, no further application of NASA-STD-5006 is needed.

The following JSC specifications are acceptable implementations of the welding requirements in this section and should be used for in-house welding at JSC:

ES SOP-004.5, Control of Weld and Braze Filler Materials, Electrodes, and Fluxing Materials

PRC-0001, Manual Arc Welding of Aluminum Alloy Hardware

PRC-0002, Process Specification for the Manual Arc Welding of Titanium Alloy Hardware

PRC-0005, Manual Arc Welding of Steel and Nickel Alloy Hardware
PRC-0007, Process Specification for the Manual Arc Welding of Developmental and Experimental Hardware

PRC-0009, Resistance Spot Welding of Battery and Electronic Assemblies

PRC-0010, Automatic and Machine Arc Welding of Steel and Nickel Alloy Hardware

PRC-0011, Semi-Automatic and Machine Stud Welding of Non Flight Hardware

PRC-0014, Friction Stir-Welding

PRC-0015, Process Specification for Automatic and Machine Arc Welding of Titanium and Titanium Alloy Hardware

a. If alternative specifications to those cited in this section are utilized or developed, those specifications shall meet the requirements of NASA-STD-5006, General Welding Requirements for Aerospace Materials.

Note: NASA-STD-5006A defines weld classes in terms of weld criticality (with Class A representing safety-critical structural welds) and AWS D17.1/D17.1M AMD 1 defines weld classes in terms of inspection requirements (with Class A representing the most stringent nondestructive inspection requirements).

b. Material Review Board disposition shall be required for weld repair/rework/processing activities that are not in accordance with the approved weld process specification (WPS).

Examples include:

- *Wrong filler metal used.*
- *More than two attempts performed at the same location on heat-sensitive materials.*
- *More than five attempts performed at the same location on materials that are not heat sensitive.*
- *Repair weld required after the weldment has been post-weld heat treated.*
- *Repair weld required after final machining has been completed.*
- *Repair extends outside the original weld zone.*
- *Weldment has been direct aged.*
- *Repairs following proof or leak test.*

c. A weld development and certification plan shall be developed for large structural welded components such as crew modules and welded cryogenic tanks that includes full scale pathfinder weldments, tooling development, and a design values program including sensitivity testing.

5.4.6.1 Fusion Welding

The processing and quality assurance requirements for manual, automatic, and semiautomatic welding for spaceflight applications that provide mission-critical functions shall meet the requirements of AWS D17.1/D17.1M, Specification for Fusion Welding for Aerospace Applications, with the following modifications/additions:

Note: AWS D17.1/D17.1M defines weld classes in terms of inspection requirements (with Class A representing the most stringent nondestructive inspection requirements).

a. Mission-critical structural welds shall comply with AWS D17.1/D17.1M, Class A requirements.

b. Other structural welds shall comply with AWS D17.1/D17.1M, Class A or Class B requirements, except internal NDE of Class B welds is required.

Internal NDE may be waived by the JSC Materials Branch when there is adequate justification, such as proof testing, or visual inspection of full joint penetration.

c. Non-critical welds (including seal welds) shall comply with AWS D17.1/D17.1M, Class C requirements.

d. All Class A and Class B welds (including manual welds), as defined by AWS D17.1/D17.1M, shall be qualified in accordance with AWS D17.1/D17.1M.

AWS G2.4/G2.4M, Guide for the Fusion Welding of Titanium and Titanium Alloys, should be used for guidance on titanium welding.

e. Titanium welds shall be light/dark straw or better (Ref. AWS D17.1/D17.1M, Table 7.1).

f. Titanium and its alloys shall be welded with alloy-matching or metallurgically compatible fillers or autogenously.

Ti-6Al-4V filler metal is considered to be metallurgically compatible with Ti-3Al-2.5V.

g. Extra low interstitial (ELI) filler wires shall be used for titanium cryogenic applications and are preferred for general applications.

h. Commercially pure (CP) titanium filler shall not be used on Ti-6Al-4V or other alloyed base material.

Hydride formation can occur in the weld, which can produce a brittle, catastrophic failure.

i. Nitrogen, hydrogen, carbon dioxide, and mixtures containing these gases shall not be used in welding titanium and its alloys.

Care needs to be exercised to ensure complete inert gas (argon or helium) coverage during welding.

(1) The inert gas shall have a dew point of -60º C (-76º F) or lower.

j. Welded alpha and alpha plus beta titanium alloys shall be stress relieved in a vacuum or inert gas environment (Ar or He), or stress relieved in air with verification of oxide removal per SAE AMS-H-81200 or SAE AMS2801, or certified in the as-welded condition.

k. Titanium beta alloys that are welded shall be evaluated on a case-by-case basis with respect to stress relief.

Note: Stress relief of weldments does not require tensile test coupons.

l. Laser welding for spaceflight hardware that provides mission-critical functions shall comply with AWS D17.1/D17.1M or AWS C7.4/C7.4M, Process Specification and Operator Qualification for Laser Beam Welding.

m. Electron beam welding for spaceflight hardware that provides mission-critical functions shall comply with AWS D17.1/D17.1M or SAE AMS2680, Electron-Beam Welding for Fatigue Critical Applications.

Compliance with SAE AMS2680 is preferred but compliance with AWS D17.1/D17.1M is acceptable.

n. The following welding design and fabrication practices permitted by AWS D17.1/D17.1M shall not be used without an approved MUA to document the acceptance rationale:

a. Welding from both sides if full penetration of the first pass is not verified (either by inspection of the back side or by grinding prior to welding on the opposite side).

(2) Partial weld penetration in structural welds.

(3) Straightening operation after welding.

(4) Lap welds in structural applications.

o. Procedure Qualification shall meeting the following requirements in addition to those required by AWS D17.

(1) Repair welds shall be qualified along with weld procedure in accordance with AWS D17.1/D17.1M

(2) Allowable weld parameter tolerances shall be qualified for automatic and semi-automatic welds.

(3) Welding parameters for shall qualified for manual welds, allowing a range for current.

(4) A confidence weld for aluminum alloy welds shall be made in accordance with JSC PRC-001.

(5) Tensile Testing, NDE, and metallographic examination is required for all procedure qualification. Bend testing may not be substituted for tensile testing.

(6) Tack area of qualification weld shall be examined during qualification to show tack weld is consumed.

If tensile coupons cannot be machined from qualification welds, a delta qualification weld simulating the production weld may be made and evaluated in addition to standard AWS qualification coupons that can be tensile tested, with the approval of the JSC Materials Engineering. The simulation weld shall be subjected to NDE and metallographic examination.

Qualification strength requirements should be included in weld qualification test acceptance.

q. Weld qualification mechanical acceptance test strengths and design values shall be approved by JSC M&P prior to welding.

Qualification strength values are not the same as materials design values.

5.4.6.2 Resistance Welding

Resistance welding for spaceflight hardware that provides mission-critical functions, including resistance spot welding (RSW), shall meet the requirements of AWS D17.2/D17.2M, Specification for Resistance Welding for Aerospace Applications.

5.4.6.3 Friction-Stir Welding of Aluminum Alloys

Friction-stir welding of aluminum alloys for spaceflight hardware that provides mission-critical functions shall meet the requirements of AWS D17.3/D17.3M, Specification for Friction Stir Welding of Aluminum Alloys for Aerospace Applications.

5.4.6.4 Inertia Welding

Inertia welding for spaceflight hardware that provides mission-critical functions shall meet the requirements of MIL-STD-1252, Inertia Friction Welding Process, Procedure and Performance Qualification.

a. Surface inspection (penetrant) and volumetric inspection (radiography) shall be performed.

b. All welds shall be proof tested.

c. Inertia welds used in fluid systems shall be helium leak tested.

Acceptable helium leak rates should be defined by the system.

5.4.7 BRAZING

a. Brazing for spaceflight hardware that provides mission-critical functions shall be conducted in accordance with AWS C3.3, Design, Manufacture, and Inspection of Critical Brazed Components, Recommended Practices for.

b. Brazing of aluminum alloys for spaceflight hardware that provides mission-critical functions shall meet the requirements of AWS C3.7M/C3.7, Specification for Aluminum Brazing.

c. Torch, induction, and furnace brazing for spaceflight hardware that provides mission-critical functions shall meet the requirements of AWS C3.4M/C3.4, Specification for Torch Brazing; AWS C3.5M/C3.5, Specification for Induction Brazing; and AWS C3.6M/C3.6, Specification for Furnace Brazing, respectively.

d. Braze filler metals shall conform to ES SOP-004.5, Control of Weld and Braze Filler Materials, Electrodes, and Fluxing Materials.

e. Subsequent fusion-welding operations in the vicinity of brazed joints or other operations involving high temperatures that might affect the brazed joint shall be prohibited for spaceflight hardware that provides mission-critical functions unless it can be demonstrated that the fixturing, processes, methods, and/or procedures employed will preclude degradation of the braze joint.

f. Brazed joints used in spaceflight hardware that provides mission-critical functions shall be designed for shear loading and shall not be relied upon for strength in axial loading for structural parts.

g. The shear strength of brazed joints used in spaceflight hardware that provides mission-critical functions shall be evaluated in accordance with AWS C3.2M/C3.2, Standard Method for Evaluating the Strength of Brazed Joints.

h. For furnace brazing of complex configurations of spaceflight hardware that provides mission-critical functions, 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.

5.4.8 STRUCTURAL SOLDERING

Soldering shall not be used for structural applications.

5.4.9 ELECTRICAL DISCHARGE MACHINING AND LASER MACHINING

a. Electrical discharge machining (EDM) and laser machining (LM) processes for spaceflight hardware that provides mission-critical functions shall be controlled to limit the depth of the oxide layer, the recast layer, and the heat-affected zone.

(1) The oxide layer, when present, shall be removed from the surface.

(2) 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 oxide layer for the EDM processes contains gaps, voids and laps between highly oxidized particles that are partially fused to the recast zone layer. This porous, re-fused layer can trap *liquids during subsequent processing if it is not removed. In addition, the oxide layer can contain brass particles from the EDM wire.*

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.

b. EDM/LM schedules for spaceflight hardware that provides mission-critical functions 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.

5.4.10 NICKEL PLATING

a. Electrodeposited nickel plating for spaceflight hardware that provides mission-critical functions shall be applied according to the requirements of SAE AMS2403, Plating, Nickel General Purpose; SAE AMS2423, Plating, Nickel Hard Deposit; or ASTM B689, Standard Specification for Electroplated Engineering Nickel Coatings.

PRC-5004, Electrodeposited Nickel Plating, should be used for in-house electrodeposited nickel plating at JSC.

b. Electroless nickel plate for spaceflight hardware that provides mission-critical functions shall be applied per SAE AMS2404, Plating, Electroless Nickel, or ASTM B733, Standard Specification for Autocatalytic (Electroless) Nickel-Phosphorus Coatings on Metal.

c. The nickel-aluminum interface in nickel-plated aluminum used in spaceflight hardware that provides mission-critical functions shall be protected from exposure to corrosive environments.

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

5.4.11 ADDITIVE MANUFACTURING

[MPR 174] Spaceflight hardware manufactured by additive manufacturing techniques shall be designed, produced, and documented in compliance with NASA-STD-6030.

NOTE: The requirements of NASA-STD-6030 do not encompass all requirements for an AM part (flammability, toxic offgassing, vacuum outgassing, etc. also apply).

Additive Manufacturing Control Plans are reviewed and approved by the responsible NASA program or project, with concurrence from the responsible NASA M&P organization per section 4.2 of NASA-STD-6030.

An Equipment and Facilities Control Plan per NASA-STD-6033, Additive Manufacturing Requirements for Equipment and Facility Control, is developed by the AM part producer and approved by the cognizant engineering organization per section 4.5 of NASA-STD-6030.

Material Property Suites used to design Class A and B additively manufactured parts are reviewed and approved by the responsible NASA program or project, with concurrence from the responsible NASA M&P organization per section 6 of NASA-STD-6030.

Part Production Plans are reviewed and approved by the responsible NASA program or project, with concurrence from the responsible NASA M&P organization per section 7 of NASA-STD-6030.

5.4.12 PRECISION CLEAN HARDWARE

Precision clean hardware shall be cleaned and packaged in accordance with JPR 5322.1, PRC-5001, or GSDO-RQMT-1080.

The following additional requirements apply to ensure such hardware is maintained clean during assembly and operation.

5.4.12.1 Assembly, Cleaning, Flushing, and Testing Fluids

a. The assembly, cleaning, flushing, and testing fluid surface cleanliness requirement shall be the same as the surface cleanliness level required by the operational system this fluid is to be used within.

b. Residual cleaning, flushing, and testing fluids shall be removed prior to charging with the operating fluid (removal by flushing with the operating fluid is permitted when appropriate).

Positive verification is required only when specified.

5.4.12.2 Personnel Training

a. A certification-training course shall be established and required for anyone working around precision-cleaned hardware.

b. The focus of the certification-training course shall be on personnel awareness.

c. The certification-training course shall require a minimum 1-hour of instruction time.

d. As a minimum, the certification-training course content shall include definition of precision cleanliness, problems that have occurred with precision-cleaned hardware, the best practices for maintaining cleanliness, and specific controls identified at the site where work will be performed.

5.4.12.3 Welding Precision-Cleaned Hardware (Including Tube Preparation)

a. Whenever precision-cleaned hardware must be maintained clean during welding into an assembly, the welding operation shall be performed in a dedicated Class 100,000 or better Clean Work Area (CWA).

Temporary tents over the weld area and/or local monitors located in the area of welding may be required to ensure the Class 100,000 environment is being met.

b. Portable particle counters shall be located as close as possible to the work area, so as to monitor local contaminants during tube preparation and welding.

c. Tools used in weld preparation and welding (such as cutter, weld head, files) shall be visibly cleaned per JPR 5322.1 or PRC-5001 and maintained clean (e.g. bagged when not in use).

d. For hardware that cannot be subsequently precision-cleaned, a proven method for protecting against system contamination during tube preparation shall be implemented.

One method for protecting against system contamination during tube preparation is the use of a physical barrier, such as plugs.

(1) The installation and removal of plugs shall be tracked by a reliable method and independently verified.

(2) Prior to plug removal the exposed internal surfaces of the tube shall be cleaned using a swab wetted with an approved solvent.

(3) Positive backpressure shall be maintained as the plug is removed.

e. Tube cutting and facing shall be controlled as follows:

(1) Tube cutters shall use a sharp blade, changed frequently.

(2) Tube cutting shall be performed with minimal cutter pressure to aid in preventing particle generation.

(3) Vacuum shall be used during tube facing operations to remove particulate.

(4) Whenever possible, facing operations shall be performed away from the weld assembly area, to reduce particulate contamination of the welding work area.

(5) Tube facing shall be performed without the use of cutting oils, other fluids, lubricants or coolants.

(6) Abrasives, including sandpaper or abrasive pads, shall not be used inside tubes or when unprotected internal surfaces are exposed.

(7) After each tube preparation, and prior to welding, a high-velocity gas purge shall be performed.

(8) The purge gas velocity shall be the maximum attainable using a 90-psig source.

(9) Purge gas used during facing and welding shall meet the hydrocarbon, moisture, and particulate controls of the applicable welding specification or for the system under assembly (whichever is the more stringent).

(10) The purge gas shall be supplied through precision-cleaned low-nonvolatile residue (NVR)/particulate tubing such as polyethylene, nylon, Teflon, or ethyl vinyl acetate. [Standard grade Tygon is not acceptable for use.]

f. Contamination controls when welding O2 systems shall be as follows:

(1) Regulators used during purging operations shall have O2 compatible grease.

(2) Purge tubing shall be verified to be O2 compatible.

(3) Bagging materials used to store O2 tubes, hoses, components and welded assemblies shall be cleaned to the same level of cleanliness as the O2 hardware and verified to be O2 compatible.

5.4.12.4 Ground Support Equipment (GSE) Interfaces

a. GSE supply interface/final filters interfacing with precision-cleaned flight fluid systems shall be located as close to the flight hardware interface as possible.

b. Interface filters shall be placed on outlet lines if it is determined that some operations, such as servicing or deservicing fluids, could permit flow in a reverse direction.

c. Supply system hardware and/or GSE located upstream of the interface/final filter shall be cleaned and verified to the same NVR level as that used for the flight hardware.

The particulate cleanliness of supply system hardware/GSE located upstream of the interface/final filter may be verified to a different particulate cleanliness level and using a different cleanliness level specification from that used for the flight hardware, because the flight hardware is protected by the interface/final filter. The interface/final filter does not protect against NVR contamination; a higher NVR level could contaminate the flight hardware.

d. GSE fluid hardware (such as hoses, servicing units) shall be handled with the same cleanliness procedures as flight hardware.

5.4.12.5 Convoluted Flex Hoses

a. Convoluted metal flex hoses shall receive special attention to cleaning.

(1) All detail flex hoses shall be verified as precision-clean in a vertical orientation.

(2) For flex hose tube diameters equal to or greater than one inch, verification of precision cleanliness shall be performed by sampling a rinse fluid applied

internally through use of a high-pressure nozzle to the entire length of the flex hose.

For flex hose tube diameters less than one inch, the use of a high-pressure nozzle is preferred, but verification may be performed by flushing a rinse fluid through the entire length of the flex hose with flex hose agitation.

b. Precision cleaning shall be considered successful when the verification rinse fluid indicates compliance with the flex hose engineering drawing cleanliness requirement.

5.4.12.6 Maintaining System Cleanliness

a. Hardware (including GSE) that has not been precision-cleaned shall not be brought into the vicinity of precision-cleaned flight hardware (for fit checks etc.) without protection to the flight hardware (i.e., wrapped in approved packaging material).

b. Clean room bags shall always be used to transport cleaned hardware (including GSE), even short distances when outside of the clean room environment.

c. Precision-cleaned hardware shall be exposed only in a particulate controlled environment, including the use of flow benches providing a Class 100,000 CWA or better, when conducting hardware inspections.

d. Clean room gloves shall be used during all handling of precision-cleaned flight hardware and GSE.

e. Any inspection tools that are to be exposed to precision-cleaned fluid systems hardware (borescopes, etc.) shall be visibly cleaned and maintained clean.

f. Solvents used for such cleaning shall be filtered to 10 microns or better prior to use.

g. All precision cleaned open tubes and lines shall be protected, i.e. wrapped or bagged with approved materials, as soon as possible after fabrication, until final installation.

h. All precision-cleaned fluid systems configured for flight shall have integrity seals installed.

i. Precision cleaned hardware that has been welded shall remain capped (non-particle generating caps, or wrapped and taped) at the ends during x-ray operations to avoid potential contamination of hardware.

5.4.12.7 Sampling For Residual Solvents Incompatible With Fluid Systems

a. When a flammable solvent such as isopropyl alcohol (IPA) or cyclohexane is used for cleaning, flushing, or testing of liquid and gaseous oxygen systems or nitrogen tetroxide systems, the residual concentration of flammable solvent shall be verified as within acceptable limits prior to the introduction of flight fluids.

b. After purging with an inert gas, a 24 hour "lock-up" of the component or assembled component shall be conducted to assure that enough time is provided for contaminant solvent to volatilize, thus achieving concentration equilibrium so that gas sampling will provide an accurate reflection of the residual solvent concentration.

c. The solvent concentration in "lock-up" gas samples shall not exceed 18 ppm when measured as methane.

d. When water is used for cleaning, flushing, or testing of systems that use ammonia (NH3) as the operating fluid, the residual concentration of water must be verified as within acceptable limits prior to the introduction of flight fluids.

(1) After purging with a dry gas, a 24 hour "lock-up" of the component or assembly shall be conducted to ensure that enough time is provided for contaminant water to volatilize, thus achieving concentration equilibrium so that gas sampling will provide an accurate reflection of the residual water concentration.

(2) The water concentration in "lock-up" gas samples shall not exceed a dew point of –50 °C (-58 °F).

5.4.13 Composite Manufacturing Processes

Composite hardware and bonds are highly susceptible to process variations and high quality control standards are needed to assure aerospace quality hardware. Contamination should be rigorously controlled as chemical contamination may weaken the material and debris can cause fiber cutting, fiber breakage, or delaminations.

The reliability of manufacturing processes for composite/bonded structures shall be demonstrated.

The following JSC specifications should be used for in-house composite manufacturing at JSC:

- *PRC-6001, Manufacture of Composite Laminate Prepreg. Parts*
- *PRC-6002, Assembly of Sandwich Structures*
- *PRC-6003, Trimming and Drilling of Composites*

5.5 MATERIAL NONDESTRUCTIVE INSPECTION

5.5.1 Nondestructive Evaluation (NDE) PLAN

a. The NDE Plan shall address the process for establishment, implementation, execution, and control of NDE through design, manufacturing, operations, and maintenance of spaceflight hardware.

Plan contractors are required to generate an NDE Plan for JSC approval. The NDE Plan for in-house hardware manufactured by JSC is in development. Requirements for nondestructive inspection of JSC flight hardware are documented in applicable PRCs. The following PRCs are for nondestructive inspection of JSC flight hardware:

- *PRC-6501 Ultrasonic Inspection of Composites*
- *PRC-6503 Radiographic Inspection*
- *PRC-6504 Ultrasonic Inspection of Wrought Metals*
- *PRC-6505 Magnetic Particle Inspection*
- *PRC-6506 Liquid Penetrant Inspection*
- *PRC-6509 Eddy Current Inspection*
- *PRC-6510 Process Specification for Ultrasonic Inspection of Welds*

Additional nondestructive inspection PRCs will be generated when needed.

b. NDE shall meet the intent of MIL-HDBK-6870, Inspection Program Requirements, Nondestructive for Aircraft and Missile Materials and Parts and, when fracture control is applicable, the requirements of NASA-STD-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-5009 are applicable. It is expected that fracture-critical and safety-critical parts have surface and volumetric inspections unless there is rationale that it is not necessary. The need for internal (volumetric) inspection depends on the application and on materials characteristics such as thickness, product form, and other factors. Internal inspection requirements and methods should be determined early in the design process so that proper flaw screening is accomplished.

c. As a minimum, forgings, castings, formings, non-fracture-critical low risk parts, and low margin fail-safe parts shall be non-destructively inspected.

This inspection does not necessarily have to be quantitative in accordance with NASA-STD-5009, but should provide screening for larger cracks or defects.

d. Qualification and certification of personnel involved in nondestructive testing shall comply with ES SOP 0009.86, Written Practice for Certification and Qualification of Nondestructive Evaluation Personnel, or NAS410, NAS Certification and Qualification of Nondestructive Test Personnel.

5.5.2 NDE ETCHING

a. All machined or otherwise mechanically disturbed surfaces that are to be fluorescent dye-penetrant inspected shall be adequately etched to assure removal of smeared, masking material prior to penetrant application, with the following exceptions:

(1) Previously etched parts do not need etching if the surface has not been smeared since the last etching.
(2) When supporting rationale is provided, close tolerance parts may be machined near-final and etched and penetrant inspected before final machining in lieu of etching and penetrant inspecting after final machining.

b. The etching procedure shall specify the minimum amount of material to be removed to ensure that smeared metal does not mask cracks.

Minimum material removal requirements for fracture-critical hardware are identified in NASA-STD-5009.

c. If etching is not feasible, it shall be demonstrated by a Probability of Detection (POD) study approved by JSC M&P that the required flaw size can be reliably detected.

5.6 SPECIAL MATERIALS REQUIREMENTS

5.6.1 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. Residual stresses may be harmful in structural applications when the part is subjected to fatigue loading, operation stresses, or corrosive environments. Special consideration should be given to the possibility of high residual stresses that might develop during off-nominal processing, such as repeated weld repairs in the same location. Residual stresses should be controlled or minimized during the fabrication sequence by special treatments, such as annealing and stress relieving. Bending and forming of tubing (for example, stainless steel and titanium tubing) is typically not stress relieved.

a. Estimates of residual stresses in structural or stress-corrosion-sensitive hardware, shall be considered in structural analyses and corrosion/stress-corrosion assessments.

Residual stresses should be quantified by an appropriate technique (such as x-ray diffraction).

c. The straightening of warped parts in structural hardware shall require an approved MUA.

5.6.2 SANDWICH ASSEMBLIES

Many spaceflight hardware failures have been attributed to both vented and non-vented sandwich assemblies (using either perforated or non-perforated honeycomb core) that were compromised by the expansion of trapped gas and/or water vapor in-flight, causing internal pressure build-up and subsequent face-sheet separation. Structural sandwich assemblies using honeycomb or open-cell core constructions that are exposed to ascent-aerodynamic heating and/or vacuum exposure may be either vented to relieve internal pressure or sealed and protected to preclude accumulation of water or other contaminates inside the sandwich structure.

a. For vented sandwich architectures, the differential pressure on ascent shall be adequately relieved to preclude core-to-face sheet bond line "peel" failure modes that could result in face-sheet separation.

Venting analysis methods are complex and may be difficult to verify. Testing should be conducted to verify that the venting architectures selected perform as intended in the as-built flight structures. "Peel" failure modes at the core-to-facesheet bondline should be characterized with expected defects (damage tolerance) and evaluated against the expected combined loading environments associated with internal pressure, temperature, absorbed water/humidity, and externally applied loads.

b. Sandwich architectures that are not vented shall be capable of withstanding pressure buildup without violating strength and stability requirements.

Sandwich assemblies that are not vented may result in higher internal design pressures during flight. As for vented sandwich architectures, verification of non-vented sandwich assemblies should include evaluation of credible "peel" failure modes when exposed to all expected combined loading environments. Additionally, fatigue performance should be interrogated to evaluate the effects of thermal cycling and the associated variation in internal gas pressure.

c. Structural sandwich assemblies shall be designed to prevent the entrance and entrapment of water vapor or other contaminants into the core structure.

Regardless of the venting architecture, careful consideration of water intrusion pathways at both the part and assembly level is necessary. Sources of water intrusion include absorption, diffusion, condensation, cryo-pumping, and rain/wind-driven rainwater prior to launch.

d. Structural honeycomb sandwich assemblies that will be subjected to heating shall be tested for the expected environments to show that the construction can withstand them.

Elevated temperatures from panel heating can soften adhesives and cause failure. Catastrophic spacecraft structural failures have been associated with ascent-aerodynamic heating (including the effects of water/water vapor), or on-orbit thermal cycling. Testing should address expected defects commensurate with damage tolerance requirements. Acceptance / proof testing of each flight article should address the combined loading environment, including rapid decompression.

e. Sandwich assemblies using perforated and moisture-absorbing cores shall be protected from water intrusion during assembly and prelaunch activities.

Certain sandwich core materials, e.g. Nomex or Kevlar aramids, are capable of absorbing significant amounts of moisture. Selection of such materials may require environmental conditioning prior to launch in addition to discrete water intrusion protections.

f. Sandwich assemblies that utilize aluminum honeycomb core and may be exposed to condensed moisture/water shall be electrically isolated from carbon/graphite facesheets to limit the potential for galvanic corrosion to compromise the honeycomb sandwich assembly.

Aluminum in contact with carbon/graphite produces an electrochemical potential difference of greater than 1 volt. If moisture/water enters the sandwich assembly by diffusion, condensation, cryo-pumping, rain etc., electrical isolation of the galvanic couple will significantly reduce (but not eliminate) the risk of corrosion degradation. The method(s) selected to provide galvanic isolation should be evaluated against all relevant design environments throughout the life cycle of the part. Effective galvanic isolation can be achieved by incorporating fiberglass isolation plies of adequate thickness (e.g., > 0.005") at the core-to-facesheet interface, as long as over-lap splices are incorporated throughout the part. Where moisture/water intrusion is expected, nonmetallic core is preferred.

g. Structural sandwich constructions and core materials shall be designed, evaluated, and tested in accordance with the requirements of CMH-17 Volume 6: Structural Sandwich Composites.

5.6.3 CORROSION PREVENTION AND CONTROL

All parts, assemblies, and equipment used in spaceflight hardware that provides mission-critical functions, including spares, shall be finished to provide protection from corrosion in accordance with the requirements of NASA-STD-6012, Corrosion Protection for Space Flight Hardware, with the following exceptions:

a. SAE AMS2404 is permitted for electroless nickel plating as an alternative to ASTM B733-15.

b. Titanium fasteners may be used in contact with graphite composites, provided that they are wet installed with sealant or primer materials.

c. The ISS internal environment is considered to be Class 5, not Class 7.

The following JSC specifications should be used for in-house corrosion protection at JSC:

- *PRC-4002, Application of Thermal and Corrosion Control Paints and Coatings*
- *PRC-4004, Sealing of Joints and Faying Surfaces*

- *PRC-5005, Process Specification for the Chemical Conversion Coating of Aluminum Alloys*
- *PRC-5006, Anodizing of Aluminum Alloys*
- *PRC-5008, Specialty Anodizing of Aluminum Alloys to Control Optical Properties*
- *PRC-5011, Polytetrafluoroethylene (PTFE) – Impregnated or Codeposited Surface Treatment of Aluminum Alloys*

The appropriate JSC specification needs to be used for each hardware application (for example, chemical conversion coatings are rarely adequate for long-term corrosion protection).

5.6.3.1 Passivation

Corrosion-resistant steels used in spaceflight hardware that provides mission-critical functions shall be passivated in accordance with PRC 5002 after machining.

5.6.3.2 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.

5.6.4 HYDROGEN EMBRITTLEMENT

Hydrogen embrittlement through hydrogen-metals interactions can be classified into three broad categories: hydrogen environmental embrittlement (HEE), internal hydrogen embrittlement (IHE), and hydrogen reaction embrittlement (HRE). In general, hydrogen environmental embrittlement represents the condition where the materials are exposed to a high-pressure gaseous hydrogen environment. The hydrogen for internal hydrogen embrittlement is usually not from a high-pressure gaseous system, but from an electrochemical process such as electroplating, corrosion, cathodic charging, and even from thermal charging. The hydrogen for internal hydrogen embrittlement can also come from moisture and enter the metals during welding, casting, and solidification processes from the foundry.

The hydrogen environmental embrittlement and internal hydrogen embrittlement effects are similar in many instances and they both require an external applied stress in order for the hydrogen embrittlement effects to occur. In contrast, hydrogen reaction embrittlement is usually irreversible hydrogen damage caused by a chemical reaction with hydrogen and such damage can occur without an external applied stress. This form of hydrogen damage can occur in materials such as titanium, zirconium, and some types of iron or steel-based alloys.

Overall, hydrogen embrittlement of materials is not very well understood and only limited materials property data have been generated. NASA/TM-2016-218602, Hydrogen Embrittlement, provides a detailed description of hydrogen embrittlement mechanisms, a comprehensive summary of existing hydrogen embrittlement data, and guidance on selection of materials and control of processes to prevent hydrogen embrittlement. It is a companion document to ANSI/AIAA G-095, Guide to Safety of Hydrogen and Hydrogen Systems.

a. When designing liquid or gaseous hydrogen systems, the degradation of metallic materials properties by hydrogen embrittlement shall be addressed in the Materials and Processes Selection, Control, and Implementation Plan.

b. An MUA shall be written rationalizing the selection of metallic materials to preclude cracking 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.

c. Electrochemical processes or exposure to acids or bases during manufacturing or processing of spaceflight hardware that provides mission-critical functions shall be controlled to prevent hydrogen embrittlement, or embrittlement relief treatment shall be performed promptly after processing.

(1) When acid cleaning baths or plating processes are used on steel parts for spaceflight hardware that provides mission-critical functions, the part shall be baked in accordance with SAE AMS2759/9, Hydrogen Embrittlement Relief (Baking) of Steel Parts, to alleviate potential hydrogen embrittlement problems.

5.6.5 INTERMETALLIC COMPOUNDS

When joining two or more metals together (soldering, wire bonding, etc.), intermetallic compounds can form that are problematic to the metal joint, leading to a weakened mechanical or electrical connection. Problems can arise from embrittlement, changes in density, or conductivity of the intermetallic compound. Gold-indium and gold-tin are two of the more common systems that form intermetallic compounds that will degrade a metal joint.

5.6.5.1 Gold-Indium Intermetallic Formation

Indium reacts with gold to form a succession of gold-indium intermetallic compounds. The gold-indium intermetallic compounds occupy a volume approximately four times the original volume of the consumed gold and are brittle. The original mechanical and thermal properties of gold are degraded by this intermetallic reaction possibly resulting in unreliable electrical interconnections. The gold-indium intermetallic formation progresses significantly even at room temperature and accelerates at elevated temperatures.

Gold shall not be used in contact with indium or an indium alloy (such as indium solder) for spaceflight hardware that provides mission-critical functions.

5.6.5.2 Gold-Tin Intermetallic Formation

The combination of gold and tin is subject to two distinct degradation mechanisms: gold embrittlement of tin-based solder joints and fretting corrosion of gold-coated contacts when mated with tin or tin alloy-coated contacts.

When tin-based solder is used to join gold-plated surfaces, the gold coatings will dissolve into the final solder joint. If the concentration of gold in the tin-based solder joint exceeds approximately 3 percent by weight, then a brittle gold-tin intermetallic compound may form within the joint that can impact the long-term reliability of the solder joint.

a. When used with tin-based solder joints in mission-critical hardware, gold shall be removed from at least 95 percent of the surface to be soldered of all component leads, component terminations, and solder terminals.

A double tinning process or dynamic solder wave may be used for gold removal prior to mounting the component on the assembly.

The combination of one gold-coated surface and one tin-coated or tin-alloy-coated surface for separable contact interfaces (e.g., electrical connector contact pairs) is highly prone to fretting corrosion, which can build up an electrically insulating tin-oxide film at the contact interface, resulting in increased contact resistance.

b. Gold-coated contacts shall not be mated with tin or tin alloy-coated contacts for separable contact interfaces in mission-critical hardware.

5.6.5.3 Gold-Aluminum Intermetallic Formation

An aluminum-rich intermetallic phase, the $AuAl_2$ *intermetallic known as "Purple Plague," is inherent (and not necessarily harmful) to gold-aluminum brazing; however, if excessive heat is applied too much of the intermetallic can form at the braze/part interface, causing joint failure. A gold-rich phase, the* Au_5Al_2 *intermetallic known as "White Plague," is always detrimental. Its formation is catalyzed by silicon, so care should be taken to keep the braze joint zone free of contamination.*

a. Gold-aluminum brazing processes shall be controlled to minimize formation of the $AuAl_2$ intermetallic known as "Purple Plague" and prevent formation of the Au_5Al_2 intermetallic known as "White Plague."

Purple Plague is a significant problem in microelectronic applications, because as purple plague forms, it reduces in volume. This creates cavities in the metal surrounding the purple plague, which increases electrical resistance and structurally weakens the wire bonding. White plague is worse, because it has low electrical conductivity and, if enough of it forms, the resulting electrical resistance can cause a total failure of the component.

b. Gold-aluminum bonding processes shall be controlled to prevent the formation of the $AuAl_2$ intermetallic known as "Purple Plague" and the Au_5Al_2 intermetallic known as "White Plague."

5.6.6 FASTENER INSTALLATION

The following JSC specifications should be used for in-house fastener installation at JSC:

- *PRC-9001, Installation of Solid and Blind Rivets*
- *PRC-9004, Installation of Thin-Wall Screw Thread Inserts*
- *PRC-9005, Lockwiring*
- *PRC-9006, Installation of Key-Retained Screw Thread Inserts*
- *PRC-9007, Installation of Threaded and Collared fasteners*
- *PRC-9008, Installation of Helical Coil Inserts*

5.6.6.1 Liquid Locking Compounds

If a liquid-locking compound is used as a locking feature where rotational loosening or disengagement would result in a critical or catastrophic hazard, its use shall comply with the design and quality requirements and best practices in the NASA-STD-5020, Requirements for Threaded Fastening Systems in Spaceflight Hardware sections relating to locking features and their verification.

PRC-4006, Process Specification for the Application of Liquid Locking Compounds, should be used for application of liquid-locking compounds to noncritical fasteners used in JSC GFE hardware.

Extreme care should be taken when using liquid-locking compounds on fasteners going into blind holes, because the air in the bottom of the hole can push the liquid-locking compound out of the fastener threads as the fastener is installed. Manufacturers recommend applying several drops of the product down the internal threads to the bottom of the hole, but the most reliable approach is to completely fill the blind hole with liquid-locking compound so there is no air to push the liquid-locking compound out.

5.6.6.2 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 for a period longer than 2 weeks.

5.6.7 CONTAMINATION CONTROL

Contamination, if not adequately anticipated and controlled, can result in loss of spacecraft, performance degradation, mission degradation, and/or loss or injury of flight crew. Examples of contamination sources and mechanisms include:

- *Particulate and molecular contamination from both ground processing and on-orbit migration may degrade the performance of optical devices, thermal control surfaces, and solar arrays.*

- *Particulate contamination accumulated during ground processing or generated during operations may interfere with mechanisms, bearings, and seals; may plug or restrict fluid orifices or filters; and may pose a hazard to the crew.*
- *Particulate and nonvolatile residues pose an ignition hazard within systems containing oxidizers, such as oxygen or nitrogen tetroxide. Cleaning agents intended to remove contaminants from these systems may leave reactive residues if not adequately controlled and removed.*
- *Microbial contamination within life support systems and ultrapure water systems may degrade these systems.*
- *Control of terrestrial microbial contamination and extraterrestrial material may be required in accordance with NASA Procedural Requirements (NPR) 8020.12 on Planetary Protection Provisions for Robotic Extraterrestrial Missions.*

a. Plan contractors shall generate a contamination control plan in accordance with the guidelines of ASTM E1548, Standard Practice for Preparation of Aerospace Contamination Control Plans.

b. The contamination control 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.

c. The foreign object debris (FOD) prevention program shall be established for all ground operations of mechanical and electrical systems of spaceflight 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.

d. The FOD prevention program shall conform to NAS412 "Foreign Object Damage/ Foreign Object Debris (FOD) Prevention.

e. Cleanliness levels for assembly- and subassembly-level hardware shall be identified on the engineering drawings.

5.6.7.1 Packaging

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

5.7 MATERIALS AND PROCESSES FOR ELECTRICAL COMPONENTS

The M&P requirements for electrical components established in this plan apply only to ISS hardware and payloads. The requirements for MPCV Program hardware are imposed on the program by MPCV 70059, Orion Multi-Purpose Crew Vehicle (MPCV) Program Safety and Mission Assurance (S&MA) Requirements, M&P requirements for JSC MPCV flight hardware electrical components are implemented by direct compliance with MPCV 70059 or by *compliance with in-house plans developed by the JSC Avionic Systems Division (EV) and Safety and Mission Assurance Directorate (NA).*

5.7.1 ELECTRICAL BONDING AND GROUNDING

Parts and materials used in electrical bonding and grounding shall meet the requirements of this document.

5.7.2 USE OF SILVER

Silver is prohibited as a plating on printed wiring boards, terminal boards and bus bars.

5.7.3 WIRE/CABLE ASSEMBLIES

The following shall be assembled or installed to meet the requirements of PRC-7003, Process Specification for the Manufacture of Electrical Cables, Wiring, and Harnesses, or NASA-STD-8739.4, Crimping, Interconnecting Cables, Harnesses, and Wiring.

1. Electrical connectors,
2. Interconnecting cables, harness, and wiring
3. Solder Sleeves.

5.7.4 FIBER OPTICS

Fabrication controls and processes for joining of fiber optic cable assemblies shall comply with NASA-STD-8739.5, Fiber Optic Terminations, Cable Assemblies, and Installation with the exception that process controls may be used in lieu of inspection under magnification.

5.7.5 PRINTED WIRING BOARDS

Printed wiring boards shall be designed in accordance with IPC-2221, Generic Standard on Printed Board Design and IPC-2222, Sectional Design Standard for Rigid Organic Printed Boards.

Fabrication controls and processes used in rigid printed wiring boards shall meet the requirements of IPC-6011, Generic Performance Specification for Printed Boards, and IPC-6012, Qualification and Performance Specification for Rigid Printed Boards.

The supplemental information in GSFC Supplement S-312-P003, Process Specification for Rigid Printed Boards for Space Applications and Other High Reliability Uses, should also be considered.

5.7.6 PRINTED WIRING ASSEMBLIES

Electrical circuitry shall be designed and fabricated to prevent the production of unwanted current paths by debris or foreign materials floating in the spacecraft microgravity environment.

5.7.6.1 Staking/Conformal Coating

Fabrication controls and processes used in staking and conformal coating of printed wiring boards and electronic assemblies shall meet the requirements of PRC-7002, Process Specification for the Staking and Conformal Coating of Printed Wiring Boards and Electronic Assemblies, or NASA-STD-8739.1, Workmanship Standard for Staking and Conformal Coating of Printed Wiring Boards and Assemblies

5.7.6.2 Other Processes

a. Other processes used for printed wiring assemblies shall meet the requirements in IPC J-STD-001F, Requirements for Soldered Electrical and Electronic Assemblies and IPC J-STD-001FS WAM1, Space Applications Electronic Hardware Addendum to J-STD-001F Requirements for Soldered Electrical and Electronic Assemblies, and PRC-7002, Process Specification for the Staking and Conformal Coating of Printed Wiring Boards and Electronic Assemblies, or NASA-STD-8739.1, Workmanship Standard for Staking and Conformal Coating of Printed Wiring Boards and Assemblies.

b. Component mounting shall be consistent with IPC-CM-770, Component Mounting Guidelines For Printed Boards.

5.7.7 ELECTRICAL SOLDERING

a. Fabrication controls and processes used in soldering of electrical connections shall meet the requirements of PRC-7001, Soldering of Electrical Components or IPC J-STD-001F, Requirements for Soldered Electrical and Electronic Assemblies and IPC J-STD-001FS WAM1, Space Applications Electronic Hardware Addendum to J-STD-001F Requirements for Soldered Electrical and Electronic Assemblies.

b. Surface mount devices shall be soldered according to the requirements of NASA-STD-8739.2, Workmanship Standard for Surface Mount Technology, IPC J-STD-001F and J-STD-001FS .

5.7.8 ELECTRICAL CRIMPING

a. Crimping of electrical terminations shall meet the requirements of NASA-STD-8739.4, Crimping, Interconnecting Cables, Harnesses, and Wiring.

b. Terminal lugs, splices, and two-piece shield termination rings shall meet the tensile strength and electrical requirements of SAE-AS7928.

5.7.9 ELECTRICAL WIRE WRAPPED CONNECTIONS

a. Wire wrapping shall not be used, except in Ground Support Equipment.

b. Wire wrapping shall meet the requirements of NASA-STD-8739.4, Crimping, Interconnecting Cables, Harnesses, and Wiring.

5.7.10 ELECTROSTATIC DISCHARGE CONTROL

Electrostatic discharge sensitive parts, assemblies, and equipment shall be controlled in accordance with the requirements of JPR 8730.12, Electrostatic Discharge Control Requirements for the Protection of Electrical and Electronic Parts, Assemblies, and Equipment (Excluding Electrically Initiated Devices) or ANSI/ESD S20.20, Development of an Electrostatic Discharge Control Program: Protection of Electrical and Electronic Parts, Assemblies and Equipment (Excluding Electrically Initiated Explosive Devices).

NASA-HDBK 8739.21, Workmanship Manual for Electrostatic Discharge Control provides guidance on the implementation ANSI/ESD S20.20.

6.0 REVIEWS AND VERIFICATION

6.1 REVIEWS

The JSC Materials & Processes Branch shall be notified of the system requirements review (SRR), preliminary design review (PDR), critical design review (CDR), and flight readiness review (FRR) for all JSC GFE hardware. M&P representatives will participate in these reviews, and any other reviews containing M&P issues on request. All pertinent documents and data shall be presented before or in the design reviews, including engineering drawings, drawing trees, MIULs, MUAs, and M&P specifications.

6.2 VERIFICATION

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

(1) NASA approval of plan 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.

(2) M&P signature on engineering drawings (other than for Class 1-E hardware) to verify compliance with the requirements of this document or the Materials and Processes Selection, Implementation, and Control Plan. For Class 1-E hardware, M&P review of the engineering drawings is sufficient.

(3) NASA audits of contractor M&P activities relating to hardware design and manufacturing.

(4) NASA approval of MUAs.

(5) NASA approval of MIULs (when required).

(6) Issuance of Materials Certification as described in Section 3.2.1 or 3.2.2.

APPENDIX A ABBREVIATIONS AND ACRONYMS

/sec	Per Second
AIAA	American Institute of Aeronautics and Astronautics
AM	Additively Manufactured
AMS	Aerospace Material Specification
ANSI	American National Standards Institute
AS	Aerospace Standard
ASTM	ASTM International (formerly American Society for Testing and Materials)
AWS	American Welding Society
BZT	Benzotriazole
CCP	Contamination Control Plan
CDR	Critical Design Review
cm	Centimeter
CMH	Composite Materials Handbook
COTS	Commercial Off-The-Shelf
CP	Commercially Pure
CR	Contractor Report
CVCM	Collected Volatile Condensable Materials
°C	Degrees Celsius
°F	Degrees Fahrenheit
D	Dimensional
DMLS	Direct Metal Laser Sintering
DOT	Department of Transportation
DRD	Data Requirements Description
EDM	Electrical Discharge Machining
EEE	Electrical, Electronic, and Electromechanical
ELI	Extra Low Interstitial
ESD	Electrostatic Discharge
ETFE	Ethylene Tetrafluoroethylene
FAA	Federal Aviation Administration
FEP	Fluorinated Ethylene Propylene
FOD	Foreign Object Damage/Debris
FRR	Flight Readiness Review
g	Gram
GEIA	Government Electronics and Information Technology Association
GOX	Gaseous Oxygen
GSE	Ground Support Equipment
HDBK	Handbook
HEE	Hydrogen Environmental Embrittlement
HRE	Hydrogen Reaction Embrittlement
IHE	Internal Hydrogen Embrittlement
in	Inch
JSC	Johnson Space Center

kPa	Kilopascals
ksi	Kilopounds per Square Inch
lb	Pound
LM	Laser Machining
LOX	Liquid Oxygen
M&P	Materials and Processes
MAPTIS	Materials and Processes Technical Information System
MIL	Military
MIUL	Materials Identification and Usage List
mm	Millimeter
MMPDS	Metallic Materials Properties Development and Standardization
MNL	Manual
MPa	Megapascals
MSFC	Marshall Space Flight Center
MUA	Material(s) Usage Agreement
NAS	National Aerospace Standard
NASA	National Aeronautics and Space Administration
NDE	Nondestructive Evaluation
NDI	Nondestructive Inspection
NDT	Nondestructive Testing
NPR	NASA Procedural Requirements
PDF	Portable Document Format
PDP	Part Development Plans
PDR	Preliminary Design Review
PFA	Perfluoroalkoxy
PH	Precipitation Hardened/Hardenable
PQR	Procedure Qualification Record
PSIA	Pounds per Square Inch Absolute
PTFE	Polytetrafluoroethylene
PVC	Polyvinyl Chloride
RH	Relative Humidity
RSW	Resistance Spot Welding
RTV	Room Temperature Vulcanizing (rubber)
SAE	SAE International (formerly Society of Automotive Engineers)
SDR	System Definition Review
sec	Second
SLM	Selective Laser Melting
SMAC	Spacecraft Maximum Allowable Concentration
SOW	Statement of Work
SPEC	Specification
SRR	System Requirements Review
STD	Standard
TM	Technical Memorandum
TML	Total Mass Loss

UTS	Ultimate Tensile Strength
UV	Ultraviolet
VCM	Volatile Condensable Materials
WPS	Welding Procedure Specification
	Weld Process Specification
WVR	Water Vapor Recovery

APPENDIX B DEFINITIONS

Additive Manufacturing: Any process for making a three-dimensional object from a 3-D model or other electronic data source primarily through processes in which successive layers of material are deposited under computer control.

Catastrophic Hazard: Presence of a risk situation that could directly result in a catastrophic event, which is defined as loss of life, disabling injury, or loss of a major national asset.

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

Critical Hazard: Hazard that can result in the potential for severe injury, severe occupational illness, or major property/equipment damage.

Design Value: The design value is a statistically determined minimum value of a property, most commonly strength properties of materials, design features/elements, or components/parts used in the design of a structure. For A-basis strength properties, at least 99% of the population of strength values is expected to equal or exceed this lower bound with 95% confidence. For B-basis, 90% of the population of strength values is expected to equal or exceed this lower bound with 95% confidence. For metallic materials S-basis design values, the statistics defined by MMPDS are the same as for A-basis, but the test requirements are less comprehensive. Numbers of lots and test specimens required to develop design values are defined in applicable standards. The terms “material allowables,” “design allowables,” and “design values” are commonly used to address the design values used in structural analysis.

Ductile-Brittle Transition Temperature**:** Temperature at which a marked change occurs in the fracture resistance of body-centered cubic and hexagonal close-packed metals from ductile behavior to brittle behavior. The transition occurs in those metals in which the yield strength increases sharply with decreasing temperature and which are capable of fracturing by cleavage or an intergranular mode with very little accompanying plastic deformation. The transition temperature also depends on strain rate.

Fretting Corrosion: Occurs when two contacting surfaces under mechanical load are subjected to repeated relative surface motion. Mechanical wear and material transfer at the surfaces can lead to corrosion, metallic debris, and increased contact resistance due to the electrical insulating properties of corrosion products that may build up at the contact interfaces.

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

Nondestructive Evaluation (NDE)/Nondestructive Testing (NDT): Inspection techniques which do not cause physical, mechanical, or chemical changes to the part being inspected or otherwise impair its adequacy for operational service. These inspection techniques are applied to materials and structures to verify required integrity and to detect flaws.

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

Safety-Critical: Term describing any condition, event, operation, process, equipment, or system that could cause or lead to severe injury, major damage, or mission failure if performed or built improperly, or allowed to remain uncorrected.

Structural: Pertaining to 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, provide stiffness and stability, or provide support or containment.

Structure, Primary: That part of a flight vehicle or element that sustains the significant applied loads and provides main load paths for distributing reactions to applied loads. Also, the main structure that is required to sustain the significant applied loads, including pressure and thermal loads, and that, if it fails, creates a catastrophic hazard. If a component is small enough and in an environment where no serious threat is imposed if it breaks, then it is not primary structure.

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

Technical Authority: Provides technical checks and balances by assuring that safety and mission success, relevant technical standards, engineering work, and safety and reliability analysis products are being conducted properly in accordance with established, high-reliability processes independent of nontechnical program/project constraints.

Tin Pest: The allotropic transformation of tin that may occur at or below 13.2 °C, where tin transforms from β-phase into its α-phase, a grey, brittle semiconductor that occupies about 27 percent greater volume than the β-phase.

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

Wet Installed: Fasteners covered with primer or sealant during installation to prevent moisture from penetrating the fastener joint and causing corrosion.

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

APPENDIX C

JSC MATERIALS AND FRACTURE CONTROL CERTIFICATION FORM

JSC MATERIALS AND FRACTURE CONTROL CERTIFICATION

PROJECT/SUBSYSTEM MANAGER: Name / Branch	REF: **MATL – xx – xxx**
HARDWARE NAME:	PART NUMBER: See Attachment 2

APPLICABLE REQUIREMENTS:

Materials Requirements:

- ☐ JSC 27301, Materials Control Plan for JSC Flight Hardware
- ☐ NASA-STD-6016, Standard Materials and Processes Requirements for Spacecraft
- ☐ SSP 51700, Payload Safety Policy and Requirements for the International Space Station (ISS)
- ☐ SSP 57000, ISS Pressurized Payloads Interface Requirements Document
- ☐ SSP 57003, ISS External Payload Interface Requirements Document
- ☐ SSP 50021, ISS Safety Requirements Document
- ☐ SSP 30233, Space Station Requirements for Materials and Processes
- ☐ Other:

Fracture Control Requirements:

- ☐ JSC 25863, Fracture Control Plan for JSC Space-Flight Hardware
- ☐ NASA-STD-5019, Fracture Control Requirements for Spaceflight Hardware
- ☐ Other:

SPECIFIC ASSESSMENTS:

- ☐ Flammability
- ☐ Toxic Offgassing
- ☐ Stress Corrosion Cracking
- ☐ General Corrosion
- ☐ Fracture Control (☐ Not Applicable; Concurrence:)
- ☐ Age Life ☐ Other:
- ☐ Atomic Oxygen/Ultraviolet
- ☐ Thermal Vacuum Stability
- ☐ Fluid Compatibility:
- ☐ Microbiological Resistance

LOCATIONS:

☐ COTS ☐ HTV ☐ Space Station: ☐ Internal ☐ External ☐ ISS Airlock

☐ Soyuz ☐ Progress ☐ Other:

MATERIALS USAGE AGREEMENTS (MUAs):

☐ No MUA ☐ MUA Number(s):

Deviation:

LIMITATIONS: ☐ No Limitations

☐ Materials:

☐ Fracture Control:

This JSC Materials and Fracture Control Certification is consistent with existing Materials or Fracture Control Reciprocal Agreements. Materials Certification to JSC 27301 or NASA-STD-6016 and Fracture Control Certifications to JSC 25863 or NASA-STD-5019 comply with applicable materials and processes and fracture control requirements in the following program-specific documents: SSP 30233, Space Station Requirements for Materials and Processes; SSP 30558, Fracture Control Requirements for Space Station; SSP 52005, ISS Payload Flight Equipment Requirements and Guidelines for Safety-Critical Structures.

APPROVALS

Fracture Control Manager

GFE Materials Control Manager, M. Pedley

Form Updated 04-25-2018

Page **1** of **4**

APPENDIX D

JSC MATERIALS USAGE AGREEMENT FORM

and

JSC VOLATILE USAGE AGREEMENT FORM

JSC Material Usage Agreement (MUA)	MUA NUMBER	REV.	Page x of x
☐ ISS MATERIALS USAGE AGREEMENT ☐ MPCV MATERIALS USAGE AGREEMENT ☐ Others: ____________________	MUA-xxxx		
TITLE:	**CATEGORY:**	**EFFECTIVITY:**	

TYPE OF DEVIATION:	**REQUIREMENT DEVIATED:**
☐ **MATERIAL** ☐ **EQUIPMENT** **(NO. PER VEHICLE:)**	☐ **FLAMMABILITY** ☐ **TVS** ☐ **O_2 COMPATIBILITY** ☐ **OFFGASSING** ☐ **SCC** ☐ **OTHER**

EQUIPMENT	PART NUMBER	MANUFACTURER

MATERIAL	TRADE NAME	SPECIFICATION	MANUFACTURER

THICKNESS (in.)	WEIGHT (lbs.)	AREA (in^2)	LOCATION	ENVIRONMENT		
			☐ Habitable	Temperature (°F)	Pressure (psia)	Media
			☐ Non-habitable			

APPLICATION (use second sheet if required)

RATIONALE (use second sheet if required)

APPROVALS

ORIGINATOR/ORGANIZATION DATE	JSC MATERIALS AND PROCESSES BRANCH DATE
PROJECT MANAGER DATE	**PROGRAM MANAGER DATE**

Form Updated 01/30/2018

VOLATILE ORGANIC COMPOUND USAGE AGREEMENT	USAGE AGREEMENT NUMBER	REV. –	PAGE 1 OF 1
TITLE:	CATEGORY:	EFFECTIVITY:	

EQUIPMENT	PART NUMBER	MANUFACTURER
VOC(s) RELEASED	**VOC WEIGHT**	**VOC RELEASE RATE**

APPLICATION (use second sheet if required)

RATIONALE (use second sheet if required)

APPROVALS			
ORIGINATOR/ORGANIZATION	DATE	JSC MATERIALS AND PROCESSES BRANCH	DATE
PROJECT MANAGER	DATE	ECLSS AIT (Category 1 only)	DATE
CONTROL BOARD (Category 1 only)	DATE	ALCOHOL MANAGER (Category 1 only)	DATE

APPENDIX E

RETIRED CATEGORY III MUA RATIONALE CODES

The Category III MUA rationale codes in releases of JSC 27301 prior to Rev. G were incorporated (with modifications) into the body of Re. G and subsequent releases as exceptions to the requirements or have been eliminated (as was done for Revision A of NASA-STD-6016). Category III MUAs are no longer required for codes that were incorporated as exceptions. Codes were eliminated when the rationales were no longer applicable or a full MUA was considered appropriate for the deviation. The retired codes are listed here for continuity with projects working to the earlier releases.

RETIRED 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 nonflammable materials and no ignition source or propagation path.
105	Minor usage (less than 45 g (0.1 lb) mass and 13 cm^2 (2 in^2) surface area); no propagation path or ignition source.
106	Material is used in hermetically sealed container.
107	Passes test No. 10 of NASA-STD-(I)-6001, 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 is flammable but is sandwiched between nonflammable materials with edges only exposed and is more than 5 cm (2 in) from an ignition source or more than 30 cm (12 in) from other flammable materials.
112	Material is flammable but is unexposed or is overcoated with a nonflammable material.
113	Material is flammable but has a thickness less than 0.25 mm (0.010 in) and is sprayed or bonded to a metallic surface greater than 1.6 mm (0.062 in) thick.
114	Material is flammable but is used in “small amounts” and is more than 5 cm (2 in) from an ignition source or more than 30.5 cm (12 in) from other flammable materials. “Small amounts” for flammability may be quantified as follows: total weight less than 45 g (0.1 lb) and less than 13 cm^2 (2.0 in^2) surface area.

RETIRED 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 for manned flight compartment volume.
204	Materials usage in hermetically sealed container.

RETIRED FLUID SYSTEM COMPATIBILITY RATIONALE CODES

CODE	RATIONALE
301	Approved Material Usage Agreement (MUA) Category I.
302	Passes requirements in configuration.
303	Material is B-rated in MAPTIS (batch/lot testing required) but batch/lot used in hardware passed test.
304	Approved Material Usage Agreement (MUA) Category II.

RETIRED THERMAL VACUUM STABILITY RATIONALE CODES

CODE	RATIONALE
401	Approved Material Usage Agreement (MUA) Category I.
402	Approved Material Usage Agreement (MUA) Category II.
403	VCM between 0.1 and 1.0 percent; exposed area is less than 13 cm^2 (2 in^2) and not near a critical surface.
404	VCM >1.0 percent; exposed area is less than 1.6 cm^2 (0.25 in^2).
405	Unexposed, overcoated, or encapsulated with approved material.
406	Material is B-rated in MAPTIS (batch/lot testing required) but batch/lot used in hardware cured to meet requirements.
407	Meets thermal vacuum stability requirements in configuration.
408	Materials usage in hermetically sealed container.
409	Material has VCM >0.1 percent but is enclosed in a sealed container (maximum leak rate less than 1×10^{-4} cm^3/sec).

RETIRED 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 listed in table 1 of MSFC-STD-3029 for stress corrosion cracking is not exposed to a corrosive environment after final assembly through end-item use.
506	Carbon and low alloy high strength steels greater than 1240 MPa (180 ksi) used in ball bearings, springs, or similar applications where primary loading is compressive, low tensile stresses, or history of satisfactory performance.

RETIRED 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	Material does not meet the requirements of MSFC-SPEC-250, Class II, but is treated or coated in a manner which meets or exceeds the requirements of MSFC-SPEC-250. Actual surface treatment shall be listed.
611	Material does not meet the requirements of MSFC-SPEC-250, Class II, but 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.

RETIRED FLAMMABILITY STOWAGE RATIONALE CODES

CODE	RATIONALE
S01	maximum dimension 10 inches, and unstowed less than 1 day/week
S02	Unstowed less than 1 hour/day
S03	Contingency use only
S04	Maximum dimension less than 6 inches, and always stowed when not in actual use
S05	Used only when covered by crew clothing
S06	Exposed surface area less than 1 square foot, and always worn by crew when unstowed.

RETIRED 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 F

EXCEPTIONS TO NASA-STD-6016A

Exceptions are taken to three requirements in NASA-STD-6016A as follows:

STATEMENT OF REQUIREMENT FROM NASA-STD-6016:

4.1.5 M&P Usage Documentation

a. M&P usage shall be documented in an electronic, searchable parts list or separate electronic searchable Materials Identification and Usage List (MIUL) with the following exceptions:

(4) Electrical, electronic, and electromechanical (EEE) parts other than wire, cable, and exposed surfaces of connectors.

(5) Materials used in hermetically sealed electronic containers (maximum leak rate less than 1 x 10^{-4} cm^3/sec).

b. The documentation of M&P usage shall cover the final design as delivered.

c. The documentation approach shall be defined in the Materials and Processes Selection, Control, and Implementation Plan.

Recommended MIUL content is described in Appendix D, Recommended Data Requirements Documents. Material codes and ratings for materials, standard and commercial parts, and components are available in the Materials and Processes Technical Information System (MAPTIS). When required, new material codes will be assigned by NASA's Marshall Space Flight Center (MSFC). In some cases, MAPTIS contains averages for ratings or test results for generic materials controlled by military or industry specifications; the material codes for the generic materials are used.

MAPTIS is accessible via the Internet at http://maptis.nasa.gov.

Note: *Accessibility to MAPTIS is by registration only.*

STATEMENT OF IMPLEMENTATION IN JSC 27301F:

3.2.1 JSC PLAN CONTRACTOR FLIGHT HARDWARE

JSC plan contractor flight hardware refers to flight hardware developed for JSC by a contractor with an approved Materials and Processes Selection, Control, and Implementation Plan (per Section 3.1.1).

The plan contractor shall perform the following basic M&P functions:

a. The plan contractor shall provide drawing review and approval for M&P

b. The plan contractor shall provide a Materials Identification and Usage List (MIUL) (or an electronic searchable parts list) for all Criticality category 1 ISS and MPCV flight hardware. (Criticality categories are as defined in SSP 30234.) Criticality categories 1R, 1S, 1SR and 1P are not included.

***Notes**:*

3. *The MIUL is required for payload criticality 1 hardware only if the payload is Class A or Class B per SSP 50431, Space Station Program Requirements for Payloads (or equivalent classes for other program payloads)*

4. *For selected plan contractors, additional MIUL requirements may be specified in the contract.*

c. The plan contractor shall generate and approve Materials Usage Agreements (MUAs) and water-soluble Volatile Organic Compound Usage Agreements (VUAs).

Final MUA/VUA approval will be by the JSC Materials and Processes Branch.

d. The plan contractor shall provide materials certification as specified in the Materials and Processes Selection, Control, and Implementation Plan and/or the contract.

3.2.2 JSC NON-PLAN CONTRACTOR FLIGHT HARDWARE (& FLIGHT HARDWARE DESIGNED BY JSC EMPLOYEES)

The above two types of flight hardware in the title are grouped together in this section because both types of flight hardware have M&P functions that are performed by the JSC Materials & Processes Branch, as shown below:

a. The JSC Materials & Processes Branch shall provide drawing review and approval for M&P.

This requirement applies to drawings generated by JSC employees, and to most of the non-plan contractors who generate drawings in the "JSC engineering drawing system", with the following two exceptions:

(a) A few non-plan contractors who generate flight hardware drawings in the JSC engineering drawing system have been selected by the JSC Materials & Processes Branch to sign their own JSC drawings for M&P (and also generate their own MIULs and MUAs).

(b) The JSC Materials & Processes Branch does not approve contractor drawings generated per a contractor's own engineering drawing system, but does review such drawings to the extent necessary to ensure compliance with M&P requirements.

Note: JSC Materials & Processes Branch drawing review and approval may be conducted by civil servants or by in-house contractors.

b. The JSC Materials & Processes Branch shall provide a Materials Identification and Usage List (MIUL) (or an electronic searchable parts list) for Criticality category 1 flight hardware with the following exceptions:

(6) Electrical, electronic, and electromechanical (EEE) parts other than wire, cable, and exposed surfaces of connectors.

(7) Materials used in hermetically sealed electronic containers (maximum leak rate less than 1 x 10^{-4} cm^3/sec).

(8) Criticality category 1 Class 1-E hardware

Notes:

4. *The MIUL is required for payload criticality 1 hardware only if the payload is Class A or Class B per SSP 50431, Space Station Program Requirements for Payloads (or equivalent classes for other program payloads)*
5. *For selected plan contractors, additional MIUL requirements may be specified in the contract.*
6. *JSC Materials and Processes Branch functions may be performed by civil servants or in-house support contractors.*

c. The JSC Materials & Processes Branch shall provide assistance to flight hardware managers in the generation of Materials Usage Agreements (MUA)

d. The JSC Materials & Processes Branch shall approve MUAs

e. The JSC Materials & Processes Branch shall provide Materials and Fracture Control Certification.

EXCEPTION:

A Materials Identification and Usage List (MIUL) (or an electronic searchable parts list) will be generated only for Criticality category 1 spaceflight hardware. (Criticality categories for ISS are defined in SSP 30234.) Criticality categories 1R, 1S, 1SR and 1P are not included.

STATEMENT OF REQUIREMENT FROM JSC NASA-STD-6016:

4.2.1.2 Toxic Offgassing

a. All nonmetallic materials used in habitable flight compartments, with the exception of ceramics, metal oxides, inorganic glasses, and materials used in sealed container (maximum leak rate less than 1 x 10^{-4} cm^3/sec), shall meet the offgassing requirements of Test 7 of NASA-STD-6001B.

STATEMENT OF IMPLEMENTATION IN JSC 27301F:

5.1.2 TOXIC OFFGASSING

a. All nonmetallic materials used in habitable flight compartments, with the exception of ceramics, metal oxides, inorganic glasses, materials used in sealed containers, materials in International Space Station hardware containing less than 20 lb of polymeric materials, and materials in Commercial Crew Program hardware containing less than 0.5 lb of polymeric materials, shall meet the offgassing requirements of NASA-STD-6001B.

For ISS, if the total mass of polymeric materials in an end item, or a system with multiple end items (such as a set of CubeSats with deployer) is less than 20 lb, it is exempt from offgas testing or evaluation unless it contains one of the following excluded materials:

- *COTS end items that include uncured adhesives, lubricants, cleaning wipes, markers, pens, other items with uncontained liquids or gels, and hardware used for uncontained on-orbit processing of materials at elevated temperatures (such as 3D printers) are not exempt.*

- *Custom end items that include the materials listed above or foams and foamed fluorocarbons (cables) are not exempt.*

- *If excluded materials are present or the total mass of polymeric materials exceeds 20 lb, an offgassing test could be required or an offgassing evaluation could be conducted to verify that all excluded materials and major use polymeric materials are used in quantities less than the ISS maximum limit weight in the MAPTIS database.*

The same constraints apply for polymeric materials in Commercial Crew Program hardware, except that the mass limitation is 0.5 lb, not 20 lb.

EXCEPTION:

International Space Station hardware containing less than 20 lb of polymeric materials and Commercial Crew Program hardware containing less than 0.5 lb of polymeric materials are exempted from testing to verify that they meet the offgassing requirements of NASA-STD-

6001B unless the hardware includes the materials identified in 5.1.2 as excluded from the exemption.

STATEMENT OF REQUIREMENT FROM JSC NASA-STD-6016:

4.2.4.1 Heat Treatment

a. For spaceflight hardware that provides mission-critical functions, process-control tensile-test coupons shall be taken from the production part (or from the same material lot, having the same thickness as and processed identically to the production part) to verify the adequacy of the heat treatment process for the following conditions:

(1) Aluminum alloys are solution heat-treated.

(2) High-strength steels (>200 ksi (1380 MPa) UTS), tool steels, and maraging steel alloys are heat-treated to high strength levels.

(3) A286 or MP35N alloys (which have poor correlation between hardness and tensile strength) are heat treated.

(4) Titanium alloys are annealed or solution heat treated and aged.

(5) Nickel- and cobalt-based alloys are work strengthened before age hardening, resulting in age-hardened tensile strengths greater than 1030 MPa (150 ksi) UTS.

(6) Precipitation hardenable nickel- and cobalt-based alloys are solution heat treated.

Note: Representative tensile test coupons are preferred over hardness and conductivity measurements for aging of aluminum alloys.

STATEMENT OF IMPLEMENTATION IN JSC 27301F:

5.4.1 Heat Treatment

5.4.1 HEAT TREATMENT

e. For spaceflight hardware that provides mission-critical functions, process-control tensile-test coupons shall be taken from the production part (or from the same material lot, having the same thickness as and processed identically to the production part) to verify the adequacy of the heat treatment process for the following conditions:

(1) Aluminum alloys are solution heat-treated.

(2) Any quenched and tempered steel.

(3) A286 or MP35N alloys (or any alloy that has poor correlation between hardness and tensile strength) are heat treated.

(4) Titanium alloys are annealed or solution heat treated and aged.

(5) Nickel- and cobalt-based alloys are work strengthened before age hardening, resulting in age-hardened tensile strengths greater than 1030 MPa (150 ksi) UTS.

(6) Precipitation hardenable nickel- and cobalt-based alloys are re-solution heat treated other than by the mill.

EXCEPTION:

Tensile test coupons are not required when precipitation hardenable nickel- and cobalt-based alloys are re-solution heat treated by the mill.