431-RQMT-000045
Revision B
Effective Date: 10/04/2006
Expiration Date: 10/04/2011

Lunar Reconnaissance Orbiter Project

Radiation Requirements

September 14, 2006

LRO GSFC CMO

October 4, 2006

RELEASED

National Aeronautics and Space Administration

Goddard Space Flight Center
Greenbelt, Maryland

CM FOREWORD

This document is a Lunar Reconnaissance Orbiter (LRO) Project Configuration Management (CM)-controlled document. Changes to this document require prior approval of the applicable Configuration Control Board (CCB) Chairperson or designee. Proposed changes shall be submitted to the LRO CM Office (CMO), along with supportive material justifying the proposed change. Changes to this document will be made by complete revision.

Questions or comments concerning this document should be addressed to:

LRO Configuration Management Office
Mail Stop 451
Goddard Space Flight Center
Greenbelt, Maryland 20771

Signature Page

Prepared by:

10/3/06

Christian Poivey — Date
LRO Radiation Lead
MEI, Code 561

Reviewed by:

9/15/06

Mike Pryzby — Date
LRO Spacecraft Systems Engineer
Swales Aerospace, Code 543

9/15/06

Philip Luers — Date
LRO Avionics Systems Engineer
NASA/GSFC, Code 561

Approved by:

David Everett 9/15/06

David Everett — Date
LRO Mission Systems Engineer
NASA/GSFC, Code 599

LUNAR RECONNAISSANCE ORBITER PROJECT

DOCUMENT CHANGE RECORD

Sheet: 1 of 1

REV LEVEL	DESCRIPTION OF CHANGE	APPROVED BY	DATE APPROVED
Rev-	Released per 431-CCR-000037	C. Tooley	11/1/2005
Rev A	Released per 431-CCR-000058	C. Tooley	2/10/2006
Rev B	Released per 431-CCR-000155	D. Everett	10/04/2006

List of TBDs/TBRs

Item No.	**Location**	**Summary**	**Ind./Org.**	**Due Date**

TABLE OF CONTENTS

Page

LIST OF TABLES

Table Page

1.0 INTRODUCTION

This document gives the Total Ionizing Dose (TID), non-ionizing Displacement Damage Dose (DDD), and Single Event Effects (SEE) requirements for the Lunar Reconnaissance Orbiter (LRO). We have assumed in this document a top-level shielding requirement of at least 100 mils equivalent aluminum shielding between all components and free space. That is, there must be 100 mils equivalent aluminum shielding in all solid angles projected from the device out towards free-space. The requirements below assume that shielding for each component meets this minimum shielding requirement.

1.1 DEFINITIONS

Single Event Upset (SEU) - a change of state or transient induced by an energetic particle such as a cosmic ray or proton in a device. This may occur in digital, analog, and optical components or may have effects in surrounding interface circuitry (a subset known as Single Event Transients (SETs)). These are "soft" errors in that a reset or rewriting of the device causes normal device behavior thereafter.

Single Hard Error (SHE) - a SEU that causes a permanent change to the operation of a device. An example is a stuck bit in a memory device.

Single Event Latchup (SEL) - a condition that causes loss of device functionality due to a single event induced high current state. A SEL may or may not cause permanent device damage, but requires power cycling of the device to resume normal device operations.

Single Event Functional Interrupt (SEFI) – a condition that causes loss of device functionality due to a single event in a device control register. It generally requires a device reset to resume normal device operations, but, for some devices, a power cycle is necessary to resume normal device operations.

Single Event Burnout (SEB) - a condition that can cause device destruction due to a high current state in a power transistor.

Single Event Gate Rupture (SEGR) - a single ion induced condition in power MOSFETs that may result in the formation of a conducting path in the gate oxide.

Single Event Effect (SEE) - any measurable effect to a circuit due to an ion strike. This include (but is not limited to) SEUs, SETs, SHEs, SELs, SEFIs, SEBs, SEGRs, and Single Event Dielectric Rupture (SEDR).

Multiple Bit Upset (MBU) - an event induced by a single energetic particle such as a cosmic ray or proton that causes multiple upsets or transients during its path through a device or system.

Linear Energy Transfer (LET) - a measure of the energy deposited per unit length as an energetic particle travels through a material. The common LET unit is MeV*cm^2/milligram (mg) of material (International System of Units [Si] for Metal Oxide Semiconductor [MOS] devices, etc.).

Threshold LET (LET_{th}) - the minimum LET to cause an effect at a particle fluence of 1E7 ions/cm^2. Typically, a particle fluence of 1E5 ions/cm^2 is used for SEB and SEGR testing.

2.0 DOCUMENTS

2.1 APPLICABLE DOCUMENTS

431-RQMT-000174	Lunar Reconnaissance Orbiter Mission Assurance Requirements
431-SPEC-000020	Lunar Reconnaissance Orbiter Radiation Environment Specification
MIL-STD-883	Test Method Standard, Microcircuits (Method 1019.6)

2.2 REFERENCE DOCUMENTS

431-REF-000273	Single Event Effect Criticality Analysis

3.0 RADIATION REQUIREMENTS

In this document, a requirement is identified by “shall,” a good practice by “should”, permission by “may”, or “can”, expectation by “will”, and descriptive material by “is.”

3.1 COMPONENT TOTAL IONIZING DOSE

RADR-1: No effect due to TID shall cause permanent damage to, or degradation of a system or subsystem.

RADR-2: Each component shall be assessed for sensitivity to TID effects.

RADR-3: If component test data do not exist, ground testing shall be required.

RADR-4: For commercial components, testing shall be required on the flight procurement lot.

RADR-5: All testing shall be Cobalt-60 (Co-60) testing as per Test Method Standard, Microcircuits (MIL-STD-883 Method 1019.6).

RADR-6: For any component that is estimated to have on-orbit performance degradation due to TID, an analysis shall be performed to show that this degradation does not cause damage to or induce degradation of system or subsystem performance.

RADR-7: In the event that RADR-06 cannot be met, mitigation shall be added to eliminate the possibility of damage to or degradation of system or subsystem performance, and to be verified by analysis or test.

3.1.1 Total Ionizing Dose Environment Specifications

RADR-8: The top level TID requirements to be used for analysis for the 14 months mission shall be 5.4 kilorad-Si (krad-Si).

RADR-9: A radiation design margin of 2 shall be used.

RADR-10: From top-level TID requirement and the radiation design margin above, the TID requirement shall be 10.8 krad-Si.

This assumes 100 mils Aluminum shielding. Those subsystems internal to the spacecraft can assume the spacecraft structure will provide the equivalent of 20 mils of Aluminum shielding.

RADR-11: If high dose rate archival data are used for considering TID sensitivity of any particular linear bipolar or Bipolar Complementary Metal Oxide Semi-Conductor (BiCMOS) component, a radiation design margin of 7 shall be used. From top level TID requirements, the TID requirement is 37.8 krad-Si.

RADR-12: If a device's performance degradation due to TID is not acceptable using the top-level requirements, then the space radiation environments shall be estimated using a 3 dimensional Monte Carlo analysis or a ray trace analysis. Table 3-1 shows the mission dose level in function Aluminum shielding thickness.

Table 3-1. Mission Dose versus Al Shield Thickness

Al shield Thickness (mils)	Mission dose (krad-Si)
100	5.4
150	3.2
200	2.3
300	1.3

RADR-13: If the 100 mils shielding requirement is not met, the space radiation environment shall be estimated using the methods described inRADR-12 above, and the radiation design margins above will be applied to the calculated TID requirement.

3.2 COMPONENT DISPLACEMENT DAMAGE DOSE SPECIFICATION

RADR-14: No effect due to Displacement Damage Dose (DDD) shall cause permanent damage to or degradation of a system or subsystem.

RADR-15: Each component shall be assessed for potential sensitivity to DDD effects.

RADR-16: For those components deemed sensitive to DDD, if component test data do not exist, ground testing shall be required.

RADR-17: For commercial components, testing shall be required on the flight procurement lot.

RADR-18: All testing shall be performed using protons to a mission equivalent fluence.

RADR-19: For any component that is estimated to have on-orbit performance degradation due to DDD, an analysis shall be performed to show that this degradation does not cause damage to or induce degradation of system or subsystem performance.

RADR-20: In the event that RADR-19 cannot be met, mitigation shall be added to eliminate the possibility of damage to or degradation of system or subsystem performance, and verified by analysis or test.

3.2.1 Displacement Damage Dose Environment Specifications

RADR-21: The top-level DDD requirement to be used for the 14 months mission shall be 1.4E10 protons/centimenter^2 (cm^2) of 10 Megaelectron Volt (MeV) protons.

RADR-22: A radiation design margin of 2 shall be used when considering their effects on component performance.

RADR-23: From top-level DDD mission equivalent proton fluence and the radiation design margin above, the top level DDD requirement for components shall be 2.7E10 p/cm^2 of 10 MeV protons.

RADR-24: If a device's performance due to DDD is not acceptable using the top-level requirements, then the space radiation environment on this device shall be estimated using a more accurate method such as 3 dimensional Monte Carlo analysis or ray trace analysis.

RADR-25: Alternative proton energies can be used for test and analysis. The requirement shall be scaled according to the Non Ionizing Energy Loss (NIEL).

3.3 SINGLE EVENT EFFECTS SPECIFICATION

3.3.1 Component Single Event Effects Specification

RADR-26: No SEE shall cause damage to a system or a subsystem or induce performance anomalies or outages that require ground intervention to correct

RADR-27: If component test data do not exist, ground testing shall be required.

RADR-28: For commercial components, testing shall be required on the flight procurement lot.

RADR-29: Immunity shall be defined as a LETth > 75 $MeVcm^2/mg$.

RADR-30: For any component that is not immune to SEL, an analysis shall demonstrate that the SEL probability of occurrence is negligible in the LRO mission environment.

RADR-31: All N channel power Metal Oxide Semiconductor Field-Effect Transistors (MOSFETs) may be susceptible to SEB in the off mode. N channel MOSFET shall be evaluated at the worst-case application.

RADR-32: The survival V Drain-Source (V_{DS}) voltage shall be established from exposure to minimum fluence of 1E6 $ions/cm^2$ with a minimum LET of 26 $MeVcm^2/mg$ and a range that is sufficient to penetrate the depletion depth of the device at its maximum voltage. The minimum ion range as a function of rated V_{DS} is given in Table 3-2.

Table 3-2. Minimum Ion Range as a Function of Rated V_{DS}

Max rated V_{DS} (V)	Minimum ion range (μm)
Up to 100	30
100 to 250	40
250 to 400	80
400 to 1000	200

RADR-33: The application shall be derated to 75% of the established survival voltage.

RADR-34: In the event that RADR-33 cannot be met, a derating factor of 40% (of V_{DS} rated) shall be applied for up to 200V devices from International Rectifier and Intersil when no data are available.

RADR-35: For any other device type and/or vender, a derating factor of 25% shall be applied when no data is available.

RADR-36: All power MOSFET may be susceptible to SEGR in the off mode, sensitivity shall be evaluated at the worst-case application.

RADR-37: The survival V_{DS} voltage shall be established from exposure to minimum fluence of 1E6 ions/cm^2 with a minimum LET of 26 LET MeVcm^2/mg and a range that is sufficient to penetrate the depletion depth of the device at its maximum voltage. The minimum ion range as a function of rated V_{DS} is given in Table 3-1.

RADR-38: The application shall be derated to 75% of the established survival voltage.

RADR-39: In the event that RADR-38 cannot be met, a derating factor of 40% (of V_{DS} rated) shall be applied for up to 200V devices from International Rectifier and Intersil when no data are available.

RADR-40: For any other device type and or vendor, a derating factor of 25% shall be applied when no data is available.

RADR-41: For single particle events like SEU, SET, and MBU, the *criticality* of a component in its specific application shall be defined. Please refer to the Single Event Effect Criticality Analysis (SEECA) document (431-REF-000273) for details. A SEECA analysis or a Failure Modes Effects Analysis (FMEA) should be performed at the system level.

RADR-42: Component heavy-ion and proton testing (and from these a rate calculation) shall be performed on each application of each component.

RADR-43: SEE testing and analysis shall take place based on LETth of the candidate devices as described in Table 3-3.

Table 3-3. Environment to be Assessed Based on SEE Device LET Threshold

Device Threshold	Environment to be Assessed
LET_{th} < 12 $MeVcm^2$/mg	Galactic Cosmic Rays, Solar Events Heavy ions and protons
LET_{th} = 12-75 $MeVcm^2$/mg (destructive events) LETth = 12-37 $MeVcm^2$/mg (non destructive events)	Galactic Cosmic Ray Heavy Ions, Solar Events Heavy Ions
LET_{th} > 75 $MeVcm^2$/mg (destructive events) LETth > 37 $MeVcm^2$/mg (non destructive events)	No analysis required

SEE environment specification (recall top level shielding is 100 mils equivalent Al):

RADR-44: For non-destructive events, a radiation design margin of 2 shall be used on all environment estimates when considering their effects on component performance.

RADR-45: The cosmic ray integral-flux LET spectrum to be used for analysis shall be per Figure 3-10 and Table A8 of the LRO Radiation Environment Specification (431-SPEC-000020).

RADR-46: The solar particle event integral-flux LET spectrum to be used for analysis shall be per Figure 3-11 and Table A9 of the LRO Radiation Environment Specification (431-SPEC-000020).

RADR-47: The worst-case solar proton energy spectra to be used for analysis shall be per Figure 3-12 and Table A10 of the LRO Radiation Environment Specification (431-SPEC-000020).

RADR-48: The improper operation caused by single particle events like SEU, SET and MBU shall be reduced to acceptable levels.

RADR-49: Systems engineering analysis of circuit design, operating modes, duty cycle, device criticality, etc. shall be performed to determine acceptable levels for that device. Means of gaining acceptable levels include part selection, error detection and correction schemes, redundancy and voting methods, error tolerant coding, or acceptance of errors in non-critical areas.

4.0 QUALIFICATION ASSURANCE PROVISIONS

4.1 GENERAL

All requirements in this document shall be verified by one of the four methods defined below.

4.1.1 Analysis

The analysis method is used when:

- A rigorous, representative, and conclusive analysis is possible
- Test is not cost effective, and
- Inspection and demonstrations are not adequate

Analyses may include, but are not limited to, engineering analysis (which includes models and simulations), review of record, and similarity analysis.

4.1.1.1 Engineering Analysis

Engineering analysis may be quantitative, qualitative, or a combination of the two. Quantitative analysis involves the study and modeling of the physical entity whose performance is to be verified. Examples of quantitative analyses include end-to-end link analysis, structural (static and dynamic) analysis, thermal models, pointing knowledge and stability. Qualitative analyses are non-numerical and related to qualitative measure of performance, such as failure modes and effects analyses (FMEA), maintainability, and redundancy.

4.1.1.2 Validation of Records and Other Documentation Analysis

This kind of analysis uses design and manufacturing documentation to show compliance of design features and manufacturing processes. Validation of design documentation, e.g., engineering drawings, verifies that the “as-designed” hardware complies with contractual design and construction requirements. Validation of manufacturing records at end-item acceptance verifies that the “as-built” hardware has been fabricated per the approved design and associated documentation. Review and analysis of other documentation such as acceptance data packages and other compliance documentation of lower levels of assembly are valid analysis techniques.

4.1.1.3 Similarity Analysis

Similarity is included as a valid verification/qualification method. Qualification by similarity is used in lieu of test when it can be shown that an item is similar to, or identical in design to another item that has been previously qualified to equivalent, or more stringent requirements. Formal qualification documentation of the previously qualified item must be available for assessment when planning to qualify by similarity. Furthermore, an item whose design has been qualified by similarity must undergo acceptance verification to assess workmanship.

4.1.2 Demonstration

Demonstration is a verification method that provides a qualitative determination, rather than direct quantitative measurement, of the properties or functional characteristics of an end-item. The qualitative determination is made through observation with, or without test equipment or instrumentation.

4.1.3 Inspection

Inspection is the verification method used to verify construction features, workmanship, dimension, physical characteristics, and spacecraft conditions such as configuration, cleanliness, and locking hardware. Inspection also includes simple measurements such as length, and it is performed without the use of special laboratory or precision equipment. In general, requirements specifying function or performance are not verified by inspection.

4.1.4 Test

Verification by test consists of direct measurement of performance parameters relative to functional, electrical, mechanical, and environmental requirements. These measurements are obtained, during or after controlled application of functional and environmental stimuli to the test article, e.g., payload or satellite, and using instrumentation or special test equipment that is not an integral part of the test article being verified. The test activities include reduction and analysis of the test data, as appropriate. The following paragraphs define different categories of tests including performance, functional, environmental, interface, and structural tests.

4.1.4.1 Performance Test

A performance test consists of an individual test or series of electrical and/or mechanical tests conducted on flight, or flight-configured hardware and software at conditions equal to, or less than design specifications. Its purpose is to verify compliance of the test article with the stated applicable specification requirements that are verifiable by test. Typically, a full performance test is conducted at ambient conditions at the beginning and the end of a test sequence during which the test article is subjected to applicable environmental conditions, e.g., vacuum, high/low temperature extremes, or acoustics/random mechanical excitation.

4.1.4.2 Functional Tests

A functional test is a suitably chosen subset of a performance test. Typically, functional tests are conducted at ambient conditions between environmental exposures during the qualification or acceptance test sequence. The objective is to verify that prior to application of the next environment, exposure to the environment has not adversely affected the test article. When appropriate, functional tests, or a portion thereof, are conducted while the test article is exposed to a particular thermal or vacuum environment. Functional test, or a portion thereof, may also be conducted to assess the state of health of the hardware after major operations, such as transportation of flight hardware from one location to another.

4.1.4.3 Environmental Tests

Environmental testing is an individual test or series of tests conducted on flight, or flight-configured hardware to assure that flight hardware will perform satisfactorily after it is subjected to the induced launch environments, as well as its flight environment. Examples are: vibration, acoustic, temperature cycling, thermal vacuum and vacuum outgassing certification, and Electromagnetic Interference/Compatibility. Depending on the severity of the chosen environmental conditions, the purpose of the environmental exposure is to sufficiently stress the hardware so as to verify the adequacy of the design (protoflight levels and durations) or workmanship during fabrication (acceptance levels and durations).

4.1.4.4 Special Tests

Special tests are individual tests, or a series of tests conducted on flight, or flight-configured hardware to assure satisfactory performance of a particular critical element of the system, e.g., optical alignment. The special test verification category includes structural, mechanism and communication tests. Special tests may, or may not be performed in conjunction with environmental exposure.

4.1.4.5 Interface Tests

Interface tests verify the mechanical, electrical, and/or hardware-software interface between units and elements integrated into a higher level of assembly such as a module, subsystem, element, or a system.

4.1.4.6 Structural Tests

These tests are performed on structural elements, components, or assembled subsystems before delivery of the assembled structure to the integration and test organization. Structural tests designed to verify requirements of this specification may include: (1) static structural proof tests (to verify the strength/stiffness adequacy of the primary load path), and (2) dynamic tests, such as a modal survey or acoustic response test.

4.2 VERIFICATION MATRIX TABLE

The following matrix table defines the method of verification for all requirements contain in this document:

Table 4-1. Verification Matrix Table

Verification Method:		Level:
Inspection	(I)	1 System
Analysis	(A)	2 Segment
Demonstration	(D)	3 Subsytem
Test	(T)	4 Component

Requirement Number	Section Number	Object Heading	I	A	D	T	Responsible Org.
RADR-1	3.1	TID permanent damage		4			
RADR-2	3.1	TID assessment		4		4	
RADR-3	3.1	TID testing				4	
RADR-4	3.1	TID for commercial components				4	
RADR-5	3.1	Co-60 testing				4	
RADR-6	3.1	TID degraded performance		4			
RADR-7	3.1	TID mitigation		4		4	
RADR-8	3.1.1	TID top-level rqmt		4			
RADR-9	3.1.1	TID radiation design margin		4			
RADR-10	3.1.1	TID rqmt		4			
RAD-11	3.1.1	BiCMOS factor of safety		4			
RADR-12	3.1.1	TID Monte Carolo analysis		4			
RADR-13	3.1.1	TID without 100 mils shielding		4			
RADR-14	3.2	DDD permanent damage		4			
RADR-15	3.2	DDD assessment		4		4	
RADR-16	3.2	DDD testing				4	
RADR-17	3.2	DDD for commercial components				4	
RADR-18	3.2	DDD proton testing				4	
RADR-19	3.2	DDD degraded performance		4			
RADR-20	3.2	DDD mitigation		4		4	
RADR-21	3.2.1	DDD top level rqmt		4			
RADR-22	3.2.1	DDD radiation design margin		4			
RADR-23	3.2.1	DDD rqmt		4			
RADR-24	3.2.1	DDD Monte Carlo analysis		4			
RADR-25	3.2.1	DDD proton energy scaling		4			
RADR-26	3.3.1	See requiring ground intervention		4			
RADR-27	3.3.1	See ground testing				4	
RADR-28	3.3.1	See for commercial components				4	
RADR-29	3.3.1	See immunity		4		4	
RADR-30	3.3.1	See probability analysis		4			
RADR-31	3.3.1	See and N-channel CMOS		4		4	
RADR-32	3.3.1	Survival VDS voltage				4	
RADR-33	3.3.1	VDS Survival voltage derating		4			
RADR-34	3.3.1	VDS Derating for Intersil and IR		4			

RADR-35	3.3.1	VDS minimum fluence		4		4	
RADR-36	3.3.1	Power MOSFETs		4		4	
RADR-37	3.3.1	VDS minimum fluence				4	
RADR-38	3.3.1	Survival derating		4			
RADR-39	3.3.1	Survival derating		4			
RADR-40	3.3.1	Survival derating		4			
RADR-41	3.3.1	See Criticality		4/3/2/1			
RADR-42	3.3.1	Heavy Ion and Proton testing				4	
RADR-43	3.3.1	SEE testing and analysis		4		4	
RADR-44	3.3.1	SEE nondestructive design margin		4			
RADR-45	3.3.1	Cosmic ray integral flux		4			
RADR-46	3.3.1	Solar particle integral flux		4			
RADR-47	3.3.1	Solar proton spectra		4			
RADR-48	3.3.1	Improper operation		4		4	
RADR-49	3.3.1	Acceptable Level		4			

Appendix A. Abbreviations and Acronyms

Abbreviation/ Acronym	DEFINITION
BiCMOS	Bipolar Complementary Metal Oxide Semiconductor
cm^2	Centimeters squared
CMOS	Complementary Metal Oxide Semiconductor
Co-60	Cobalt 60
DDD	Displacement Damage Dose
ELDRS	Enhanced Low Dose Rate Sensitivity
FMEA	Failure Mode and Effects Analysis
krad-Si	kilorad-Si
LET	Linear Energy Transfer
LETth	Linear Energy Transfer Threshold
LRO	Lunar Reconnaissance Orbiter
MBU	Multiple Bit Upset
MeV	Megaelectron Volt
Mg	Milligram
Mil	.001 inch
MOS	Metal Oxide Semiconductor
MOSFET	Metal Oxide Semiconductor Field Effect Transistor
NIEL	Non Ionizing Energy Loss
RLEP	Robotic Lunar Exploration Program
SEB	Single Event Burnout
SEDR	Single Event Dielectric Rupture
SEE	Single Event Effect
SEECA	Single Event Effect Criticality Analysis
SEFI	Single Event Functional Interrupt
SEGR	Single Event Gate Rupture
SEL	Single Event Latchup
SET	Single Event Transient
SEU	Single Event Upset
SHE	Single Hard Errors
Si	International System of Units (Système International d'Unités)
TID	Total Ionizing Dose
V_{DS}	Voltage Drain-Source

Appendix B. Traceability Matrix

Parent Requirement			Requirement			Child Requirement		
RQMT#	**Section#**	**Object Heading**	**RQMT#**	**Section#**	**Object Heading**	**RQMT#**	**Section#**	**Object Heading**
MRD-12, MRD-13, MRD-21	3.1.1	Mission Orbit, Mission Inclination, Mission Duration	RADR-1	3.1	TID permanent damage			
MRD-12, MRD-13, MRD-21	3.1.1	Mission Orbit, Orbit Inclination, Mission Duration	RADR-2	3.1	TID assessment			
MRD-12, MRD-13, MRD-21	3.1.1	Mission Orbit, Orbit Inclination, Mission Duration	RADR-3	3.1	TID for commercial components			
MRD-12, MRD-13, MRD-21	3.1.1	Mission Orbit, Orbit Inclination, Mission Duration	RADR-4	3.1	Co-60 testing			
MRD-12, MRD-13, MRD-21	3.1.1	Mission Orbit, Orbit Inclination, Mission Duration	RADR-5	3.1	TID degraded performance			
MRD-12, MRD-13, MRD-21	3.1.1	Mission Orbit, Orbit Inclination, Mission Duration	RADR-6	3.1	TID mitigation			
MRD-12,	3.1.1	Mission Orbit,	RADR-7	3.1	TID top-level rqmt			

Parent Requirement			Requirement			Child Requirement		
RQMT#	**Section#**	**Object Heading**	**RQMT#**	**Section#**	**Object Heading**	**RQMT#**	**Section#**	**Object Heading**
MRD-13, MRD-21		Orbit Inclination, Mission Duration						
MRD-12, MRD-13, MRD-21	3.1.1	Mission Orbit, Orbit Inclination, Mission Duration	RADR-8	3.1.1	TID top level rqmt			
MRD-12, MRD-13, MRD-21	3.1.1	Mission Orbit, Orbit Inclination, Mission Duration	RADR-9	3.1.1	DID radiation design margin			
MRD-12, MRD-13, MRD-21	3.1.1	Mission Orbit, Orbit Inclination, Mission Duration	RADR-10	3.1.1	TID rqmt			
MRD-12, MRD-13, MRD-21	3.1.1	Mission Orbit, Orbit Inclination, Mission Duration	RADR-11	3.1.1	BiCMOS factor of safety			
MRD-12, MRD-13, MRD-21	3.1.1	Mission Orbit, Orbit Inclination, Mission Duration	RADR-12	3.1.1	TID Monte Carlo analysis			

Parent Requirement			Requirement			Child Requirement		
RQMT#	Section#	Object Heading	RQMT#	Section#	Object Heading	RQMT#	Section#	Object Heading
MRD-12, MRD-13, MRD-21	3.1.1	Mission Orbit, Orbit Inclination, Mission Duration	RADR-13	3.1.1	TID without 100 mils shielding			
MRD-12, MRD-13, MRD-21	3.1.1	Mission Orbit, Orbit Inclination, Mission Duration	RADR-14	3.2	DDD permanent damage			
MRD-12, MRD-13, MRD-21	3.1.1	Mission Orbit, Orbit Inclination, Mission Duration	RADR-15	3.2	DDD assessment			
MRD-12, MRD-13, MRD-21	3.1.1	Mission Orbit, Orbit Inclination, Mission Duration	RADR-16	3.2	DDD testing			
MRD-12, MRD-13, MRD-21	3.1.1	Mission Orbit, Orbit Inclination, Mission Duration	RADR-17	3.2	DDD for commercial components			
MRD-12, MRD-13, MRD-21	3.1.1	Mission Orbit, Orbit Inclination, Mission Duration	RADR-18	3.2	DDD proton testing			

Parent Requirement			Requirement			Child Requirement		
RQMT#	**Section#**	**Object Heading**	**RQMT#**	**Section#**	**Object Heading**	**RQMT#**	**Section#**	**Object Heading**
MRD-12, MRD-13, MRD-21	3.1.1	Mission Orbit, Orbit Inclination, Mission Duration	RADR-19	3.2	DDD degraded performance			
MRD-12, MRD-13, MRD-21	3.1.1	Mission Orbit, Orbit Inclination, Mission Duration	RADR-20	3.2	DDD mitigation			
MRD-12, MRD-13, MRD-21	3.1.1	Mission Orbit, Orbit Inclination, Mission Duration	RADR-21	3.2.1	DDD top level rqmt			
MRD-12, MRD-13, MRD-21	3.1.1	Mission Orbit, Orbit Inclination, Mission Duration	RADR-22	3.2.1	DDD radiation design margin			
MRD-12, MRD-13, MRD-21	3.1.1	Mission Orbit, Orbit Inclination, Mission Duration	RADR-23	3.2.1	DDD rqmt			
MRD-12, MRD-13, MRD-21	3.1.1	Mission Orbit, Orbit Inclination, Mission Duration	RADR-24	3.2.1	DDD Monte Carlo analysis			

Parent Requirement			Requirement			Child Requirement		
RQMT#	Section#	Object Heading	RQMT#	Section#	Object Heading	RQMT#	Section#	Object Heading
MRD-12, MRD-13, MRD-21	3.1.1	Mission Orbit, Orbit Inclination, Mission Duration	RADR-25	3.2.1	DDD proton energy scaling			
MRD-12, MRD-13, MRD-21	3.1.1	Mission Orbit, Orbit Inclination, Mission Duration	RADR-26	3.3.1	SEE requiring ground intervention			
MRD-12, MRD-13, MRD-21	3.1.1	Mission Orbit, Orbit Inclination, Mission Duration	RADR-27	3.3.1	SEE ground testing			
MRD-12, MRD-13, MRD-21	3.1.1	Mission Orbit, Orbit Inclination, Mission Duration	RADR-28	3.3.1	SEE for commercial components			
MRD-12, MRD-13, MRD-21	3.1.1	Mission Orbit, Orbit Inclination, Mission Duration	RADR-29	3.3.1	SEE immunity			
MRD-12, MRD-13, MRD-21	3.1.1	Mission Orbit, Orbit Inclination, Mission Duration	RADR-30	3.3.1	SEE probability analysis			
MRD-12, MRD-13, MRD-21	3.1.1	Mission Orbit, Orbit Inclination, Mission Duration	RADR-31	3.3.1	SEE and N-channel CMOS			
MRD-12, MRD-13,	3.1.1	Mission Orbit, Orbit Inclination,	RADR-32	3.3.1	Survival VDS voltage			

Parent Requirement			Requirement			Child Requirement		
RQMT#	**Section#**	**Object Heading**	**RQMT#**	**Section#**	**Object Heading**	**RQMT#**	**Section#**	**Object Heading**
MRD-21		Mission Duration						
MRD-12, MRD-13, MRD-21	3.1.1	Mission Orbit, Orbit Inclination, Mission Duration	RADR-33	3.3.1	VDS Survival voltage derating			
MRD-12, MRD-13, MRD-21	3.1.1	Mission Orbit, Orbit Inclination, Mission Duration	RADR-34	3.3.1	VDS Derating for Intersil and IR			
MRD-12, MRD-13, MRD-21	3.1.1	Mission Orbit, Orbit Inclination, Mission Duration	RADR-35	3.3.1	VDS Survival derating			
MRD-12, MRD-13, MRD-21	3.1.1	Mission Orbit, Orbit Inclination, Mission Duration	RADR-36	3.3.1	Power MOSFETs			
MRD-12, MRD-13, MRD-21	3.1.1	Mission Orbit, Orbit Inclination, Mission Duration	RADR-37	3.3.1	VDS mimimum fluence			
MRD-12, MRD-13, MRD-21	3.1.1	Mission Orbit, Orbit Inclination, Mission Duration	RADR-38	3.3.1	Survival derating			
MRD-12, MRD-13, MRD-21	3.1.1	Mission Orbit, Orbit Inclination, Mission Duration	RADR-39	3.3.1	Survival derating			
MRD-12,	3.1.1	Mission Orbit,	RADR-40	3.3.1	Survival derating			

Parent Requirement			Requirement			Child Requirement		
RQMT#	Section#	Object Heading	RQMT#	Section#	Object Heading	RQMT#	Section#	Object Heading
MRD-13, MRD-21		Orbit Inclination, Mission Duration						
MRD-12, MRD-13, MRD-21	3.1.1	Mission Orbit, Orbit Inclination, Mission Duration	RADR-41	3.3.1	SEE Criticality			
MRD-12, MRD-13, MRD-21	3.1.1	Mission Orbit, Orbit Inclination, Mission Duration	RADR-42	3.3.1	Heavy Ion and Proton testing			
MRD-12, MRD-13, MRD-21	3.1.1	Mission Orbit, Orbit Inclination, Mission Duration	RADR-43	3.3.1	SEE testing and analysis			
MRD-12, MRD-13, MRD-21	3.1.1	Mission Orbit, Orbit Inclination, Mission Duration	RADR-44	3.3.1	SEE nondestructive design margin			
MRD-12, MRD-13, MRD-21	3.1.1	Mission Orbit, Orbit Inclination, Mission Duration	RADR-45	3.3.1	Cosmic ray integral flux			
MRD-12, MRD-13, MRD-21	3.1.1	Mission Orbit, Orbit Inclination, Mission Duration	RADR-46	3.3.1	Solar particle integral flux			
MRD-12, MRD-13, MRD-21	3.1.1	Mission Orbit, Orbit Inclination, Mission Duration	RADR-47	3.3.1	Solar proton spectra			

Parent Requirement			Requirement			Child Requirement		
RQMT#	**Section#**	**Object Heading**	**RQMT#**	**Section#**	**Object Heading**	**RQMT#**	**Section#**	**Object Heading**
MRD-12, MRD-13, MRD-21	3.1.1	Mission Orbit, Orbit Inclination, Mission Duration	RADR-48	3.3.1	Improper operation			
MRD-12, MRD-13, MRD-21	3.1.1	Mission Orbit, Orbit Inclination, Mission Duration	RADR-49	3.3.1	Acceptable Levels			

NOTE: Each Requirement must have its own Object Heading.