

RATIONALE

This document defines the guidelines for minimum tasks and methods for piece part radiation hardness assurance for plastic encapsulated microcircuits and semiconductors suitable for potential use in many rugged, military, space, extreme, or other environments. These devices were categorized as commercial off the shelf devices (COTS), plastic encapsulated microcircuit/microelectronic (PEM) and/or plastic encapsulated discrete semiconductor (PEDS). Generally, plastic encapsulated devices lack RHA validation; and as such, this places the RHA performance requirement on the procuring activity. The end user assumes the responsibility for validation of vendor's RHA performance, including the lot traceability. This document provides the process flow for hardness and risk assessment toward meeting project requirements. This document will review radiation environmental constraints, mission specifications, and their anticipated impact on the microelectronic devices as provided in a project's bill of material (BOM). A part acceptance is considered on an individual basis when assessed to environmental constraints and mission specifications.

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1. SCOPE

This document is an annex to SAE Technical Report SSB-1 (the latest revision).

This document provides reference information and guidance concerning methods used by the semiconductor industry and original equipment manufacturers related to radiation hardness assessments. This document is broken into three primary sections. Section 3 discusses part characterization with focus on selection criteria and acceptance testing. Section 4 discusses design hardening for piece parts with focus on degraded design limits and radiation design margin. The last section, Section 5, of this report is on hardness assurance inspection and test. This section discusses total ionizing dose, displacement damage and single event effects testing in detail.

1.1 Radiation Hardness of EEE Parts

The radiation risk and hardness assurance assessment of the Electrical, Electronic, Electromechanical and Electro-optical (EEEE) parts used in military and aerospace applications is critical. As a minimum, the parts hardness assurance effort should include the following:

- a. Identify radiation sensitive parts in the bill of material (BOM) and, for these parts, research and obtain all available radiation reports, covering topics such as total ionizing dose (TID), single-event effects (SEE), and displacement damage (DD). For each of these reports, verify the validity of the report's test approach—namely, that the test approach used conforms to the best practices defined by the test standards governing the project and the test characteristics of these reports are applicable to the project's designs. From these reports, identify the thresholds and saturation limits for each radiation source test. For parts which do not have sufficient radiation information (or cases where no radiation test has occurred), identify the needed radiation tests for each part.
- b. Information obtained from radiation reports, where required by the project, should use a probability of success (Ps) and confidence level (C) approach (for example, use MIL-HDBK-814 for TID and DD using 99P/90C, and for SEE use confidence level error-bars (95%) as defined in J.R. Schwank, IEEE TNS, Vol. 60, p. 2101, June 2013). These adjusted degradation limits will be used as pass/fail criteria for acceptance of flight hardware during the radiation lot acceptance test (RLAT).
- c. Generation of SEE rates applicable to SEE sensitive parts should be done with actual test data. These rates are intended for box/system level SEE analyses to demonstrate compliance with allocated outage rates and system's availability/dependability requirements.
- d. Performance of Radiation Lot Acceptance Test (RLAT). This acceptance test applies to all wafer/diffusion lots intended for use in flight equipment, these RLAT tests can include TID, displacement damage, and SEE (see 3.4.1 for additional details).

1.1.1 Radiation Hardness Assurance (RHA) Methodology

The RHA methodology for implementation/execution of RHA tasks identifies a process flow and methodology for integration of the hardness assurance functions into design and manufacturing activities. Critical components of the RHA process flow include:

- a. Each project provides a unique radiation environment that applies to the applications. This environment includes heavy ion electron and proton fluxes and a total dose depth curve. These environments are used for analysis and project reporting.
- b. For each part, the radiation critical attributes pertaining to the circuit function are identified and an assessment method is established to ensure the part will meet the project minimum hardness level.
- c. For each part selected for radiation testing, an accepted methodology for radiation characterization testing is followed.
- d. The methodology for generation of radiation degradation limits should utilize a confidence level (C) and probability of success (Ps) approach.
- e. A standardized methodology for radiation lot acceptance test (RLAT) should be used. The methodology could follow those defined in the military standards document as a guide (for example MIL-PRF-38515 Appendix D).

- f. In this document the term wafer-lot is recognized; however, from an RHA perspective, the term RHA diffusion lot has higher precedence. Therefore, in this document the term wafer/diffusion lot will be used, and indicates the need for a homogeneous diffusion process for a group of wafers. It is the diffusion lot that controls the RHA response, where caution must be applied with respect to a wafer lot, which could have more than one diffusion process.
- g. Low dose rate testing of linear bipolar circuits and transistors is a strongly recommended best practice. Sufficient design margin is recommended should the part be low dose rate sensitive.
- h. For radiation testing of hybrids, follow MIL-PRF-38534 appendix G with a special note that working with the supplier to obtain the element evaluation report(s) is essential.
- i. Maintain a list of all radiation sensitive parts used in the system by generic part number and by the part number used for procurement. This list should also identify the source of supply, radiation test requirements, including RLAT, dose or exposure level, or special test requirement document that specifies each applicable radiation test requirement as well as pass/fail criteria.

1.1.2 Part Documentation

Parts and materials subject to hardness assurance process flow should include the following as a minimum.

- a. Radiation test methods used in part assessment
- b. Part drawings that call out sample size and sampling statistics used in lot acceptance
- c. Radiation type, source, and dose/exposure level
- d. End point test, pre- and post-radiation test requirements, and acceptance criteria
- e. Data reporting and analysis
- f. Special radiation tests such as electrical or radiation screening tests

Note, at the writing of this document, in general, there is no formal military performance specification for plastic encapsulated devices to become an SMD (standard microcircuit drawing) or slash sheet with an RHA rating. There may be rare cases in which a given manufacturer has used a die in an SMD with an RHA rating and offers that same die in a plastic package offering. In this case, the radiation response of the plastic package should not be assumed to be the same as the SMD RHA rated version, nor the overall radiation assessment of the product for other environments (SEE and DD). If that manufacturer has radiation test data on the plastic packaged device, then these data can be used for part documentation. If that manufacturer has radiation test data on the die used in plastic packaged device, then this data can be shown to the project for use approval.

1.1.3 Hardness Assurance Verification

The radiation assessment process flow should document that the radiation analyses ensure that under worst-case conditions, critical circuits or materials are capable of meeting the project RHA requirements.

1.1.4 Hardness Assurance Process

The hardness assurance process flow diagrams are shown in Figure 1 for total dose and Figure 2 for single-event effects. These processes begin during the preliminary design phase and iteratively compare known radiation performance of proposed design components against the allocated survivability requirements. The processes are intended to balance the requirements for component test against alternative part availability and system mitigation options, and to enable efficient arrival at a component list that meets performance and survivability requirements.

Figure 1 is applicable for cumulative radiation effects (such as TID and DD). The flow begins with the preferred part (from the bill of materials) and assesses any existing radiation data for the part. If the part meets the project radiation requirements, then it is approved for flight usage. If the part does not meet the radiation requirement, then the process allows four options. Option 1 is to radiation test the part and reassess the new radiation results to determine if the part meets radiation requirement to become approved; Option 2 is to select an alternate part and assess its radiation results to determine if the part meets the radiation requirement and can be approved (left side of the diagram). These two approaches rely on the radiation capabilities of the part. Options 3 and 4 rely on existing radiation data but invoke part derating (adding guardband) or system level mitigation approaches (power cycling, utilization factors, etc.) for part usage (right side of diagram). If after Option 3 and 4 the part is compliant to the systems requirements, then the part is approved. If the preferred part is unable to meet the requirement, the flow assumes an alternate part can be found.

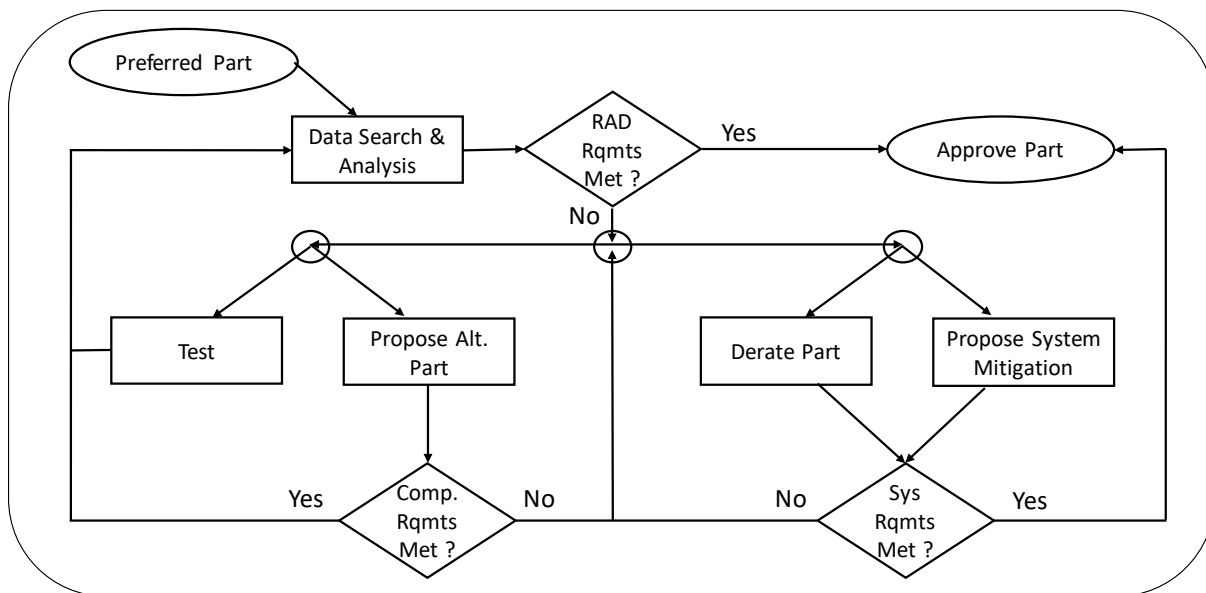


Figure 1 - Hardness assurance flow for total dose (ionizing and non-ionizing)

Figure 2 is applicable for both recoverable and destructive single-event radiation effects. The flow begins with the preferred part and assesses the radiation data for the part. If the part meets the project radiation requirements, then the part is considered an approved part. If the part does not meet the radiation requirement then the process has four options. Option 1 is to radiation test the part; Option 2 is to select an alternate part (left side of diagram). Option 2 relies on the radiation capability of the alternate part. Options 3 and 4 rely on existing radiation data but invoke changes in error-budget (increasing system level event rate limits) or circuit/system-level mitigation approaches (power cycling, utilization factors, derating, etc.) for part usage (right side of diagram). If after Option 3 or 4 the part meets the system requirements, then the systems error budget analysis is assessed; and if this is meet, then the part is compliant to the radiation requirements an is an approved part. If the preferred part is unable to meet the radiation requirement, the flow assumes an alternate part can be found. If an alternate part cannot be found a system-level, redesign or re-assessment should be exercised.

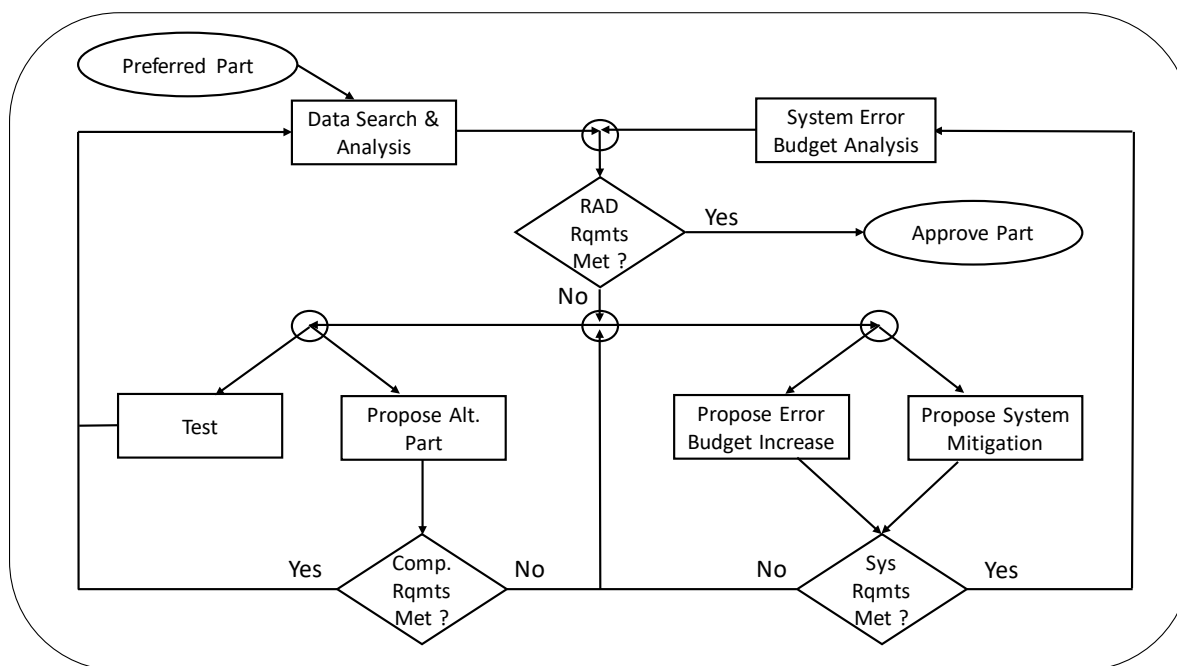


Figure 2 - Hardness assurance flow for single event effects

2. REFERENCES

2.1 Applicable Documents

The following publications form a part of this document to the extent specified herein. The latest issue of SAE publications shall apply. The applicable issue of other publications shall be the issue in effect on the date of the purchase order. In the event of conflict between the text of this document and references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

2.1.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or +1 724-776-4970 (outside USA), www.sae.org.

AS6294/1	Requirements for Plastic Encapsulated Microcircuits in Space Application
AS6294/2	Requirements for Plastic Encapsulated Microcircuits in Military and Avionics Application
AS6294/3	Requirements for Plastic Encapsulated Discrete Semiconductors in Space Application
AS6294/4	Requirements for Plastic Encapsulated Discrete Semiconductors in Military and Avionics Application

2.1.2 ASTM Publications

Available from ASTM International, 100 Barr Harbor Drive, P.O. Box C700, West Conshohocken, PA 19428-2959, Tel: 610-832-9585, www.astm.org.

ASTM F1032	Measuring Time-Dependent Total-Dose Effects in Semiconductor Devices Exposed to Pulsed Ionizing Radiation
ASTM F1192	Standard Guide for the Measurement of SEP Induced by Heavy Ion Irradiation of Semiconductor Devices

ASTM F1892 Standard Guide for Ionizing Radiation (Total Dose) Effects Testing of Semiconductor Devices

2.1.3 Other Publications

MIL-PRF-19500	Performance Specification, Semiconductor Devices, General Specification For
MIL-PRF-38535	Integrated Circuits (Microcircuits) Manufacturing, General Specification for
MIL-PRF-38534	Hybrid Microcircuits, General Specification for
MIL-HDBK-814	Ionizing Dose and Neutron Hardness Assurance Guidelines for Microcircuit and Semiconductor Devices
MIL-HDBK-815	Dose Rate Hardness Assurance Guidelines
JESD57	Test Procedures for the Measurement of Single Event Effects in Semiconductor Devices from Heavy Ion Irradiation
JESD234	Test Standard for the Measurement of Proton Radiation Single Event Effects in Electronic Devices
JEP133	Guide for the Production and Acquisition of Radiation-Hardness- Assured Multichip Modules and Hybrid Microcircuits
MIL-STD-883	Test Method Standard, Microcircuits; noting TM 1017 and TM 1019
MIL-STD-750	Test Method Standard, Test Methods for Semiconductor Devices; noting TM 1017, TM 1019 and TM 1080
ESCC22900	Total Dose Steady-State Irradiation Test Method
ESCC22500	Guidelines for Displacement Damage Irradiation Testing
ESCC25100	Single Event Effects Test Method and Guidelines
ESCC-Q-ST-60-15	Radiation hardness assurance – EEE components

3. PARTS CHARACTERIZATION

The objective of a hardness assurance part characterization process flow is two-phased. The first phase is the characterization and/or qualification phase, where the radiation hardness capability of the design is established. In the second phase, which is flight production phase, all flight parts will be drawn from lots that have successfully completed radiation lot acceptance testing.

Radiation assessment focuses on active integrated circuits (for example ICs, Hybrids) and on discrete semiconductor devices (for example transistors and diodes). Parts that do not receive radiation assessment (considered passives) include inductors, resistors, and capacitors as examples.

3.1 Part Selection Criteria.

Use of plastic encapsulated devices may imply the lack of an RHA validation; and as such, this places the RHA performance requirement on the procuring activity. The end user assumes the responsibility for validation of vendor's RHA performance, including the lot traceability. All flight lots will require radiation verification.

As a reference, the DLA Land and Maritime RHA designator levels are shown below.

Table 1 - RHA levels

RHA Level Designator	Total Ionizing Dose (TID) Level Rad (Si)
/ or -	No RHA
M	3×10^3
D	10×10^3
P	30×10^3
L	50×10^3
R	100×10^3
F	300×10^3
G	500×10^3
H	10^6

3.2 Radiation Sample Size

Radiation sample size is a function of die-traceability and the needed confidence level in the acquired radiation data to assure a rate/event prediction. The following are recommendations for sample sizes when radiation testing plastic encapsulated devices (and/or COTS) with variability in die traceability. If traceability to the wafer/diffusion lot is known, then the sample sizes can follow a minimum sample size for each radiation test. The use of an increased sample size is a function of part availability within the project provided samples.

a. Accumulative radiation defects, refer to MIL-PRF-38535, Table D-I (sampling plan).

1. Total Dose, both high dose rate (HDR) and low dose rate (LDR).

i. Refer to MIL-PRF-38535, Appendix C, Table C-I.

- A recommendation from Table D-I, using a percent defective allowable (PDA) of 10 (or a 90% confidence) with zero (0) consecutive fails (an acceptance number $C=0$) yields a 22-piece “passing” radiation hardness assurance (RHA) rating at a given TID level.
- For a higher confidence level, use a lower PDA value.

ii. For additional guidance refer to MIL-STD-883 Test Method 1019.

- Test Method 1019, also provides guidance on enhanced low dose rate sensitivity (ELDRS) testing.

iii. For additional guidance, refer to ESCC22900.

2. Displacement damage, refer to MIL-PRF-38535, Table D-I.

i. Displacement damage, Displacement Damage Dose and Neutron Fluence all refer to the same radiation test.

ii. Refer to MIL-STD-883 Test Method 1017 for more guidance.

iii. Refer to MIL-PRF-38535, Appendix C, Table C-I.

- A recommendation from Table D-I, using a PDA of 20 (or an 80% confidence) with zero (0) consecutive fails yields an 11-piece “passing” radiation hardness assurance (RHA) rating at a given neutron fluence (1 MeV equivalent) level.
- For a higher confidence level, use a lower PDA value.

iv. For additional guidance, refer to ESCC22500.