SPACE LAUNCH SYSTEM PROGRAM (SLSP) ELECTRICAL, ELECTRONIC, AND ELECTROMECHANICAL (EEE) PARTS MANAGEMENT AND CONTROL REQUIREMENTS DOCUMENT
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1.0 INTRODUCTION

1.1 Purpose

The purpose of this document is to establish baseline criteria for the selection, screening, qualification, and derating of electrical, electronic, and electromechanical (EEE) parts for use on the Space Launch System (SLS) Program flight hardware, critical ground support equipment (GSE), and Flight Safety System (FSS) hardware. This document provides the requirements necessary to ensure that appropriate parts are used in the fabrication of launch vehicle and space hardware that will meet mission reliability objectives.

1.2 Scope

This document tailors the requirements of MSFC-STD-3012, EEE Parts Management and Control Requirements for MSFC Space Flight Hardware, for the SLS projects to meet the requirements of NASA Policy Directive (NPD) 8730.2, NASA Parts Policy, by clarifying requirements implementation and approval authority. Requirements are specified for EEE parts activities from the equipment design and development phase through use and maintenance of the system and equipment. Requirements herein are intended to apply to flight hardware, critical GSE, and ground equipment connectors that mate with flight hardware connectors.

Per NASA Procedural Requirements (NPR) 8715.5, Range Flight Safety Program, Range Safety (RS) requirements will be defined in SLS-RQMT-114-01, SLSP Tailored AFSPCMAN 91-710 Eastern Range Requirements Volume 1: Air Force Space command Range Safety Policies and Procedures (derived from the Air Force Space Command Manual 91-710). Those requirements prescribe hardware and verification methods consistent with the practices of the 45th Air Force Space Wing. EEE parts requirements for this Flight Safety System (FSS) hardware are defined in Section 3.1.

Special requirements, applicable only to Marshall Space Flight Center (MSFC) in-house designs, shall be in accordance with the in-house requirements of MSFC-STD-3012.

1.3 Change Authority/Responsibility

The appropriate NASA Office of Primary Responsibility (OPR) identified for this document is the MSFC EEE Parts Engineering Organization.

Proposed changes to this document will be submitted by an SLS Program change request (CR) to the SLS Program Control Board (PCB) for disposition. All such requests will adhere to the SLS-PLAN-008, SLS Program Configuration Management Plan.

Waiver and deviation requests to the requirements specified in this document will be implemented in accordance with SLS-PLAN-008.

1.4 Applicability

This document applies to the EEE part types listed in Table 1-1. Part types not listed are not subject to the controls herein.
The EEE parts requirements also apply to EEE parts in sensor assemblies where basic sensing/transducer pieces are packaged in an assembly with other electrical part types such as wire, connector, resistor, etc.

For parts approved for use with waivers/deviations, electronic parts and materials should be manufactured and processed to applicable guidelines referenced in MIL-HDBK-454, General Guidelines for Electronic Equipment, or MIL-HDBK-1547, Electronic Parts, Materials, and Processes for Space and Launch Vehicles.

<table>
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<tr>
<th>Part Types</th>
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<tr>
<td>Capacitors</td>
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<td>5915</td>
<td>Wire and Cable</td>
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2.0 DOCUMENTS

2.1 Applicable Documents
The following documents include specifications, models, standards, guidelines, handbooks, and other special publications. The documents listed in this paragraph are applicable to the extent specified herein.

American Society for Testing and Materials (ASTM) Test Method F1192-00
Standard Guide for the Measurement of Single Event Phenomena (SEP) Induced by Heavy Ion Irradiation of Semiconductor Devices

European Space Components Coordination (ESCC) Basic Specification 25100
Single Event Effects Test Method and Guidelines

European Space Components Coordination (ESCC) Basic Specification 22900 (latest version)
Total Dose Steady-State Irradiation Test Method

MIL-STD-883
Test Method Standards Microcircuits

MSFC-STD-3012 Revision A
EEE Parts Management and Control Requirements for MSFC Space Flight Hardware

NASA-STD-8739.4
Crimping, Interconnecting Cables, Harnesses, and Wiring

2.2 Reference Documents
The following documents contain supplemental information to guide the user in the application of this document.

1999 Institute for Electrical and Electronic Engineers (IEEE) Nuclear and Space Radiation Effects Conference (NSREC) Short Course (Section IV)
Proton Effects and Test Issues for Satellite Designers

Neutron-Induced Single Event Effects Testing Across a Wide Range of Energies and Facilities and Implications for Standards
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<td>E.L. Petersen, IEEE</td>
<td>The Single Event Upset (SEU) Figure of Merit and Proton Upset Rate Calculations</td>
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<td>J. Barak, IEEE</td>
<td>Analytical Microdosimetry Model for Proton-Induced SEU in Modern Devices</td>
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Website

Single Event Effect Criticality Analysis
3.0 REQUIREMENTS

3.1 General

Criticality categories are defined in SLS-RQMT-016, Space Launch System (SLS) Program Failure Modes and Effects Analysis/Critical Items List (FMEA/CIL) Requirements Document. Each Element will develop the FMEA for their hardware in accordance with SLS-RQMT-016. Parts selection for a given hardware item is based on the worst-case criticality assigned as a result of the Element’s FMEA.

The SLS Program has approved the use of Grade 2 EEE parts in Criticality 1R# applications in cases where allocated quantitative reliability requirements can be met with the Grade 2 parts. In addition, Grade 1 parts are to be used for any Criticality 1 application (see 3.5.1.1 Grade 1 Parts for Criticality 1).

EEE Parts used in critical GSE, as defined in SLS-RQMT-016, shall meet the requirements herein. For non-critical GSE, the criteria for EEE parts selection, screening, qualification, and derating is at the program or designer’s discretion. In addition, critical and non-critical GSE connectors that mate with flight hardware connectors must meet the requirements of Section 3.9.

EEE parts used in FSS hardware shall meet the EEE parts requirements herein except when SLS-RQMT-114 prescribes specific hardware (e.g. the Model LT401 C-Band Radar Transponder) for SLS to be used for tracking or other Range Safety function. EEE parts used in this prescribed specific hardware are not subject to EEE parts management and control as defined herein.

The allocated quantitative reliability requirements for FSS hardware are defined in SLS-RQMT-114.

3.2 Part Qualification

Qualification at the piece part level shall meet the requirements of MSFC-STD-3012 Section 5.2.

3.3 Quality Assurance Requirements

Quality assurance shall comply with the requirements of MSFC-STD-3012 Section 5.3.

3.4 Application Criteria Requirements

3.4.1 Derating

Parts derating shall meet the derating requirements of MSFC-STD-3012 Section 5.4.1.

3.4.2 Operating Environment

EEE parts shall be tested to meet the operating environment requirements of MSFC-STD-3012 Section 5.4.2.
3.4.3 Ionizing Radiation

For Grades 1, 2, and 3 parts used in spaceflight applications, the effects of the projected ionizing radiation (IR) on each specific part lot shall be determined by analysis and/or test in accordance with Appendix B. The radiation evaluation will address the technology, application, and environment, including total ionizing dose (TID), Enhance Low Dose Rate Sensitivity (ELDRS), single event effects (SEE), and displacement damage.

The Element will determine if ionizing radiation analysis is necessary for parts used in Grade 4 applications.

3.4.4 Hazard Avoidance

Hazard avoidance shall comply with the requirements in MSFC-STD-3012 Section 5.4.4.

3.4.5 Cuprous Oxide (Red Plague) Control

For Grades 1, 2, and 3 parts used in spaceflight applications, the use of silver plated wire shall require the implementation of red plague control as specified in MSFC-STD-3012 Section 5.4.5 or Element approved equivalent document. The Element will determine if a red plague control plan is required for Grade 4 applications.

3.5 Configuration Control Requirements

The acquiring activity’s focal point EEE parts organization shall review and approve all EEE parts selections. At each subcontract level, the acquiring activity shall review and approve all sub-tier EEE parts selections.

3.5.1 Parts Selection

Grade 1, 2, 3, and 4 parts will be selected in accordance with the order of selection preference indicated in MSFC-STD-3012 Tables V, VI, VII, and VIII, respectively. A lower ranked part within the selected Grade will not be used if a higher ranked selection is available. The NASA Parts Selection List (NPSL) (http://nepp.nasa.gov/npsl/) may be used for additional part selection provided that the part selected meets the qualification and screening criteria for the intended application; however, NPSL parts not listed in the MSFC-STD-3012 selection tables will require nonstandard part approval.

3.5.1.1 Grade 1 Parts for Criticality 1 Applications

For hardware items used in Criticality 1 applications, Grade 1 parts shall be used in the design, modification, and fabrication of the flight equipment. Maximum use will be made of standard parts.

Parts selection shall meet the requirements contained in MSFC-STD-3012 Table V. Parts selection will be accomplished in the order indicated. A lower ranked selection will not be used if a higher ranked selection can be obtained. A nonstandard Grade 1 part may be used in accordance with MSFC-STD-3012 when a standard part is not available. The objective is to
minimize part types, utilize standard part types to the maximum extent possible, and ensure that minimum quality levels are maintained.

### 3.5.1.2 Grade 1 or 2 Parts for Criticalities 1R#, 2, 2R, and 3 Applications

For hardware items used in criticality 1R#, 2R, 2, and 3 applications, except as noted in Sections 3.5.1.3 and 3.5.1.4 below for Criticality 3 applications, Grade 1 or Grade 2 parts shall be used in the design, modification, and fabrication of the flight equipment. Grade 2 parts can be used in place of Grade 1 parts only if allocated box level reliability requirements can be met with the use of the Grade 2 parts. Maximum use will be made of standard parts.

Parts selection shall meet the requirements contained in MSFC-STD-3012 Table VI. Parts selection will be accomplished in the order indicated. A lower ranked selection will not be used if a higher ranked selection can be obtained. A nonstandard Grade 2 part may be used in accordance with MSFC-STD-3012 when a standard part is not available. The objective is to minimize part types, utilize standard part types to the maximum extent possible, and ensure that minimum quality levels are maintained.

### 3.5.1.3 Grade 3 Parts for Criticality 3 Applications and for Criticality 1R#, 2, 2R, and 3 GSE Applications

For Criticality 3 applications, the SLS Elements may approve the use of Grade 3 parts in the design, modification, and fabrication of the flight equipment.

Parts selection shall meet the requirements contained in MSFC-STD-3012 Table VII. Parts selection will be accomplished in the order indicated. A lower ranked selection will not be used if a higher ranked selection can be obtained. A nonstandard Grade 3 part may be used in accordance with MSFC-STD-3012 when a standard part is not available. The objective is to minimize part types, utilize standard part types to the maximum extent possible, and ensure that minimum quality levels are maintained.

#### 3.5.1.3.1 Grade 3 Parts for Criticality 1R#, 2, 2R, and 3 GSE Applications

Grade 3 parts may be used in GSE Criticality 1R#, 2, 2R, and 3 GSE applications with Element approval or Ground Systems Development Office (GSDO) approval for Kennedy Space Center (KSC) ground systems. Grade 3 parts shall be qualified for the GSE operational environment and redundancy implemented for critical applications.

### 3.5.1.4 Grade 4 Parts for Criticality 3 Applications and for Criticality 1R#, 2, 2R, and 3 GSE Applications

For Criticality 3 applications, the SLS Elements may approve the use of Grade 4 parts in the design, modification, and fabrication of the flight equipment. Parts selection shall conform to the requirements contained in MSFC-STD-3012 Table VIII.
3.5.1.4.1 Grade 4 Parts for Criticality 1R#, 2, 2R, and 3 GSE Applications

Grade 4 parts may be used in GSE Criticality 1R#, 2, 2R, and 3 GSE applications with Element approval or GSDO approval for KSC ground systems. Grade 4 parts shall be qualified for the GSE operational environment and redundancy implemented for critical applications.

3.5.2 Standard and Nonstandard Parts

Standard and nonstandard parts are as defined in MSFC-STD-3012 Section 5.5.2.

3.5.3 Nonstandard Part Approval Request (NSPAR)

Parts not designated as standard parts in MSFC-STD-3012 Table V, VI, or VII as applicable, are nonstandard and shall be approved by the appropriate SLS Element. A Nonstandard Part Approval Request (NSPAR) form (MSFC Form 4346 or equivalent) shall be submitted by the equipment design activity for each nonstandard part. NSPARs are only applicable for approval of nonstandard parts of the required grade for the intended application. Pre-coordination of NSPARs with the Element is recommended. The NSPAR should be reviewed and approved at each contract tier before submittal to the next higher tier. The NSPAR shall include any applicable part specification or control documents, other than military or NASA standards. NSPARs shall identify additional screening/qualification applied to military standard parts. There are no nonstandard Grade 4 parts; therefore, NSPARs are not required for Grade 4 parts.

With Element approval, a parts control board may be used to review and approve nonstandard parts in lieu of NSPARs. The following information shall be traceable to the nonstandard part: (1) Identification of equipment in which the non-standard part is used (assembly, component and system), (2) contractor name, (3) description of part and part Grade as defined in MSFC-STD-3012 Revision A, (4) drawing/specification number (e.g. SCD number), (5) part number, (6) manufacturer and manufacturer's equivalent part number, (7) technical rationale why a nonstandard part is required, (8) test data and previous usage experience, (9) application analysis for the part (worst case analysis and derating), (10) review of applicable GIDEP/NASA Alerts, and (11) qualification test data.

3.5.4 Specifications and Control Drawings

Specifications and control drawings shall meet the requirements of MSFC-STD-3012 Section 5.5.3.

3.5.5 Plastic Encapsulated Microcircuits (PEMs)

Plastic encapsulated microcircuits shall be subjected to the PEMs insertion requirements contained in MSFC-STD-3012 Appendix B, “Instructions for Plastic Encapsulated Microcircuit (PEM) Selection, Screening, and Qualification.” PEMs shall not be used in applications that require Grade 1 parts without a deviation/waiver. The requirements of MSFC-STD-3012 Appendix B do not apply to MIL-PRF-38535, Integrated Circuits (Microcircuits) Manufacturing, General Specification for, Class N qualified microcircuits. Screening and qualification requirements for Class N microcircuits shall be per the standard parts and selection preferences tables of MSFC-STD-3012.
3.5.6 **Part Substitutions**

For Grades 1, 2, and 3, substitution of different parts for the part numbers listed in assembly parts lists and bills of material shall be prohibited, or restricted to criteria or specific substitution lists having the prior approval of the acquiring activity. Substituted parts shall comply with applicable requirements herein and shall be listed in the As-Designed EEE Parts List.

3.5.7 **As-Designed EEE Parts Lists**

The equipment design activity shall develop an As-Designed EEE Parts List for each deliverable end item in accordance with the requirements of MSFC-STD-3012 Section 5.6.2. As-Designed EEE Parts Lists shall be submitted to the prime contractor’s EEE parts engineering organization for review. As-Designed EEE Parts Lists shall be submitted in a searchable electronic format.

3.5.8 **As-Built EEE Parts Lists**

The equipment manufacturing activity shall develop an As-Built EEE Parts List for each deliverable end item in accordance with the requirements of MSFC-STD-3012 Section 5.6.5. As-Built EEE Parts Lists shall be submitted to the prime contractor’s EEE parts engineering organization for review. As-Built EEE Parts Lists shall be submitted in a searchable electronic format.

3.5.9 **Traceability**

Traceability shall meet the requirements of MSFC-STD-3012 Section 5.5.7.

3.6 **Obsolescence Management, Counterfeit Avoidance, and Parts Availability Requirements**

3.6.1 **Obsolescence Management**

Obsolescence management shall be in accordance with MSFC-STD-3012 Section 5.7.1.

3.6.2 **Counterfeit EEE Parts Avoidance**

Counterfeit EEE parts shall be avoided by complying with MSFC-STD-3012 Section 5.3.1. If parts cannot be procured from the original component manufacturer (OCM) or one of its franchised vendors, counterfeit parts shall be avoided by complying with MSFC-STD-3012 Section 5.7.2.

3.6.3 **Parts Availability**

Consideration should be given in EEE parts selection and procurement to ensuring parts availability for equipment repair and new builds throughout the projected life of the equipment and design.

The acquiring activity should procure a minimum quantity of 20 percent over the actual number of parts required to support equipment maintenance, planned future builds, and potential future builds where any of the following applies: (1) the part is a commercial part rather than a military part.
or NASA standard part, (2) the applicable military or NASA standard is identified as “not for new design,” or equivalent, (3) the same part may not be available for future procurement within the life of the design, (4) the minimum buy for the part exceeds or very nearly equals the lifetime requirement for the design, or (5) to reduce the possibility of acquiring counterfeit parts. For further guidance, refer to Section 3.6.1 herein.

3.7 Manufacturing Handling and Storage Requirements

3.7.1 Electrostatic Discharge (ESD) Control
ESD control shall be in accordance with MSFC-STD-3012 Section 5.8.1.

3.7.2 Environmental Control
Environmental control shall be in accordance with MSFC-STD-3012 Section 5.8.2.

3.7.3 Part Age and Storage Restriction
EEE parts older than 5 years from date of manufacture that are selected for flight hardware will be reviewed to determine the need for re-screening. Parts stored in conditions where moisture or ESD are not controlled shall not be used.

3.7.4 Allowance for Testing Fallout
Procured quantities should allow for nominal fallout of parts in lot sample or screening tests where these losses would deduct from the quantity available for use. When possible, parts should be ordered from a single lot date code to reduce the number of parts needed for destructive qualification testing.

3.7.5 Manufacturing Process Compatibility
Parts shall be compatible with manufacturing processes in accordance with MSFC-STD-3012 Section 5.8.5.

3.7.6 Suspect Parts
Suspect parts shall be handled in accordance with MSFC-STD-3012 Section 5.8.6.

3.7.7 Reuse of EEE Parts
EEE parts (except connectors) unsoldered from printed circuit boards or assemblies shall not be reused unless approved by the Element. If connectors are approved for reuse by the Element, the connectors shall be thoroughly cleaned, inspected, and tested per NASA-STD-8739.4, Crimping, Interconnecting Cables, Harnesses, and Wiring, prior to reuse.
3.8 Heritage Hardware and Off-the-Shelf (OTS) Hardware Requirements

3.8.1 Heritage Hardware

Hardware qualified and used in space or space launch applications and accepted for use by NASA to support human spaceflight programs is defined as heritage hardware. Heritage hardware will not be used in applications that have a EEE part grade level requirement higher than the grade level to which it has been qualified; for example, Grade level 3 or 4 heritage hardware cannot be used in a Grade 1 or Grade 2 application.

3.8.1.1 Modification of Heritage Hardware

Any EEE part configuration change to heritage hardware (e.g. a part change where the new part has a different form, fit, or function than the heritage part) is considered a modification and is no longer considered heritage hardware. EEE parts used in the modification shall meet the EEE part requirements herein.

3.8.2 Off-the-Shelf Hardware Requirements

Off-the-shelf hardware is an assembly, part, or design that is readily available for procurement, usually to catalog specifications, without the necessity of generating detailed procurement specifications for the item. EEE parts used in OTS hardware shall meet the requirements of this document.

3.9 Ground Support Equipment (GSE) To Flight Hardware Electrical Interfaces

The GSE to flight hardware electrical interfaces shall meet the requirements of MSFC-STD-3012 Section 5.10.
4.0 REVIEW, AUDIT, AND VERIFICATION OF PART REQUIREMENTS

4.1 Review of Parts Management and Control Requirements Documents
Sub-tier EEE Parts Management and Control documents will be reviewed for compliance with the requirements herein.

4.2 Audit of EEE Parts Process Requirements
EEE Parts Management and Control process requirements (Government/Industry Data Exchange Program (GIDEP) Acute Launch Emergency Restraint Tip (ALERT) tracking, counterfeit avoidance, obsolescence analysis, etc.) shall be audited for compliance with the process requirements of this document.

4.3 Verification of EEE Parts Circuit Design Requirements
Verification requirements apply to Grades 1, 2, and 3. The Element shall verify the EEE parts circuit design requirements have been met. The following four records provide objective evidence of verification.

1. As-designed EEE Parts List data items shall be analyzed to determine what EEE parts are used by design.
2. NSPARs data items or equivalent data shall be analyzed to determine the terms for acceptance and use of the applicable EEE parts.
3. EEE Parts Derating Analysis Report data items shall be analyzed to determine what derating is achieved for the application.
4. As-built EEE Parts List data items shall be analyzed to determine that only traceable approved EEE parts and sources are used.

Success criteria shall be that the analyses of (1), (2), (3), and (4) above show compliance with the requirements herein.
### APPENDIX A

**ACRONYMS AND ABBREVIATIONS AND GLOSSARY OF TERMS**

#### A1.0 ACRONYMS AND ABBREVIATIONS

<table>
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<tr>
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<th>Description</th>
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<tr>
<td>ALERT</td>
<td>Acute Launch Emergency Restraint Tip</td>
</tr>
<tr>
<td>ASTM</td>
<td>American Society for Testing and Materials</td>
</tr>
<tr>
<td>CCD</td>
<td>Charge Couple Device</td>
</tr>
<tr>
<td>CI</td>
<td>Configuration Item</td>
</tr>
<tr>
<td>CIL</td>
<td>Critical Items List</td>
</tr>
<tr>
<td>CMOS</td>
<td>Complementary Metal-Oxide-Semiconductor</td>
</tr>
<tr>
<td>CR</td>
<td>Change Request</td>
</tr>
<tr>
<td>DD</td>
<td>Displacement Damage</td>
</tr>
<tr>
<td>DDD</td>
<td>Displacement Damage Dose</td>
</tr>
<tr>
<td>DLA</td>
<td>Defense Logistics Agency</td>
</tr>
<tr>
<td>DRM</td>
<td>Design Reference Mission</td>
</tr>
<tr>
<td>DSNE</td>
<td>Design Specifications for Natural Environment</td>
</tr>
<tr>
<td>EDAC</td>
<td>Error Detection and Correction</td>
</tr>
<tr>
<td>EEE</td>
<td>Electrical, Electronic, and Electromechanical</td>
</tr>
<tr>
<td>ELDRS</td>
<td>Enhance Low Dose Rate Sensitivity</td>
</tr>
<tr>
<td>ESCC</td>
<td>European Space Components Coordination</td>
</tr>
<tr>
<td>ESD</td>
<td>Electrostatic Discharge</td>
</tr>
<tr>
<td>FMEA</td>
<td>Failure Modes and Effects Analysis</td>
</tr>
<tr>
<td>FSS</td>
<td>Flight Safety System</td>
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<tr>
<td>GIDEP</td>
<td>Government/Industry Data Exchange Program</td>
</tr>
<tr>
<td>GSDO</td>
<td>Ground Systems Development Office</td>
</tr>
<tr>
<td>GSE</td>
<td>Ground Support Equipment</td>
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Gy: Gray
HDBK: Handbook
IEEE: Institute for Electrical and Electronic Engineers
IR: Ionizing Radiation
LDC: Lot Date Code
KSC: Kennedy Space Center
LET: Linear Energy Transfer
LOC: Loss of Crew
LOM: Loss of Mission
MeV: Megaelectron Volt
MIL: Military
MOSFET: Metal-Oxide-Semiconductor Field Effect Transistor
MSFC: Marshall Space Flight Center
NASA: National Aeronautics and Space Administration
MeV: Mega (Million) Electron Volts
NIEL: Non-Ionizing Energy Loss
NPD: NASA Policy Directive
NPR: NASA Procedural Requirements
NPSL: NASA Parts Selection List
NSPAR: Nonstandard Part Approval Request
NSREC: Nuclear and Space Radiation Effects Conference
OCM: Original Component Manufacturer
OPR: Office of Primary Responsibility
OTS: Off-the-Shelf
PCB: Program Control Board
PDR Preliminary Design Review
PEM Plastic Encapsulated Microcircuit
PRF Performance
RDM Radiation Design Margin
RHA Radiation Hardness Assurance
RHAP Radiation Hardness Assurance Plan
RLAT Radiation Lot Acceptance Testing
RQMT Requirement
RS Range Safety
SEB Single-Event Burnout
SEE Single Event Effect
SEFI Single-Event Functional Interrupt
SEGR Single-Event Gate Rupture
SEL Single-Event Latchup
SEM Scanning Electron Microscopy
SET Single-Event Transients
SEU Single-Event Upset
Si Silicon
SLS Space Launch System
SPENVIS Space Environment Information System
STD Standard
TBD To Be Determined
TID Total Ionizing Dose
V Volt(s)
VDS Drain-to-Source Voltage
VGS Gate-to-Source Voltage

A2.0 GLOSSARY OF TERMS

Commercial A classification for an assembly, part, or design for which the item manufacturer or vendor establishes performance and quality standards pursuant to market forces rather than by enforceable compliance to a government or industry standard.

Critical GSE Ground Support Equipment that is required to operate during launch processing at the launch pad and during the terminal countdown. This is equipment or hardware that interfaces directly with the stack, which if it fails during the countdown or launch would potentially cause loss of mission, vehicle, or life.

Derating Derating of a part is the intentional reduction of its electrical, mechanical and thermal stresses for the purpose of providing a margin between the applied stress and the actual demonstrated limit of the part’s capabilities.

Deviation A specific written authorization, granted prior to the manufacture of a Configuration Item (CI), to depart from a particular requirement of a CI’s current approved configuration for a specific number of units or a specified period of time.

Grade 1 A classification which designates EEE parts of the highest practical quality standards.

Grade 2 A classification which designates EEE parts of high, but generally not the highest, quality standards.

Grade 3 A classification which designates EEE parts which generally meet some formal industry quality standards, but usually the lowest quality class option that is available under the standards.

Grade 4 A classification which designates EEE parts for which no predefined quality classification is imposed.

Heritage Hardware Hardware that is qualified and used in space or space launch applications and accepted for use by NASA to support human spaceflight programs.

Lot Date Code (LDC) An identification, usually marked on a EEE part and prescribed by the applicable specification, to identify parts which have been processed as a batch.

The electronic version is the official approved document. Verify this is the correct version before use.
Nonstandard Part A EEE part that meets program piece part qualification requirements and is designated “nonstandard” in the applicable MSFC-STD-3012 Grade level table.

Off-The-Shelf (OTS) Assembly, part, or design that is readily available for procurement, usually to catalog specifications, without the necessity of generating detailed procurement specifications for the item.

Qualification Tests consisting of mechanical, electrical, and environmental inspections intended to verify that materials, design, performance, and long-term reliability of the part are consistent with the specification and intended application, and to ensure that manufacturer processes are consistent from lot to lot.

Screening Tests intended to remove nonconforming parts (parts with random defects that are likely to result in early failures, known as infant mortality) from an otherwise acceptable lot and thus increase confidence in the reliability of the parts selected for use.

Standard Part A EEE part that meets program piece part qualification requirements and is designated “standard” in the applicable Grade level table.

Waiver A written authorization, granted after manufacture, to accept a CI that is found to depart from specified requirement(s) of the CI’s current approved configuration for a specific number of units or a specified period of time.
# APPENDIX B

## IONIZING RADIATION CONTROL

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B1.0 INTRODUCTION
This document defines the Ionizing Radiation (IR) control processes and verification requirements for the Space Launch Systems (SLS) vehicles and the radiation hardness assurance (RHA) requirements for active electronic and photoelectronic components to be used in all vehicle elements, systems, subsystems and lower level assemblies. Threats considered include single-event effects (SEE) and degradation due to total ionizing dose (TID) and displacement damage (DD). Plasma-driven issues including unshielded material degradation and electrostatic discharge, bulk electrostatic discharge, as well as mission dose issues related to shielded optical, structural and thermal materials and solar panel components are not treated in this appendix.

B2.0 IONIZING RADIATION LEAD
Vehicle Management has the responsibility for the natural environments and has established an IR Lead for the SLS Program. The IR Lead’s responsibilities shall include:

1. Advising the Chief Engineers on all IR issues
2. Interfacing with electrical, electronic, and electromechanical (EEE) parts and system design groups of the respective organizations on IR issues
3. Interfacing with the materials, thermal and contamination group of the respective organizations on IR issues concerning EEE Parts
4. Interfacing with the power generation, sensors and optical system groups of the respective organizations on IR issues concerning EEE Parts
5. Advising on matters related to IR testing and analysis
6. Addressing issues related to IR requirements verification

B3.0 RADIATION ENVIRONMENTAL REQUIREMENTS
The radiation environmental specifications for the space system are given in the SLS-SPEC-159, Cross-Program Design Specification for Natural Environments (DSNE). The environment specification details the high-energy solar particle and galactic cosmic ray environments as well as those from the trapped radiation belts.

All electronic systems shall be capable of meeting the vehicle specifications while operating in the applicable ionizing radiation environments. The applicable IR environments are defined in the correlation matrix contained in SLS-SPEC-044-07, SLSP Vehicle Design Environments Volume 7: Natural Environments, where all applicable sections of the DSNE are mapped to the Elements that may encounter that environment in one or more Design Reference Mission (DRM). The following sections define the verification methodologies and verification requirements for electronic equipment with respect to the effects of these applicable environments.

B3.1 Total Ionizing Dose
Total ionizing dose refers to the ionizing energy deposited in a unit mass by energetic particles. The metric unit for dose is the Gray (abbreviated Gy), although dose is also commonly quoted in
rads (1 Gy = 100 rad). Because absorbed dose depends on material properties, it is customary to specify the material under consideration when discussing dose – thus Gy(Si) means Grays deposited in silicon. Detailed in the DSNE are the total ionizing dose specification, the particle environment, and the total ionizing dose versus depth curve.

A more accurate estimate may be obtained, if deemed necessary or required, through detailed dose mapping (e.g., ray tracing, sector analysis or Monte Carlo transport). Use of transport tools incorporated in Space Environment Information System (SPENVIS), Space Radiation, and NOVICE software tool sets are acceptable. The transport calculations should be documented, including the code used, shield geometry/materials assumed and the external environment specification used, and made available for review.

**B3.2 Displacement Damage**

Devices that are sensitive to DD from high-energy protons and electrons, such as electro-optic devices, charge coupled devices (CCDs), optocouplers, and bipolar devices, are to be evaluated in a manner similar to that for Total Ionizing Dose. For materials for which displacement damage is known to be proportional to Non-Ionizing Energy Loss (NIEL), equivalent fluence of protons or neutrons may be used for hardness verification purposes. Specified in the DSNE is the displacement damage (silicon only) versus depth curve. If the use of NIEL leads to inconsistent equivalent fluences at different energies, then the test-particle energy at which the highest displacement damage dose is derived should be used (see 1999 Institute for Electrical and Electronic Engineers (IEEE) Nuclear and Space Radiation Effects Conference (NSREC) Short Course, Section IV, Proton Effects and Test Issues for Satellite Designers).

**B3.3 Synergistic Ionizing and Displacement Effects**

A subset of integrated circuits has demonstrated enhanced damage when low rate ionizing doses and displacement damage doses are applied in succession or simultaneously. This synergistic damage may differ qualitatively and quantitatively from that observed when the parts are exposed to only one type of radiation (ionizing or displacing). Devices at particular risk for this effect include high precision bipolar linear devices, such as monolithic references and regulators, as well as devices that include lateral bipolar transistor construction. Parts exposed to both environments and are at risk for synergistic ionizing and displacement effects should be evaluated for both radiation environments as discussed in the previous sections.

**B3.4 Single Event Effects**

SEE in the environment defined in the DSNE are caused by galactic cosmic rays, solar ions, solar and trapped protons and atmospheric neutrons. The DSNE provides the proton and heavy ion fluences and fluxes for both background levels and solar particle events.

SEE are the prompt responses of semiconductor devices to the passage of individual ionizing particles through sensitive regions within the device. In general, the more charge that is deposited in the sensitive region, the more likely the device is to exhibit a given SEE. For this reason, the device response is parameterized in terms of the ion’s linear energy transfer (LET) – a measure of the charge density of the track left by the ion. The LET at which a device first
begins to exhibit a given SEE is known as the threshold LET for that effect. Because low LET ions are much more plentiful in space than high-energy ions, lower threshold LET corresponds to higher SEE rates. For LETs above the threshold, the SEE susceptibility tends to rise more rapidly at first and then tends toward saturation.

The susceptibility of the device is usually given as a cross section with units of area. The cross section is defined like a nuclear cross section – the number of events divided by the fluence needed to cause that number of events. However, the SEE cross section is usually related to (though not equal to) the area in the die that is vulnerable to the effect at the given LET. The cross section versus LET curve carries the information about device SEE response to be used in predicting the rate of occurrence of that SEE for the device. This curve is produced by irradiating the device with ions of several different LETs and measuring the cross section for each LET value. For the purpose of rate calculations, the saturated cross section for a given SEE is the value of the cross section where it has effectively stopped rising with increasing LET and the threshold LET is the highest LET for which the SEE is not observed.

SEE generally fall into two major categories: destructive and non-destructive. The more serious effects are destructive, typically resulting in damage, and these include single-event latchup (SEL), single-event burnout (SEB), and single-event gate rupture (SEGR). Non-destructive effects generally do not cause damage in the device. Non-destructive effects include single-event upset (SEU), single-event functional interrupt (SEFI), and single-event transients (SET). These effects are discussed in the following subsections.

For any device demonstrating a heavy-ion SEE threshold LET of 15 MeV-cm²/mg or less, the overall SEE rate should be stated as the sum of both heavy ion and proton rates. Proton rates can either be based on proton testing or be bounded by a conservative analysis based on the heavy ion test data (see Barak and Petersen referenced in Section 2.2). (In addition, useful proton testing information can be found in the referenced document “Proton Test Guideline Development – Lessons Learned.”)

**B3.4.1 Destructive Single Event Effects**

Whenever possible, subsystem, instrument or component design teams must use parts that are not susceptible to destructive single-event effects in their designs. Any SEL or other high-current error mode is considered destructive until sufficient evidence is presented proving that no latent damage results.

Any part with potential susceptibility to destructive SEE or which performs a function that impacts mission health, safety or performance requirements shall be analyzed to determine an estimated probability of failure. If no applicable test data exists then the probability of failure can be bounded by assuming that every particle that hits the die area produces a destructive event (for protons and neutrons it can be assumed that one particle in 10⁴ produce a spallation event that could then produce the destructive event). If that analysis yields an accepted failure probability, then no test data is required. However, if it is deemed too high to meet the system’s required specifications, then test data shall be taken that characterizes the heavy ion response (and/or the neutron/proton response, as appropriate) according to the standards set in Section B5.
B3.4.1.1 Single-Event Latchup (SEL)

Electronic parts that are susceptible to destructive SEL (i.e., are not immune as defined in Section B5.2.2) should not be used, unless a suitable replacement part cannot be found. Detection and recovery techniques should be incorporated for parts susceptible to non-destructive latchup, and that the probability of SEL occurrence be sufficiently low such that vehicle reliability and performance are not adversely impacted. All SEL-susceptible parts are to be identified and a reliability analyses performed.

Parts susceptible to SEL and do not meet the failure probability analysis, described above, should not be used without thorough characterization of all SEL modes to which the part is susceptible. Non-susceptibility is demonstrated by testing to full fluence levels as stated in additional SEE test requirements in Section B5.2.2.

Any device that will be used in a long duration segment of a DRM (> 1 month) and exhibits a high-current, non-destructive error mechanism giving rise to a current exceeding device specifications or a current density within the device greater than \(10^6\) A/cm\(^2\) should be screened for latent damage subsequent to SEE testing according to the guidelines given in Section B5.2.8 of this document.

B3.4.1.2 Single-Event Burnout and Single-Event Gate Rupture

Since all parts that can be susceptible to SEB or SEGR can have a defined safe operating zone (based on bias and environment), use of parts operated in a manner such that they are susceptible to destructive SEB and SEGR are prohibited.

All power metal-oxide-semiconductor field effect transistors (MOSFETs), discrete power bipolar junction transistors, and other devices susceptible to SEB and/or SEGR shall have supporting test data or analyses that show all applied voltages are in their safe operating regions for each circuit application. Table B3-1 lists the application Drain-to-Source Voltage (VDS) conditions that require SEB/SEGR testing for several categories of these devices: (1) SEE hardened, (2) MIL or space-qualified parts, (3) parts with known failure thresholds, and (4) commercial parts.

The listed VDS conditions are assumed to apply to applications with off-state Gate-to-Source Voltage (VGS) of \(-1\) volt \((V) \leq VGS \leq 1\) V. Applications with higher off-state VGS require supporting test data. All test data used to meet these criteria must also meet the additional SEE test requirements as stated in section B5.2.2.
Table B3-1. Application Conditions Requiring SEB/SEGR Testing

<table>
<thead>
<tr>
<th>Device Category</th>
<th>VDS Condition Requiring Test</th>
<th>Comment</th>
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<tbody>
<tr>
<td>SEE-Hardened</td>
<td>V_{DS} &gt; 75% of vendor-defined safe operating area ceiling</td>
<td>Qualified with ions meeting requirements of Section B5.2.2 except LET ≥ 37 MeV-cm^2/mg</td>
</tr>
<tr>
<td>Non-commercial parts MIL or Space Qualified</td>
<td>V_{DS} &gt; 35% of rated V_{DS}</td>
<td>off-state: -1 V ≤ V_{GS} ≤ 1 V</td>
</tr>
<tr>
<td>Any part with existing test data</td>
<td>V_{DS} &gt; 75% of highest passing V_{DS}</td>
<td>Tested with ions meeting requirements of Section B5.2.2 except LET ≥ 37 MeV-cm^2/mg</td>
</tr>
<tr>
<td>Commercial – Non-Critical Application</td>
<td>V_{DS} &gt; 20% of rated V_{DS}</td>
<td>off-state: -1 V ≤ V_{GS} ≤ 1 V</td>
</tr>
<tr>
<td>Commercial – Critical Application &amp; All others</td>
<td>V_{DS} &gt; 75% of highest passing V_{DS}</td>
<td>Tested with ions meeting requirements of Section B5.2.2 except LET ≥ 37 MeV-cm^2/mg</td>
</tr>
</tbody>
</table>

B3.4.1.3 Other Destructive Single-Event Modes

Subsystem, instrument or component design teams should identify critical functions of all devices susceptible to single-event induced hard failure modes and gather sufficient information about these functions and their implementation to estimate failure rates. For the purposes of analysis, stuck bits should be considered destructive failures. However, annealing characteristics may be considered as mitigating factors in categorizing the resulting errors.

B3.4.1.4 Mitigation of Destructive SEE

In all critical system designs where devices have shown a susceptibility to destructive SEE, subsystem, instrument or component design teams should implement and verify schemes to mitigate effects of SEE induced destructive failures. All destructive SEE mitigation schemes should be demonstrated effective through SEE testing, not analysis. Any adverse consequences of the mitigation (i.e., diminished speed or performance, interruption of operations by spurious SEL indications, data loss, etc.) should be documented.

B3.4.2 Single Event Upset, Transient and Functional Interrupt

The energetic particle environment responsible for SEU, SET and SEFI is specified in the DSNE.

Device, unit, and system upset rates due to heavy ions and protons should be calculated for the worst-case background and during solar particle events. Devices susceptible to SET should be considered in the analysis if those transients can lead to the upset of another device.

Approval of part usage should be based on SEU/SEFI susceptibility and application in the system. A functional analysis of an upset at the unit and system levels should be performed. The unit-level upset rate should include the effects of error detection and correction (EDAC),
memory scrubbing, and other mitigation techniques, if applicable. The worst-case background upset rate (including transients) should be such that there is no disruption of critical mission functions and that all system performance requirements are met. In addition, there should be no single-event-induced catastrophic failures or permanent disruption of critical mission functions due to the solar event environment specified in the DSNE.

**B3.4.3 System Transient Upset Analysis**

Non-destructive events can lead to system failures by the event within the device causing a system failure, the event in one device impacting the proper operation of another device or the event in a device leading to erroneous system output that impacts the proper operation of an external system. All of these conditions, if occurring during a sensitive time, can lead to a catastrophic failure. Therefore, all non-destructive device SEE modes need to be examined for their effect on the system in which they reside. This analysis should be done based on the criticality of the device in question (i.e., non-critical devices do not need detailed analyses, critical application devices need a detailed analysis, and some level of analysis for moderate critical devices). A procedure for implementing SEE criticality analysis is given in a paper titled, “Single Event Effect Criticality Analysis” and is posted at [http://radhome.gsfc.nasa.gov/radhome/papers/seecai.htm](http://radhome.gsfc.nasa.gov/radhome/papers/seecai.htm). Details of the process to be used should be contained in a Hardness Assurance Plan.

**B4.0 HARDNESS ASSURANCE PLAN**

Each SLS Element Office is responsible for the implementation of the requirements herein. Therefore each SLS Element Office should develop a Radiation Hardness Assurance Plan (RHAP) or adopt the details of this appendix as applicable to ensure radiation design and/or verification issues have been appropriately addressed in the design and/or verification activity. This plan should be available for review by each Element’s Preliminary Design Review (PDR). A RHAP is a document that details the processes and methodologies that will be used to ensure that the design that is covered by the RHAP will meet all the ionizing radiation requirements of SLS and this document. Items that must be part of the RHAP include, but are not limited to, requirements for radiation tolerance by means of part procurement, radiation testing protocols and methodologies, and radiation effects mitigations (e.g., shielding, capacitive filtering of transients, EDAC, etc.). Following a properly written RHAP throughout the design process will ensure that all radiation requirements are met when the design is complete.

**B5.0 RADIATION TESTING**

Radiation testing can fall into two categories – engineering characterization testing and Radiation Lot Acceptance Testing (RLAT). Radiation engineering characterization test data is obtained on active devices to verify acceptable performance of the EEE part types in the required radiation environment. RLAT is done to qualify the flight lots of EEE parts for the application of the flight systems. The general test standards of this section apply to both engineering characterization and RLAT testing, except as noted.
B5.1 TID/DDD Testing

B5.1.1 Design margin for TID and Displacement Damage Dose (DDD)

Each part used in the system has associated with it a Radiation Design Margin (RDM) relative to its total ionizing dose and displacement damage dose environment. The radiation design margin for a part is defined as follows:

\[
\text{RDM} = \frac{\text{Dose at which Device is Derated for Radiation Degradation}}{\text{Expected Dose in System Use During Mission Life}}
\]

Here, the expected dose is the dose for the radiation environment, at the part, transported through the available shielding distribution. Devices guaranteed radiation hard to TID (by manufacturer or via Defense Logistics Agency (DLA) RHA rating) for the appropriate application conditions (e.g., bias, dose rate, temperature, etc.) with a design margin of 4 or higher (given considerations for worst-case application conditions), do not require any further justification or RLAT. Otherwise, all active devices should be subject to RLAT - unless it can be clearly demonstrated that a device type has significant margin above the minimum requirement of 2 considering lot-to-lot variation, process maturity and control, and expected device applications. Supporting evidence must include technical rationale, device data, and statistical analysis.

B5.1.2 Expected Dose

For each part in those systems having the In-Space environments as applicable, the expected TID and DDD for the mission duration, at the piece-part level, can be determined by radiation transport analysis. This analysis will bound the radiation levels expected for each piece part based on the environment (as defined by the \(4\pi\) dose-versus-depth curve given in the DSNE, Section 3.3.1) and the effective shielding (including structure, unit housing, device packaging material, etc.) surrounding the radiation-sensitive volume. If detailed dose mapping is not performed, the \(4\pi\) dose-versus-depth curve should be used conservatively to estimate the expected dose. That is, the assumed shielding thickness should be the minimum value traversed by any ray from the piece-part to the external environment.

Details of each design team’s radiation transport and shielding analysis method(s) should be documented in the Radiation Hardness Assurance Plan.

B5.1.3 Test Methods

Unless otherwise specified, total-dose tests shall be conducted in accordance with the most current version of Test Method 1019 of MIL-STD-883, Test Method Standards Microcircuits, or European Space Components Coordination (ESCC) Basic Specification 22900 for all part types. For complementary metal–oxide–semiconductor (CMOS) devices, rebound testing for time dependent effects is required. For devices containing bipolar elements, which may exhibit enhanced low dose rate sensitivity (ELDRS), testing shall be conducted at the lower extreme of the methods’ specified dose-rate ranges.
Displacement damage testing should be performed either using fast neutrons from a nuclear reactor, in accordance with the latest version of MIL-STD-883 Test Method 1017 (or an equivalent method) or using high-energy protons from an accelerator. Guidance for displacement damage testing can be found in 1999 IEEE NSREC Short Course (Section IV) and Proton Test Guideline Development – Lessons Learned.

For devices that may be susceptible to synergistic effects, displacement damage and ionizing dose testing should be investigated. If these two mechanisms are tested separately, their effects should be combined in the most conservative manner consistent with data and understanding of the technology. The chosen method for combination should be documented and justified in the final test report.

**B5.1.4 Existing Test Data**

Existing test data and reports may be used provided all of the following conditions are met:

1. The part was tested previously and represents the same design, layout and process and originated from the same manufacturer or the test data are representative of a given part family/technology that historical data have shown to be very stable and relatively insensitive to radiation degradation at the levels of interest for the SLS program.
2. The radiation exposure bias circuit and dose rate used would render the same or more radiation damage to the part compared with that for the SLS program.
3. The test data and reports conform to the test method requirements as stated in Section B5.1.3.
4. Test data that demonstrate consistent radiation performance from lot-to-lot are available.

**B5.1.5 Sampling Statistics**

Hardness capability is defined as 90% confidence that the probability of survival of parts in the sampled flight lot is at least 99% (based on the sample size tested and the derated parameter level or functional survival level). Unless otherwise demonstrated, the statistical distribution for parametric data from a lot sample should be assumed to be normal, as long as the standard deviation is less than 20% of the sample mean. If applicable, other distributions may be used as the test data require. Devices with known bi-modal or other non-normal distribution-parametric or functional radiation responses can be used. For flight part usage greater than 10 parts, sensitivity to the assumed distribution form may introduce systematic errors into the analysis. Consultation with the IR Lead for this situation is recommended.

**B5.1.6 Test Requirements**

Each test should have documented test requirements (per test plan), and a test report should document any deviations from the test plan and the results of the testing. The standards for the report are outlined in Section B5.1.8. RLAT requirements are provided in Section B5.3.
B5.1.7 Test Samples

The test samples used for engineering characterization should be representative of flight devices used in the SLS program. Test samples used for RLAT shall be taken from the flight lot. For the purposes of TID and DDD testing, the flight lot should include all devices from the same wafer diffusion lot (whenever feasible) and the same package lot date code, unless it can be shown that thermal stresses characteristic of packaging and other post-processing do not affect TID/DDD performance. Test sample selection shall be based on the following:

1. Test samples shall be from the same process line as flight samples. Traceability shall exist from the characterization or RLAT samples to the flight lot. Devices shall be burned in prior to testing (if flight devices are to be or have already been burned in).

2. The samples should be of sufficient quantity to provide an adequate statistical base for the purposes of the test. The required minimum number of samples is five per test group plus one control sample. A test group is usually a subset of the total test sample. The number of test groups required depends upon the device technology and the device application. For example, an engineering characterization for ELDRS suspect bipolar linear device that will be used in cold-spare equipment may require four (4) test groups to cover: low dose rate, high dose rate, biased and unbiased conditions.

3. It is acceptable to use engineering test data as lot acceptance data as long as the engineering test samples were taken from the flight lot(s) and burned in (if flight devices are burned in).

B5.1.8 Test Planning and Reporting

Each radiation test plan should be a controlled document that contains the details of each device being tested and the test procedures to be followed for each device.

Each radiation test report should be a controlled document that contains the details of each device tested and the test procedures followed for each device. Test data and report should be available for review by the IR Lead as soon as possible after the test.

B5.2 Single Event Effects Testing

Single-event-effects testing should be conducted, for potentially vulnerable technologies, when there is no test data available to demonstrate compliance with requirements of Section B3.4. Existing test data must also meet the additional test requirements of Section B5.2.2.

B5.2.1 Test Methods

B5.2.1.1 Heavy Ion SEE Testing

Single event effects characterization tests shall be conducted in accordance with the latest version of ASTM Test Method F1192 or ESCC Basic Specification 25100 for all part types and
following the additional standards set forth in Section B5.2.2. In the event of conflict, the requirements of Section B5.2.2 take precedence.

**B5.2.1.2 Proton SEE Testing**

While there is currently no released proton SEE test standard, one is currently nearing completion. The bulk of this standard is based on two documents listed in the reference section and the information contained within them should be used in the development of test plans. They are the “Proton Test Guideline Development – Lessons Learned” and the “Proton Effects and Test Issues for Satellite Designers.” Once the test standard document is released, it will be evaluated for inclusion in the SLS program.

**B5.2.1.3 Neutron SEE Testing**

Currently there is no official test standard for neutron SEE testing, nor is there one in development. The best reference document on this topic is “Neutron-Induced Single Event Effects Testing Across a Wide Range of Energies and Facilities and Implications for Standards” and the information contained in this paper should be used as a guide for developing neutron SEE test plans.

**B5.2.2 Additional SEE Testing Standards**

In addition to the methods of the documents called out in Section B5.2.1, the following test standards are necessary to ensure data quality. Failure to follow these standards can lead to erroneous data and/or insufficient data to address the environments as stated in the DSNE.

Unless the threshold for the SEE is greater than 37 MeV-cm²/mg, cross section versus LET curves should be constructed with data for at least three different ions. Except for measurements of MOSFET sensitivity to SEGR and SEB, devices should be irradiated at a minimum of two different angles for each ion used.

For destructive SEE qualification testing, ions should have a minimum range of 50 microns (preferably 100 microns) into the device sensitive region.

The ratio of the saturated cross section to the cross section at the minimum LET used in testing should be at least 10.

For LET thresholds greater than 1 and less than 37 MeV-cm²/mg, sufficient data should be collected to determine threshold accurately enough to achieve a valid rate calculation for the calculation method used.

Fits to the cross section versus LET curve should bound the data in the curve, and “funnelling” should not be considered in the rate calculation - unless it can be shown to be necessary to account for observed device response.

Critical applications – where the occurrence of a particular SEE would result in loss of a critical system or other significant capability, the part(s) is considered immune if the effect is not observed after a fluence of $3.0 \times 10^8$ ions/cm² (for test-ions having LET > 80 MeVcm²/mg). This fluence can be accumulated over several device samples.
Non-critical applications – in some cases, a device may not exhibit a particular SEE during testing. While this may indicate that the device is immune to the effect, the lack of a positive result may also be due to a statistical fluctuation. Moreover, in many cases the number of parts being flown may be much larger than the number of parts tested. For these reasons, it is important in establishing a definition of immunity that has statistical rigor and that the number of parts and the importance of the application be taken into account. For the purposes of SEE analysis, immunity to SEE is established if no incidence of the effect is observed after irradiation of the part by a fluence of:

a) \(3.0 \times 10^7\) ions per cm\(^2\) (at LET > 60 MeVcm\(^2\)/mg) for flight lots \(\leq 10\) parts.

b) \(3.0 \times 10^6\) ions per cm\(^2\) \(\times\) number of parts in the flight lot (at LET > 60 MeVcm\(^2\)/mg) for \(10 <\) flight lot \(\leq 100\).

c) \(3.0 \times 10^8\) ions per cm\(^2\) (at LET > 80 MeVcm\(^2\)/mg) for flight lots with \(>100\) parts.

These fluences can be accumulated over several device samples.

For non-destructive SEE tests, a cross section should be determined from a minimum of 100 events, or a minimum fluence level is reached as follows:

d) \(3.0 \times 10^7\) ions per cm\(^2\) (at LET > 60 MeVcm\(^2\)/mg) for flight lots \(\leq 10\) parts.

e) \(3.0 \times 10^6\) ions per cm\(^2\) \(\times\) # of parts in the flight lot (at LET > 60 MeVcm\(^2\)/mg) for \(10 \leq\) flight lot \(\leq 100\).

f) \(3.0 \times 10^8\) ions per cm\(^2\) (at LET > 80 MeVcm\(^2\)/mg) for flight lots with \(>100\) parts.

These fluences can be accumulated over several device samples.

Some part families have been established by a long history of use in space hardware to be effectively immune to SEE. The main family in this group is the CD4000 series of radiation hardened logic devices. Similar heritage may apply to some other technologies, such as CMOS on sapphire technologies. These latter parts may be considered immune to SEE after the IR Lead has reviewed the available data, heritage information and application.

### B5.2.3 Existing Test Data and Reports

Existing test data and reports may be used provided all of the following conditions are met:

1. (a) The part that was tested previously represents the same design, layout and process from the same manufacturer; or (b) the test data are representative of a given part family/technology that historical data have shown to be very stable and relatively insensitive to single event effects at the levels of interest for the SLS program.

2. The radiation exposure bias circuit used would render the same or greater SEE response in the part compared with that for the SLS program.

3. The test data and reports conform to the requirements of the latest version of ASTM Test Method F1192 or ESCC Basic Specification 25100 and the additional standards of Section B5.2.2 for SEE testing.
4. Test data that demonstrate consistent radiation performance from lot-to-lot are available.

**B5.2.4 Sampling Statistics**

For SEE testing, determination of the proper sample size must take into consideration dose sensitivity of the parts, the likely level of part-to-part variation and issues regarding the destructive nature of the effect. For non-destructive SEE testing of DLA controlled parts where dose sensitivity is not an issue, a sample size of 3-5 parts is usually adequate. For non-DLA controlled parts, the minimum sample size should be five. For destructive SEE testing, the sample size should be sufficient to characterize the vulnerability of the parts over LET, angle, temperature and other relevant parameters. The analysis should demonstrate that part-to-part variability does not significantly affect the analysis conclusions.

**B5.2.5 Test Requirements**

Each test should have documented test requirements (per test plan) and a test report should document any deviations from the test plan and the results of the testing. The standards for the report are outlined in Section B5.2.7. RLAT requirements are provided in Section B5.3.

**B5.2.6 Test Samples**

The test samples used for engineering characterization shall be representative of flight devices used in the SLS program. Test samples used for RLAT shall be taken from the flight lot. For the purposes of SEE and displacement damage testing, the flight lot should include all devices produced during the same wafer diffusion run (whenever feasible). Test sample selection shall be based on the following:

1. Test samples shall be from the same process line as flight samples. Traceability shall exist from the characterization or RLAT samples to the flight lot.
2. The samples shall be of sufficient quantity to provide an adequate statistical base for the purposes of the test.
3. It is acceptable to use engineering test data as lot acceptance data as long as the engineering test samples were taken from the flight lot(s).
4. It is acceptable to use engineering test data (archival data) for qualification as long as the part is manufactured in a radiation hardened fabrication facility. For commercial parts, lot specific data are required or the design team should develop an analysis demonstrating that SEE performance is consistent from lot to lot.

**B5.2.7 Test Planning and Reporting**

Each radiation test plan should be a controlled document that contains the details of each device being tested and the test procedures to be followed for each device.

Each radiation test report should be a controlled document that contains the details of each device tested and the test procedures followed for each device. Test data and report should be available for review by the IR Lead as soon as possible after the test.
B5.2.8 Recommended Post-Test Screening For Latent Damage From Radiation-Induced High-Current Single-Event Effects

Latent damage can be caused by a single energetic particle (proton or heavy ion) passing through a microelectronic device, and inducing a high current (locally or globally) that can compromise device integrity. The most common mechanism by which this can occur is called SEL. SEL may cause some devices to fail immediately, while others may “recover” after a cycling of the power on/off/on. However, these latter devices, or those for which circuit-level current limiting prevents immediate failure, may still experience latent effects, including cracked dielectrics and compromised metallization. If a device is being tested for flight qualification at single event facilities and experiences such a “non-destructive” SEL (or other high-current event), additional post-test characterization is necessary to ensure that post-SEL reliability is not compromised by latent damage. Additional SEL testing may also be warranted to ensure that all SEL modes have been characterized, or if the initial SEL testing was done with current limiting that could have inhibited destructive effects or latent damage arising from SEL events that were observed.

During a typical heavy-ion SEE test, when SEL is observed, the key parameters that are sought are:

1. Event cross section (\(\sigma\)) [cm\(^2\)] versus LET [MeVcm\(^2\)/mg] curve – illustrates the sensitivity of the SEL mechanism to increasing deposited charge by the ion.
2. Event LET threshold (LET\(_{th}\)) – the maximum amount of deposited energy that does NOT cause an event for any device up to a particle fluence of \(10^7\) particles/cm\(^2\) during a test run.
3. Saturation cross-section (\(\sigma_{sat}\)) – the value of the event cross section, \(\sigma\), where the cross section versus LET curve has flattened out and increases little with increasing LET. In some cases, where test time is limited, \(\sigma_{sat}\) may be estimated by measuring \(\sigma\) at a high LET value.
4. Current signatures – (or power draw) of the events and the power reduction required to remove the event.
5. Dwell behavior – In some cases, dwell tests are performed, in which the high current event is allowed to remain in-place for some TBD time period before removal of power (and hence the event).
6. Temperature dependence – Typically, SEL testing is performed at higher than room temperature in order to provide a worst-case scenario (100ºC, for example, or an agreed upon \(\Delta T\) over worst-case operating conditions).

Unfortunately, heavy ion testing at an accelerator is often limited by time and/or cost constraints. If a device has large numbers of nodes that are sensitive to SEL, each with a different current signature, it may be impossible to induce every SEL that can occur during a broad beam irradiation. To identify what nodes within a device are SEL sensitive and their associated current signatures, a focused ion beam or laser test (if feasible) is recommended. This allows the test organization to scan the device nodes in conjunction with a photomicrograph and identify each current signature and sensitive node. (This, however, does not replace the need for heavy ion
testing due to the limitations of both the focused ion beam and laser test techniques.) A minimum of three samples of the device should be scanned in such a manner to gather some statistics.

For devices that are sensitive to proton-induced SEL, proton irradiation may be used as an additional risk-investigation. The relationship between proton and heavy ion induced SEL is not completely known, but a proton test can be used to determine sensitivity to SEL issues for many low-earth orbits (low inclination). Higher energies (≥50 MeV is acceptable, > 150 MeV is preferred) are recommended to ensure that recoil ions have sufficient range that observation of SEL is not range limited. Moreover, larger sample sizes may be needed because the much lower proton cross sections mean proton tests cause more TID damage per error observed than do heavy-ion experiments. Fluence levels should be chosen based on device TID sensitivity and mission exposure profiles.

The following is recommended for latent damage testing of samples after SEL testing:

1. Optical microscopy of the device (500x min, 1000x preferred)
2. Scanning electron microscopy (SEM)
3. Life tests with associated failure analyses
4. Thermal cycling (full-functional)
5. Maximum rating test and analysis (drive device to maximum rated limits to look for “hot spots”; use an un-irradiated device as a reference; techniques such as infrared camera or liquid crystal film might be used to detect hot spots)

There are several additional issues for which no completely satisfactory answers currently exist. For example, the limited penetration range of ions typically used for SEE testing necessitates removal of any material (lid, coating, plastic, etc…) from the die. Such “de-lidding” may itself stress the device and compromise mechanical and thermal packaging integrity. Improved handling (for example, keeping the device in nitrogen or vacuum even during irradiation) can limit some of these effects, but can increase qualification test costs significantly (a factor of 3x or so). In addition, it is not clear that an SEL that induces latent damage in a de-lidded device would necessarily cause the same effect in an intact packaged device, given that de-lidding may increase the device’s exposure to moisture, change its thermal properties, etc. Higher energy heavy ion facilities (such as Michigan State University’s National Superconducting Cyclotron Laboratory) produce ions with greater penetration and may obviate the need to de-lid typical devices, thus simplifying many of these concerns.

**B5.3 Radiation Lot Acceptance Test**

If required for a device type, RLAT shall be performed to verify acceptable performance of flight lot devices in the required radiation environment. The RLAT plan and procedure should be written according to the requirements of Section B5.1.8 or B5.2.7 (as applicable).

**B6.0 VERIFICATION ANALYSES**

Verification of the system capability to meet radiation requirements should include performance of device characterization, radiation transport documentation, circuit analysis, and where necessary performance of radiation lot acceptance testing. Ionizing Radiation qualification
testing should be performed on active parts that have no appropriate radiation response information available. All IR test data and the event rate data developed from the SEE analyses for all flight safety and mission critical components should be included in the Element’s Loss of Crew/Loss of Mission (LOC/LOM) analysis. All Element analyses should then be rolled up into the overall integrated vehicle’s LOC/LOM numbers.

**B6.1 Radiation Transport Analysis**

A radiation transport analysis should be completed for all electronic systems. Bounding mission doses and displacement damage fluences should be determined by using the vehicle environments as specified in the DSNE, or transporting them through models of the vehicle’s shielding. This analysis should document the radiation design margins for devices used.

**B6.2 Worst Case Analysis**

In addition to temperature and aging, worst case analyses completed for electronic systems should incorporate total dose and displacement damage parametric degradation for worst-case application conditions.

Radiation parametric deratings are a means of incorporating device degradation due to TID and DD effects into the worst-case analysis to ensure that the system will continue to operate as intended at end of life. Parameters for each EEE piece part should be derated assuming at least 2 times the part’s actual combined TID and DDD exposure level. For those parameters where the design cannot withstand the derating at this level, a lower level may be achieved by adding local shielding as determined by an appropriate part-level radiation transport analysis. The parametric degradation should be documented and included in the worst-case circuit analysis.

**B6.3 Single-Event Effects Analysis**

Analysis documenting the impact of single-event effects on performance, from circuit to system level, should be completed for all electronic systems. Radiation sources considered should include atmospheric neutrons, trapped particles, solar event particles and galactic cosmic rays, as applicable. SEE rate prediction should make use of the methods and techniques as laid out in “The SEU Figure of Merit and Proton Upset Rate Calculations” and “Analytical Microdosimetry Model for Proton-Induced SEU in Modern Devices” documents (see Section 2.2).
APPENDIX C
OPEN WORK

C1.0 TO BE DETERMINED

Table C1-1 lists the specific To Be Determined (TBD) items in the document that are not yet known. The TBD is inserted as a placeholder wherever the required data is needed and is formatted in bold type within carets. The TBD item is sequentially numbered as applicable (i.e., <TBD-001> is the first undetermined item assigned in the document). As each TBD is resolved, the updated text is inserted in each place that the TBD appears in the document and the item is removed from this table. As new TBD items are assigned, they will be added to this list in accordance with the above described numbering scheme. Original TBDs will not be renumbered.

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C2.0 TO BE RESOLVED

Table C2-1 lists the specific To Be Resolved (TBR) issues in the document that are not yet known. The TBR is inserted as a placeholder wherever the required data is needed and is formatted in bold type within carets. The TBR issue is sequentially numbered as applicable (i.e., <TBR-001> is the first unresolved issue assigned in the document). As each TBR is resolved, the updated text is inserted in each place that the TBR appears in the document and the issue is removed from this table. As new TBR issues are assigned, they will be added to this list in accordance with the above described numbering scheme. Original TBRs will not be renumbered.

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C3.0 FORWARD WORK

Table B3-1 lists the specific forward work items identified during this document’s Change Request (CR) review and evaluation. Each item is given a sequential number using a similar format to that for the TBDs and TBRs. For each item, include the section number(s) of this document that the open work will impact, and in the Description include the specific number of the comment from the Change Evaluation (CE), i.e., CE-10, CE-27. Do not include a placeholder for forward work items in the body of the document; list them only in Table B3-1.

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