Radiation Hardness Assurance (RHA) Requirements for Sentinel 5 Precursor Project

EEE & opto-electronic devices

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Date: 22/11/11

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1. SCOPE OF THE DOCUMENT

The purpose of this document is to provide Space Radiation Hardness Assurance (RHA) Requirements to follow during any space program in order to prove that the system will continue to perform its function throughout program mission duration.

These RHA requirements apply to all space systems contractors and equipment providers. Specifically, this document

- Discuss methods to calculate the internal ionising and non ionising radiation environment and the resulting effects
- Provides EEE part test and analysis requirements to be used by suppliers to ensure completeness and consistency in reporting and analysing EEE part radiation response and qualification
- Provides system level verification reporting requirements that will allow equipment Total Ionising Dose (TID), Total Non Ionising Dose (TNID, also called “displacement damage”) and SEE rates to be folded into higher-level reliability calculations.

These RHA requirements specifically apply to EEE and opto-electronic devices used in space system and sub systems; for material aspects, RHA policy is placed under [AD 2] umbrella.
2. DOCUMENTATION & TERMINOLOGY

2.1 Reference Documents

The Reference Documents are not contractual but they may offer a better understanding of this document.

<table>
<thead>
<tr>
<th>Ref.</th>
<th>Document name</th>
<th>Document Ref.</th>
<th>Issue</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>RD 1</td>
<td>&quot;NOVICE, A radiation transport/shielding code&quot;, T.M. Jordan</td>
<td>E.M.P. Consultants report</td>
<td>N/A</td>
<td>January, 1960</td>
</tr>
<tr>
<td>RD 3</td>
<td>DOSRAD Software User’s Manual</td>
<td>MOS.UM.90969.ASTR</td>
<td>03</td>
<td>September, 2004</td>
</tr>
<tr>
<td>RD 4</td>
<td>&quot;Ionizing Dose and Neutrons Hardness Assurance guidelines for Semiconductor Devices and Microcircuits&quot;</td>
<td>MIL-HDBK-814</td>
<td>N/A</td>
<td>February, 1994</td>
</tr>
<tr>
<td>RD 5</td>
<td>&quot;IONIZING RADIATION (TOTAL DOSE) TEST PROCEDURE&quot;</td>
<td>MIL-STD-883G, METHOD 1019.7</td>
<td>N/A</td>
<td>February, 2006</td>
</tr>
<tr>
<td>RD 6</td>
<td>&quot;Total dose steady state irradiation test method&quot;</td>
<td>ESCC detail specification n°22900</td>
<td>2</td>
<td>August, 2003</td>
</tr>
<tr>
<td>RD 9</td>
<td>&quot;Reliability prediction of electronic equipment&quot;</td>
<td>MIL-HDBK-217</td>
<td>F</td>
<td>February, 1995</td>
</tr>
<tr>
<td>RD 10</td>
<td>&quot;Single Event Effects test method and guidelines&quot;</td>
<td>ESA SCC basic specification n°25100</td>
<td>1</td>
<td>October, 1995</td>
</tr>
<tr>
<td>RD 11</td>
<td>TEST PROCEDURE FOR THE MANAGEMENT OF SINGLE-EVENT EFFECTS IN SEMICONDUCTOR DEVICES FROM HEAVY ION IRRADIATION:</td>
<td>JEDEC standard JESD57</td>
<td>N/A</td>
<td>December, 1996</td>
</tr>
</tbody>
</table>

Table 1: Reference Documents
2.2 Applicable Documents

The Applicable Documents, applicable to the satellite, contain additional requirements to be used during product design, development, manufacturing, assembly, tests and delivery.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>AD 1</td>
<td>Space Environment Specification for S5p program</td>
<td>S5P.TN.ASU.SY.00007</td>
</tr>
<tr>
<td>AD 2</td>
<td>Generic Radiation Hardness Assurance (RHA) requirements for Materials used on space program</td>
<td>ADS-E-0848</td>
</tr>
</tbody>
</table>

Table 2: Applicable Documents
2.3 Terminology & abbreviations

Specific abbreviations used in the present document are given in the following table.

<table>
<thead>
<tr>
<th>Abbrev.</th>
<th>Meaning</th>
<th>Abbrev.</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>ADC</td>
<td>Analog to Digital Converter</td>
<td>CDR</td>
<td>Critical Design Review</td>
</tr>
<tr>
<td>DAC</td>
<td>Digital to Analog Converter</td>
<td>DC</td>
<td>Date Code</td>
</tr>
<tr>
<td>DCL</td>
<td>Declared Component List</td>
<td>DD</td>
<td>Displacement Damage</td>
</tr>
<tr>
<td>DDEF</td>
<td>Displacement Damage Equivalent Fluence</td>
<td>DDF</td>
<td>Displacement Damage Sensitivity Fluence</td>
</tr>
<tr>
<td>EDAC</td>
<td>Error Detection And Correction</td>
<td>EEE</td>
<td>Electrical, Electronic, Electromechanical</td>
</tr>
<tr>
<td>ELDRS</td>
<td>Enhanced Low Dose Rate Sensitivity</td>
<td>EQSR</td>
<td>Equipment Qualification Status Review</td>
</tr>
<tr>
<td>ERAD</td>
<td>Equipment Radiation analysis</td>
<td>ERCB</td>
<td>Equipment Radiation Control Board</td>
</tr>
<tr>
<td>ERDL</td>
<td>Effective Radiation Design Lifetime</td>
<td>ESRR</td>
<td>Equipment Supplier Radiation review</td>
</tr>
<tr>
<td>FM</td>
<td>Flight Model</td>
<td>FMECA</td>
<td>Failure Modes Effects and Criticality Analysis</td>
</tr>
<tr>
<td>GCR</td>
<td>Galactic Cosmic Rays</td>
<td>LDR</td>
<td>Low Dose Rate</td>
</tr>
<tr>
<td>LET</td>
<td>Linear Energy Transfer</td>
<td>MBU</td>
<td>Multiple Bit Upset</td>
</tr>
<tr>
<td>MOS</td>
<td>Metal Oxide Semiconductor</td>
<td>NIEL</td>
<td>Non Ionizing Energy Loss</td>
</tr>
<tr>
<td>PCB</td>
<td>Part Control Board</td>
<td>PDR</td>
<td>Preliminary Design Review</td>
</tr>
<tr>
<td>PLL</td>
<td>Phase-Locked Loop</td>
<td>PWM</td>
<td>Pulse Width Modulator</td>
</tr>
<tr>
<td>RADHARD</td>
<td>Radiation Hardened</td>
<td>RADLAT</td>
<td>Radiation Lot Acceptance Test</td>
</tr>
<tr>
<td>RFD</td>
<td>Request For Deviation</td>
<td>RFW</td>
<td>Request For Waiver</td>
</tr>
<tr>
<td>RHA</td>
<td>Radiation Hardness Assurance</td>
<td>RVT</td>
<td>Radiation Verification Testing</td>
</tr>
<tr>
<td>SEB</td>
<td>Single Event Burn-out</td>
<td>SED</td>
<td>Single Event Disturb</td>
</tr>
<tr>
<td>SEDR</td>
<td>Single Event Dielectric Rupture</td>
<td>SEE</td>
<td>Single Event Effect</td>
</tr>
<tr>
<td>SEFI</td>
<td>Single Event Functional Interrupt</td>
<td>SEGR</td>
<td>Single Event Gate Rupture</td>
</tr>
<tr>
<td>SEL</td>
<td>Single Event Latch-up</td>
<td>SESB</td>
<td>Single Event Snap Back</td>
</tr>
<tr>
<td>SET</td>
<td>Single Event Transient</td>
<td>SEU</td>
<td>Single Event Upset</td>
</tr>
<tr>
<td>SHE</td>
<td>Single Hard Error</td>
<td>SOI</td>
<td>Silicon On Insulator</td>
</tr>
<tr>
<td>TID</td>
<td>Total Ionizing Dose</td>
<td>TIDL</td>
<td>Total Ionizing Dose Level</td>
</tr>
<tr>
<td>TIDS</td>
<td>Total Ionizing Dose Sensitivity</td>
<td>TNID</td>
<td>Total Non Ionizing Dose</td>
</tr>
<tr>
<td>TNIDL</td>
<td>Total Non Ionizing Dose Level</td>
<td>TNIIDS</td>
<td>Total Non Ionizing Dose Sensitivity</td>
</tr>
<tr>
<td>WC</td>
<td>Worst Case</td>
<td>WCA</td>
<td>Worst Case Analysis</td>
</tr>
</tbody>
</table>

Table 3: Abbreviation Tables
3. INTRODUCTION

The Space radiation environment can lead to extremely harsh operating conditions for the electronic on-board equipment’s and systems. Radiation accelerates the aging of the EEE parts and material (long term effects: Total Ionising and Non Ionising Dose) and can lead to a degradation of electrical performances; it can also create transient phenomena on EEE parts (Single Event Effects (SEE)). Such damage at electronic part level can in turn induce damage or functional failure at equipment and system levels.

**Total Ionizing Dose (TID)** is due to energetic light particles such as electrons, photons and protons impinging on material, where they generate electron/hole pairs. Some fraction of these pairs will recombine, but a fraction will remain trapped as charges in parts layers. These charges are likely to cause progressive TID damage. Degradation leads to irreversible parametric drifts and eventually functional failures at device level. The component drift must then be considered in the equipment Worst-Case Analyses (WCA) with drifts due to displacement damage, aging and other effects.

In addition to ionisation effects, Space particles (protons and electrons) can also deposit **Total Non-Ionising Dose (TNID)** and cause **Displacement Damage (DD)** in Silicon and other semiconductor material. As an energetic particle collides with an atom, the atom can be knocked free from its lattice site to an interstitial site and leaves behind a vacancy. If the displaced atom has sufficient energy, it can in turn displace other atoms. Displacement Damage leads to irreversible parametric drifts and eventually functional failures at component level. The component drift must be considered in the equipment WCA, with drifts due to TID, ageing and other relevant effects.

**Single Event Effects (SEE)** are due to very energetic heavy ions (Galactic Cosmic Rays and solar flares) and protons (Van Allen trapped protons belt and solar flares) generating very dense electron-hole plasmas when crossing semiconductors devices. The induced micro current spike can trigger internal parasitic structures and cause destructive and/or non destructive events. Unlike TID effect, which is progressive and cause general damage, SEE are instantaneous, generally non cumulative, cause localized damage and may be reversible (example: SEU) or irreversible (example: SEL).
4. OVERVIEW OF RADIATION ASSURANCE PROCESS

This section describes the major tasks involved in Radiation Spacecraft design (see Figure 1). This is the flow to be followed.

```
Figure 1: Overview of the radiation process
```

REQ GEN1: in case of non-compliance to any of the requirements presented in this specification, a Request For Deviation (RFD) or a Request For Waiver (RFW) shall be issued towards EADS ASTRIUM project team; in this document, equipment supplier shall provide with all necessary information required for part acceptance status.
5. RADIATION ENVIRONMENT
The radiation environment specifically applicable to the S5P program is defined in [AD 1].

6. TOTAL IONIZING DOSE EVALUATION AND HARDNESS ASSURANCE

6.1 TID Level (TIDL) calculation
TID to be received at die level (Total Ionising Dose level: TIDL) shall be calculated for active parts, taking into account spacecraft, equipment and part shielding.

Total dose simulations can be performed either using 3D sector based codes or 3D Monte Carlo transport codes. Sector based analysis codes to be used are NOVICE/SIGMA [RD 1], FASTRAD [RD 2] or SYSTEMA/DOSRAD [RD 3]. Monte Carlo Code to be used is NOVICE/ADJOINT [RD 1] or GEANT4 [RD 12]. Other codes shall be agreed by project before use.

**REQ TID01:** TIDL shall be calculated for all active parts, using either Ray Tracing or 3D Monte Carlo technique, taking into account spacecraft, equipment and part shielding.

**REQ TID02:** The user shall identify the calculation tool, nature and method (including calculation parameters) used for these TID calculations as well as spacecraft shielding hypothesis, if any.

6.1.1 Sector based/ray tracing analysis
In order to carry out sector based analysis, particle fluxes are converted into Total Ionising Dose-Depth Curve. TID depth curve gives the received TID D(r) inside a specific normalized shielding geometry, for a range of shielding thickness r, for a given radiation environment. The so-called "solid sphere" and "shell sphere" (cf Figure 2) TID depth curves specifically applicable to concerned program are defined in the program radiation environment specification [AD 1].

![Solid aluminium sphere of radius r and center O](image1)

![Shell aluminium sphere of radius R, thickness r and center O](image2)

*Figure 2a: Solid sphere 1-D shielding model. Figure 2b: Shell sphere 1-D shielding model (Y,Z plan).*
Shielding sphere material usually is made of Aluminium while detector is in Silicon. If necessary, TID depth curves can be provided for other target and/or shielding materials.

Sector based analysis is performed using a numerical solid angle integration around a target point. For each solid angle sector, a ray is traced from the target to the outside of the geometry model. The total mass thickness encountered by the ray is then used to determine the corresponding TID level by reference to the dose-depth curve. Techniques are developed to determine the thickness (t) crossed by a ray for an elemental sector: the NORM and the SLANT technique described in Figure 3.

**Figure 3:** So called NORM and SLANT techniques for sector based analysis.

**REQ TID03:** SLANT technique shall only be used in conjunction with the solid sphere TID depth curve while NORM technique shall be used together with the shell sphere TID depth curve.

**REQ TID04:** Sector based analysis calculation shall be implemented as follows:

1/ calculating the dose at the centre (called the detector in the following) of a sphere: The $4\pi$ spherical surface surrounding the detector shall then be sectored into N elementary solid angles, considering that:

- The total number of elementary solid angles shall be greater than 2000 sectors; they shall be equally distributed over the full space solid angle ($4\pi$ steradian).

Or,

2/ calculating the dose at the centre (called the detector in the following) of a parallelepiped: Ray tracing calculations shall then follow the procedure described here under:

- Each face is meshed $N_1 \times N_2$ ($20 \leq N_i$),

- $M$ rays ($M \geq 20$) are launched from the detector within each mesh.

### 3D Monte Carlo analysis

The 3D Monte Carlo analysis method can be used in order to get the best estimate of the deposited dose.

**REQ TID05:** If the NOVICE (ADJOINT) code is used, histories number shall be > 2000 and TIDL results should have an uncertainty less than 10%.

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6.2 Component type TID Sensitivity (TIDS) determination

Device selection relies on the comparison between component type TID Sensitivity (TIDS) and associated Total Ionising Dose level (TIDL) to be received within the equipment. Then, TIDS determination is required for all active EEE parts types.

**REQ TID06:** Component type TIDS is defined and referred as such in the radiation analysis according to the comparison of its parametric and functional performance obtained during TID ground testing with:

- The parametric & functional type limits given in detail specification if any or manufacturer data book, or,
- The maximum limits acceptable (Design Dose) so that equipment will operate according to specification over Effective Radiation Design Lifetime (ERDL). Design Dose determination shall be provided to EADS ASTRIUM through referenced WCA document.

Component type TIDS shall then be defined as:

1/ "statistical" approach (preferred approach, after [RD 4]):

"KTL factor" approach: total dose level corresponding to worst case delta parametric shift, after radiation exposure, with the KTL factor applied to it, added to the parametric and functional type limit. KTL factor are associated with a probability P of 0.9 and a confidence level (CL) of 0.9 (90% of parts from a given lot have a failure level above the type TIDS, with a confidence level of 90%).

- \( \Delta X_L = \langle \delta x \rangle + K_{TL}(n,CL,P) \sigma \) For increasing total dose shift
- \( \Delta X_L = \langle \delta x \rangle - K_{TL}(n,CL,P) \sigma \) For decreasing total dose shift

\( \sigma \) is the standard deviation, measured from the n tested samples, according to the following formulae:

\[
\sigma^2 := \frac{1}{n-1} \sum_{i=1}^{n} (x_i - m)^2
\]

Where the xi’s are the different values measured from the sample of size n.

With this fixed parameters, the table below gives the KTL coefficients to apply as a function of the sample size "n". This applies when the n samples are in the same electrical configuration.

<table>
<thead>
<tr>
<th>n</th>
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<tr>
<td>3</td>
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<tr>
<td>4</td>
<td>3.188</td>
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<td>5</td>
<td>2.742</td>
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<tr>
<td>6</td>
<td>2.493</td>
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<td>8</td>
<td>2.218</td>
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<tr>
<td>9</td>
<td>2.133</td>
</tr>
<tr>
<td>10</td>
<td>2.065</td>
</tr>
</tbody>
</table>

**KTL Table:** One sided tolerance limits KTL for CL = 0.9 and P = 0.9

2/ "worst case" approach: total dose level at which the worst case part of the worst case lot exceeds its limits, as defined here above, with a minimum sampling size of 10 devices per lot,
REQ TID07: TIDS shall be defined for all active EEE parts types used within the system/sub-system under analysis.

Note 1: TIDS of devices can be different depending on their biasing state (biased or unbiased). Therefore, as soon as a device spends a significant portion of the mission time (>10%) in a different biasing state than the rest of the mission, analysis has to be performed with the worst biasing state or both have to be analyzed. In this latter case, adequate sampling size shall be considered for both biasing states (biased and unbiased).

Note 2: a “part” is defined as being a single die (“quad” devices are not considered as 4 samples).

6.3 Devices selection towards TID: categorization methodology

Chapter 6.3.1 presents the acceptable methodology for TIDS determination, based on TID ground testing data acquisition.

§6.3.2 presents the methodology to be followed for TID ground testing.

Chapter 6.3.3 details the acceptance rules for using TID test reports as a reference for TIDS determination.

6.3.1 Categorization process

REQ TID08: All active part types shall be categorized as follows:

**Group 1:** \(2 \times \text{(received TIDL)} < \text{Component type TIDS}\)

=> No generic requirements. FM lot is accepted as is.

**Group 2:** \(1.2 \times \text{(received TIDL)} < \text{Component type TIDS} < 2 \times \text{(received TIDL)}\)

=> RADiation Lot Acceptance Testing, RADLAT (also called Radiation Verification Testing, RVT). If FM lot TIDS is larger than 1.2 times (received TIDL), the FM lot is accepted.

**Group 3:** \(\text{Component type TIDS} < 1.2 \times \text{(received TIDL)}\)

=> Part not acceptable as is. Shielding of parts, replacement, or any other solutions shall be found in order to transfer part from group 3 to group 1 or 2.

As far as possible, Group 1 component types shall be preferred in order to limit the number of potential lot testing and analysis. If a device is in Group 2 it may be accepted but will require an RFD to justify its use.
6.3.2 Applicable methodology for TID ground testing

**REQ TID09:** for TIDS determination or validation on a specific part type, TID testing method shall comply with the following rules (listed 1 to 5):

1- Test performed in accordance with European ESA/SCC22900 [RD 6] or US MIL-STD 883D 1019.7 [RD 5] total dose test procedures, with a recommended sample size as defined in REQ TID06.

2- High dose rate can be used for MOS technologies (except when "rebound" phenomena is observed, see REQ TID13) but not for bipolar and BiCMOS technologies (including discrete transistors). For these latter technologies, requirement is to use dose rate specified in the ESA/SCC22900 low dose rate window (36 to 360 rad(Si)/h).

3- For traceability purpose, test devices (including reference sample) shall be unambiguously identified: the following information is required: part number, electrical function, manufacturer, Date Code, diffusion lot, wafer plant, device technology, quality level, procurement specification.

In the following, distinction has been made, when necessary, between TIDS component type determination (so-called "evaluation") and validation (lot acceptance testing).

4- **Input:** typical conditions of use for application, with identification of critical electrical parameters for the application [evaluation]; dose evaluation data [lot acceptance testing].

5- **Task:**

   - Irradiation testing according to test plan up to part type functional failure or:
     - i/ up to at least 2 time the dose level of application (TIDL) [evaluation],
     - ii/ up to at least 1.2 time the dose level of application (TIDL) [lot acceptance testing].

   - Irradiation performed under the application or worst-case bias (test plan needs design authority validation), temperature and frequency,

   - For MOS only, dose rate below 36 krad(Si)/h and post-irradiation annealing (100°C, 168 hours).

   - Characterization of functionality and:
     - i/ all relevant electrical parameter specified in device specification [evaluation].
     - ii/ all electrical parameter critical for concerned application [lot acceptance testing].

6- **Output:** determination of parametric and functional Total Ionising Dose Sensitivity.

*Note: it is recommended to include a picture of the die within the test report, for traceability purpose.*
6.3.3  Acceptance criteria for use of previous TID test reports

REQ TID10: for TIDS estimates on a specific part type, used TID test report shall comply with the following rules:

- Test performed in accordance with European ESA/SCC22900 [RD 6] or US MIL-STD 883D 1019.7 [RD 5] total dose test procedures, with dose rate included in ESA/SCC22900 low dose rate window for devices (including discrete transistors) using bipolar or BiCMOS technology (36 to 360 rad(Si)/h)

and,

- Provided the tested parts are manufactured with technology similar (subcontractor to provide EADS ASTRUM project team with evidence of similarity for approval) to the technology to be used for FM parts (except if technology changes are proven not to alter dose hardness), parts tested date code
  
  i/ within 4 years compared to FM parts Date Code (DC), or,

  ii/ tested parts from the same diffusion lot as the FM parts, whatever date code,

and,

- Test biasing conditions worst or equivalent to the application (needs design authority validation).

and,

- No rebound effect observed during testing (see REQ TID13)

REQ TID11: If no existing acceptable data allows the determination of component type TIDS, TID evaluation of considered type has to be performed following methodology described in §6.3.2 .

6.3.4  Specific cases regarding TID part selection

Some device technologies are inherently robust to Total Ionizing Dose effects. The classes of parts presented in Table 4 are considered as total dose insensitive up to a TIDL of 300 krads(Si):

<table>
<thead>
<tr>
<th>Non Zener Diodes</th>
<th>Not sensitive up to 300 Krad(Si)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GaAs</td>
<td>Gallium Arsenide devices such as FETs and HEMTs show little parametric variation.</td>
</tr>
<tr>
<td>Std TTL Logic</td>
<td>Extensive testing on 54XX, 54L, 54S devices show these parts to be only marginally degraded</td>
</tr>
<tr>
<td>ECL</td>
<td>Emitter Coupled Logic devices exhibit little parametric shift out to several Mrad(Si)</td>
</tr>
<tr>
<td>Microwave Devices</td>
<td>Step Recovery, Varactor, Schottky, Microwave Mixer and Multiplier Diodes exhibit negligible shifts</td>
</tr>
</tbody>
</table>

Table 4: device families hard to TIDL up to 300 krads(Si)
REQ TID12: if calculated TIDL exceeds 300 krad(Si), TID analysis shall be performed as presented in the previous chapter for other "sensitive" devices.

NMOS transistors are subject to a long-term mechanism known as "rebound effect": if an irradiated device is kept under bias at an elevated temperature for several hours (after irradiation), the threshold voltage is observed to return or exceed its original value. As a result, behaviour of such devices at space dose rate is very difficult to determine.

REQ TID13: because heavy shielding and/or Extremely Low Dose Rate testing will be required, devices exhibiting a "rebound effect" shall be avoided. In any case, when such behaviour has been identified, radiation data shall be provided to EADS ASTRIUM project team for review and approval prior use.

7. TOTAL NON IONIZING DOSE (TNID) – DISPLACEMENT DAMAGE (DD) EVALUATION AND HARDNESS ASSURANCE

7.1 TNID Level (TNIDL) - Displacement Damage Equivalent Fluence (DDEF) calculation

Both protons and electrons can deposit Total Non Ionising Dose (TNID) that may induce displacement damage in semiconductor devices. The part of deposited energy involved in displacement defects creation is called Non Ionising Energy Loss (NIEL). The TNID deposited by the particle flux spectrum may be converted into a fluence of mono-energetic particles (Displacement Damage Equivalent Fluence, DDEF) producing the same amount of defects (typically 1 MeV neutrons or 10 MeV protons). This correlation between different particles with different energies is based on the energetic dependency of the NIEL for the considered particles and materials.

The 3D Monte Carlo analysis method is the preferred method to be used in order to get the best estimate of the equivalent proton fluence value at part level. Output of 3D Monte Carlo calculation will be a Total Non Ionising Dose Level (TNIDL); X MeV equivalent proton fluence will then be obtained in dividing the TNIDL by the NIEL value at the concerned proton energy.

REQ TNID01: X MeV equivalent proton fluence (Displacement Damage Equivalent Fluence : DDEF) to be received at die level shall be calculated for all opto-electronic parts, and any EEE bipolar based device receiving more than 100 krad(Si) taking into account spacecraft, equipment and part shielding.

REQ TNID02: If the NOVICE (ADJOINT) code is used, histories number shall be > 2000 and TNIDL results should have an uncertainty less than 10%.

REQ TNID03: In case the equipment provider decides to use NIEL tables other than the ones provided in annex (§10. ), they shall be submitted to EADS ASTRIUM project review and approval prior use.
In case equipment provider does not dispose of 3D Monte Carlo tool, an approximate calculation methodology may be followed:

- To first determine the TIDL at part level as required in §6.1.
- To deduce from applicable TID depth curve [AD 1] the equivalent Al shielding corresponding to this TIDL. Dose-depth curve used for equivalent shielding determination should be of the same nature than the one used for TIDL calculation at part level: for example, if shell sphere has been used (in conjunction with NORM method) for total dose calculation, shell sphere dose-depth curve should also be used for equivalent shielding determination.
- To determine from the TNID-depth curve the TNIDL that corresponds to this shielding.
- To deduce the associated DDEF from TNID curve provided in [AD 1] by of the use of applicable NIEL tables (see annex (§10.)), may also be provided in [AD 1]).

**REQ TNID04:** Approximate method results shall be detailed and submitted to EADS ASTRIUM project team for review and approval.

### 7.2 Component type TNID Sensitivity (TNIDS)/Displacement Damage Sensitivity Fluence (DDSF) determination

Most of the time, devices sensitive to displacement damage are also sensitive to ionising dose. Then, displacement damage/TNID hardness assurance should first consider the TID tolerance of the device in order to evaluate its overall radiation degradation.

The methodology to implement for TNIDS/DDSF determination must be selected as a function of the degradation observed on the electrical parameter:

- First case: if the degradation must be considered in terms of relative degradation compared with the initial value (for example CTR on optocoupler), the “Methodology A” must be applied
- Second case: if the degradation is not dependant of the initial value, the “Methodology B” must be applied.

1. To determine TID induced degradation (if any) of the relevant parameter P(TID) at TIDL calculated for 2 x ERDL if no RADLAT (RVT) is available, at 1.2 x ERDL if a RADLAT is available.

The TID induced degradation of the parameter P(TID) shall be expressed as:

<table>
<thead>
<tr>
<th>Methodology A</th>
<th>P(TIDL) = K_{TID} \times P_0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Methodology B</td>
<td>DeltaP(TIDL)</td>
</tr>
</tbody>
</table>

P(TIDL) is the parameter value when exposed at a given TIDL.
KTID is the TID degradation factor, extracted from TID ground testing; 0 < KTID < 1

P₀ is the value of P prior irradiation.

2. To determine TNID induced degradation (if any) of the relevant parameter P(TNID) at the desired TNIDL/DDEF:

The TNID induced degradation of the parameter P(TNID) shall be expressed as:

<table>
<thead>
<tr>
<th>Methodology A</th>
<th>P(TNIDL) = KTNID x P₀</th>
</tr>
</thead>
<tbody>
<tr>
<td>Methodology B</td>
<td>ΔP(TNIDL)</td>
</tr>
</tbody>
</table>

P(TNIDL) is the parameter value when exposed at a given TNIDL.

KTNID is the TNID degradation factor, extracted from TNID ground testing; 0 < KTNID < 1

P₀ is the value of P prior irradiation.

3. To determine component type TNIDS or DDSF according to the comparison of its parametric performance P(RAD) obtained during TNID AND TID ground testing with:

- The parametric & functional type limits determined by detail specification (or manufacturer data book), or,
- The maximum limits acceptable so that equipment will operate according to specification over Effective Radiation Design Lifetime (ERDL).

The parameter P(RAD) shall be expressed as:

<table>
<thead>
<tr>
<th>Methodology A</th>
<th>P(RAD) = KTNID x KTID x P₀</th>
</tr>
</thead>
<tbody>
<tr>
<td>Methodology B</td>
<td>ΔP(RAD) = ΔP(TIDL) + ΔP(TNIDL)</td>
</tr>
</tbody>
</table>

KTNID is the TNID degradation factor extracted from TNID ground testing; 0 < KTNID < 1

KTID is the TID degradation factor as calculated previously; 0 < KTID < 1

P₀ is the value of P prior irradiation.

Component type TNIDS or DDSF shall then be defined as:

1/ "statistical" approach:

"KTL factor" approach: total dose level corresponding to worst case delta parametric shift, after radiation exposure, with the KTL factor applied to it, added to the parametric and functional type limit. KTL factor are associated with a probability P of 0.9 and a confidence level (CL) of 0.9 (90% of parts from a given lot have a failure level above the type TIDS, with a confidence level of 90%).

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\[- \Delta XL = <\delta x> + KTL(n,CL,P) \sigma \text{ For increasing total dose shift}\]
\[- \Delta XL = <\delta x> - KTL(n,CL,P) \sigma \text{ For decreasing total dose shift.}\]

With this fixed parameters, see KTL Table coefficients (in REQ TID06) to apply as a function of the sample size "n".

2/ "worst case" approach : TNID level or DDEF at which P(RAD) of the worst case part of the worst case lot exceeds its limits, as defined here above, with a minimum sampling size of 10 devices.

**REQ TNID05:** TNIDS and/or DDSF shall be defined for all part types sensitive to DD used within the system/sub-system under analysis as detailed in the present chapter.

**Note 1:** TNIDS of devices can be different depending on their biasing state (biased or unbiased). Therefore, as soon as a device spends a significant portion of the mission time (>10\%) in a different biasing state than the rest of the mission, analysis has to be performed with the worst biasing state, or both have to be analyzed. In this latter case, adequate sampling size shall be considered for both biasing states (biased and unbiased).

**Note 2:** a “part” is defined as being a single die (“quad” devices are not considered as 4 samples).

### 7.3 Devices selection towards TNID/Displacement Damage

#### 7.3.1 Categorization methodology

Once TNIDL/DDEF and TNIDS/DDSF validity has been established according to § 7.1 and § 7.2, all opto-electronic parts, and any EEE bipolar based device receiving more than 100 krad(Si) taking into account spacecraft, equipment and part shielding, shall be categorized as follows:

**REQ TNID06:** all parts sensitive to DD shall be categorized as follows:

**Group 1:** \[2 \times (\text{received \ DDEF}) < \text{component type DDFS}\]

\[\Rightarrow \text{No generic requirements. FM lot is accepted as is.}\]

**Group 2:** \[1.2 \times (\text{received \ DDEF}) < \text{component type DDFS} < 2 \times (\text{received \ DDEF})\]

\[\Rightarrow \text{Proton RADLAT (proton RVT) as per §7.3.2. If FM lot parametric and functional hardness fluence level is larger than 1.2 times the DDFS level, the FM lot is accepted.}\]

**Group 3:** \[\text{component type DDFS} < 1.2 \times (\text{received \ DDEF})\]

\[\Rightarrow \text{Part not acceptable as is.}\]

Shielding of parts, replacement, or any other solutions shall be found in order to transfer part from group 3 to group 1 or 2.

As far as possible, Group 1 component types shall be preferred in order to limit the number of potential lot testing and analysis. If a device is in Group 2 it may be accepted but will require an RFD to justify its use.
7.3.2 Applicable methodology for TNID/Displacement damage ground testing

TNID testing is generally performed by the means of proton (or neutron) irradiations: the devices are exposed to protons (or neutrons) of one or several energies (protons and neutrons accelerators are mono-energetic) up to a selected fluence level. Since recent studies [RD 7] demonstrate that equivalence between radiation damage (displacement and total dose) initiated by (neutron + dose) and proton testing is not yet evidenced for all types of displacement damage sensitive devices, proton testing is recommended as a baseline for radiation characterization of such devices.

However, up to now, no standard testing procedures exists concerning protons irradiation. Such an irradiation will be accepted when subcontractor establishes that test result (and especially the overall test accuracy) will provide the information required for part acceptance status.

REQ TNID07: for TNIDS/DDSF determination or validation on a specific part type, TNID testing method shall comply with the following rules (listed 1 to 3):

1- Input: typical conditions of use for application, with identification of critical electrical parameters for the application [evaluation]; displacement damage evaluation data [lot acceptance testing].

2- Task:
   - Irradiation of a number of samples as defined in § 6.2 and according to test plan up to part type functional failure or:
     i/ up to 2 time the fluence level of application [evaluation]
     ii/ up to at least 1.2 time the fluence level of application [lot acceptance testing].
   - Characterization of functionality and:
     i/ all relevant electrical parameters specified [evaluation].
     ii/ all electrical parameters critical for concerned application [lot acceptance testing].

3- Output: determination of parametric and functional TNIDS/DDSF of irradiated device type.
7.3.3 Acceptance criteria for use of previous test reports

**REQ TNID08:** For TNIDS/DDSF estimates on a specific part type, the used TNID test report shall comply with the following rules:

- Displacement damage can be investigated by the mean of proton or neutron irradiation. However, up to now, no standard testing procedures exist. Such an irradiation will be accepted when subcontractor establishes that test result (and especially the overall test accuracy) will provide the information required for part acceptance status.

and,

- Provided the tested parts are manufactured with technology similar (subcontractor to provide EADS ASTRIUM project team with evidence of similarity for approval) to the technology to be used for FM parts (except if technology changes are proven not to alter displacement damage hardness), the parts tested date code:
  1. within 4 years compared to FM parts Date Code (DC), or,
  2. tested parts from the same diffusion lot as FM parts, whatever date code,

and,

- Test biasing conditions worst or equivalent to the application.

If no acceptable data allows determining component type TNIDS/DDSF, displacement damage evaluation of considered type has to be performed following methodology described in §7.3.2.
8. SINGLE EVENT PHENOMENA (SEP) HARDNESS ASSURANCE

Cosmic rays and solar flares (ions and protons) can induce various Single Event Phenomena (SEP, also called Single Event Effects (SEE)); they are caused by the energy deposited by the particle as it interacts with the sensitive portions of an electrical device. They can be destructive or non-destructive. The following tables, extracted from [RD 8] provides a non exhaustive list of these effects:

<table>
<thead>
<tr>
<th>SEE type</th>
<th>Impact</th>
<th>Affected devices &amp; technologies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Latchup - SEL</td>
<td>High-current conditions</td>
<td>CMOS, biCMOS devices</td>
</tr>
<tr>
<td>Snapback - SESB</td>
<td>High-current conditions</td>
<td>N-channel MOSFET, SOI devices</td>
</tr>
<tr>
<td>Burnout - SEB</td>
<td>Destructive burnout</td>
<td>BJT, Power MOSFET, MESFET</td>
</tr>
<tr>
<td>Gate Rupture - SEGR</td>
<td>Rupture of gate dielectric</td>
<td>Power MOSFETs</td>
</tr>
<tr>
<td>Dielectric Rupture - SEDR</td>
<td>Rupture of dielectric</td>
<td>Non-volatile NMOS struct., FPGA, linear devices...</td>
</tr>
</tbody>
</table>

Table 5: destructive Single Event Effects

<table>
<thead>
<tr>
<th>SEE type</th>
<th>Impact</th>
<th>Affected devices &amp; technologies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upset - SEU</td>
<td>Corruption of the information stored in a memory element</td>
<td>Memories, latches in logic devices</td>
</tr>
<tr>
<td>Multiple Bit Upset - MBU</td>
<td>Several memory elements corrupted by a single strike</td>
<td>Memories, latches in logic devices</td>
</tr>
<tr>
<td>Functional Interrupt -SEFI</td>
<td>Loss of normal operation</td>
<td>Complex devices with built-in state/control sections</td>
</tr>
<tr>
<td>Transient - SET</td>
<td>Impulse response of certain amplitude and duration</td>
<td>Analog and Mixed Signal circuits, Photonics</td>
</tr>
<tr>
<td>Disturb - SED</td>
<td>Momentary corruption of the information stored in a bit</td>
<td>Combinational logic, latches in logic devices</td>
</tr>
<tr>
<td>Single Hard Error – SHE(*)</td>
<td>Unalterable change of state in a memory element</td>
<td>Memories, latches in logic devices</td>
</tr>
</tbody>
</table>

(*) Not destructive effect for the device, but permanent damage for the memory cell.

Table 6: non destructive Single Event Effects

8.1 SEP categorization

In the following, \( \text{LET}_{\text{th}}(\text{SEP}) \) means "threshold LET" for a specific kind of SEP: as an example, \( \text{LET}_{\text{th}}(\text{SEL}) \) is the LET threshold for Single Event Latch-up. \( \text{LET}_{\text{th}}(\text{SEP}) \) will preferentially be determined thanks to Weibull fitting function. Any other definition has to be submitted to EADS ASTRIUM project approval prior use.
**REQ SEP01:** All silicon based EEE parts shall be put in one of the following group of SEP sensitivity:

<table>
<thead>
<tr>
<th>Group</th>
<th>LET_{th}(SEP)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>A</strong></td>
<td>&gt; 60 MeV.cm^{2}/mg</td>
</tr>
<tr>
<td><strong>B</strong></td>
<td>60 MeV.cm^{2}/mg &gt; LET_{th}(SEP) &gt; 15 MeV.cm^{2}/mg</td>
</tr>
<tr>
<td><strong>C</strong></td>
<td>15 MeV.cm^{2}/mg &gt; LET_{th}(SEP)</td>
</tr>
</tbody>
</table>

The component type is considered as not sensitive to the specific SEP. Event rate can be neglected.

=> no further actions, device is accepted "as is".

**Group B**

- The component type is sensitive to Heavy ion induced SEP but not sensitive to proton induced SEP.
  - Heavy ion induced SEP rate shall be calculated following method A (§8.2, Applicable prediction techniques).
  - Part types shall be acceptable according to acceptance criteria for SEP (§8.3). If this is not the case, part replacement or implementation of proper countermeasure is required: error correction, design hardening, any solution at equipment or system level lowering the maximum error rate acceptable so that part type will be acceptable.

**Group C**

- The component type is expected to be sensitive to Heavy ion and Proton induced SEP.
  - Calculation of heavy ion induced SEP rate shall follow Method A while proton contribution shall follow method B (§8.2, Applicable prediction techniques).
  - Part types shall be acceptable according to acceptance criteria for SEP (§8.3). If this is not the case, part replacement or implementation of proper countermeasure is required: error correction, design hardening, any solution at equipment or system level lowering the maximum error rate so that part type will be acceptable.

*Note:* the LET value of 60 MeV.cm^{2}/mg shall be obtained with normal incidence beam and minimum ion penetration depth of >> device sensitive depth, this latter being defined according to device technology and SEP nature.

Non silicon based parts (e.g. GaAs parts) shall be treated separately since key LET values for classification between groups A, B and C depends on the EEE part material. Such kind of part should follow similar criteria with relevant key LET values delivered when necessary by the project upon request.

### 8.2 Applicable SEE rate prediction techniques

**REQ SEP02:** SEE rate predictions shall follow method A for heavy ion calculation and method B for proton calculation.
Method A: Applicable for Heavy Ion induced SEP rate prediction

*Input:*

1/ Cross section experimental curve giving at least LET threshold and saturation cross-section, and Weibull parameter if known.
2/ LET Spectra for cosmic rays and heavy ions solar flare as given in radiation environment specification [AD 1].
3/ Estimate of device sensitive volume

*Task:* Use integrative method for calculation of error rate, taking into account the whole cross section curve.

*Output:* Heavy Ion contribution to error rate.

Method B: Applicable for Proton induced SEP rate prediction.

*Input:*

1/ Cross-section experimental curve giving saturation cross-section and 2 others cross section/energy point in the proton energy at minimum ranging from 30 to 200 MeV
2/ Integral energy spectra for trapped and solar flare protons as given in radiation environment specification [AD 1]

*Task:* Use integrative method for calculation of error rate, taking into account the whole cross section curve.

*Output:* Proton contribution to error rate.

When Heavy ion cross-section experimental curve exists, proton cross-section curve can be simulated by adapted tools (SIMPA, PROFIT) and must be correlated with experimental data. (Note that the SIMPA and PROFIT tools are only suitable for memory devices)

**REQ SEP03:** extrapolation from heavy ion to proton cross-section curve methodology shall be submitted to EADS ASTRIUM project approval before use in error rate prediction.

**REQ SEP04:** heavy ion prediction technique requires the use of CREME based codes.

Heavy ions and proton induced SEP rates during mission are calculated separately under normal and flare conditions, according to environment specification [AD 1], and will be added to give the "out-of-flare" error.
rate prediction and "during-flare" error rate. References to test reports and environment used will be identified. Table 11 gives the standard format of error rate presentation:

<table>
<thead>
<tr>
<th></th>
<th>Error rate under no-flare environment</th>
<th>Error rate under flare environment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heavy Ion contribution</td>
<td>ER1</td>
<td>ER'1</td>
</tr>
<tr>
<td>Proton contribution</td>
<td>ER2</td>
<td>ER'2</td>
</tr>
<tr>
<td>TOTAL Error Rate</td>
<td>ER1+ER2</td>
<td>ER'1+ER'2</td>
</tr>
</tbody>
</table>

Table 7: error rate table

8.3 SEP part acceptance criteria

8.3.1 Destructive SEE

**REQ SEP05**: the destructive SEE rate (calculated as required in §8.2) has to be at least 10 times lower than \( \lambda_{\text{dev}} \), intrinsic device failure rate, as determined using [RD 9] at 25°C, or relevant experimental set of reliability data.

**REQ SEP06**: in any case, part types sensitive to destructive Single Event Phenomena (e.g. group B or group C devices) can not be accepted without analysing its impact on equipment and system reliability during the full design life time, including solar flare.

Latch up protection circuitry can be used only after project acceptance. The impact on part reliability of successive Latch-up removal shall be analysed.

**REQ SEP07**: for Single Event Burnout (SEB) and Single Event Gate Rupture (SEGR), baseline of radiation assurance approach shall be constituted:

- by the application of the derating rules provided here below (numbered 1 to 2), or,

- by SEB and SEGR rate calculation. Methodology used for such a calculation shall be provided to EADS ASTRIUM project team for review and approval before use. In this case, REQ SEP05 and REQ SEP06 apply.

1. Acceptable SEGR and SEB data exist (see §8.5 for test data acceptance criteria)

Acceptable evaluation phase data will give drain to source threshold voltages (\( V_{\text{dsth}} \)) versus LET and gate to source voltage (\( V_{gs} \)), for static OFF conditions and case temperature. Worst case \( V_{\text{dsth}}(WC) \) will be defined.

The derating consists of maintaining \( V_{ds} \) within safe operation limits over the full design lifetime as:

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• \( V_{ds} \leq 0.80 \times V_{\text{dsh}}(\text{WC}) \), with \( |IV_{gs}| < |IV_{\text{gmax}}| \) used during testing for \( V_{\text{dsh}}(\text{WC}) \) estimate and,

• \( T_{\text{test}} < T_{\text{case}} \) where \( T_{\text{test}} \) is the case temperature used during testing, for \( V_{\text{dsh}}(\text{WC}) \) estimate.

For old parts from Fairchild (Harris, Intersil) heritage products still available and from International Rectifier generation 3 and 4 device types, derating rules on bias conditions (VDS, VGS) can be used in order to prevent:

- SEB permanent damage for N-Channel Power MOSFETs (P-Channel are not sensitive to SEB):
  • \( V_{\text{DS}} < 50\% \times BVDSS @ BVDSS < 200 \text{ Volts} \)

- SEGR permanent damage:
  • N Channel : \( V_{G} > 0 \text{ Volt} \)
  • P Channel : \( V_{G} < 0 \text{ Volt} \)

For VDS above 50%, BVDSS > 200 Volts or other manufacturers (or technology generation for IR devices), REQ SEP08 applies.

2. No acceptable SEGR and SEB data exist

REQ SEP08: in the case that no acceptable SEGR and SEB data exist on the device type under analysis, testing will be required.

8.3.2 Non destructive SEE

REQ SEP09: The subcontractor is required to perform a SEE effects analysis in order to identify the SEE effects, criticality and occurrence rate. Part types sensitive to non-destructive Single Event (SEU for example) may be accepted under the following conditions (numbered 1 to 3):

1- Any electronic equipment shall meet its specification under no-flare environment. Parts that cannot fill this criterion shall be rejected.

2- Worst-case performance of any electronic equipment shall be calculated taking into account no-flare and solar flare environment. If its worst-case performance exceeds the specification due to solar flare constraint, use of any part sensitive to non-destructive SEE shall be traced through a RFD (Request For Deviation).

3- SEE rate calculation shall be performed according to applicable methods presented in §8.2.
REQ SEP10: for Single Event Transient (SET), baseline of radiation assurance approach shall be the analysis of the effect of a SET on equipment performance. It shall be demonstrated that a SET will not produce equipment out of specification (including untimely protection triggering).

REQ SEP11: the nature of the SET to consider is defined for some device types in Table 8. If specific data exist regarding device under analysis, these data shall be provided to EADS ASTRIUM project for approval prior to use.

REQ SEP12: the equipment design performance shall be demonstrated by the equipment supplier through accurate analysis/simulation; simulation hypotheses (e.g. simulation model and boundary condition used) shall be provided within radiation (or FMECA) analysis.

<table>
<thead>
<tr>
<th>Device type</th>
<th>SET nature at device output (*)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operational amplifier</td>
<td>$\Delta V_{\text{max}} = +/- V_{\text{CC}} &amp; \Delta t_{\text{max}} = 15 \mu s$</td>
</tr>
<tr>
<td>Comparator</td>
<td>$\Delta V_{\text{max}} = +/- V_{\text{CC}} &amp; \Delta t_{\text{max}} = 10 \mu s$</td>
</tr>
<tr>
<td>Voltage Regulator</td>
<td>$\Delta V_{\text{max}} = +/- V_{\text{IN}} &amp; \Delta t_{\text{max}} = 10 \mu s$</td>
</tr>
<tr>
<td>Voltage Reference</td>
<td>$\Delta V_{\text{max}} = +/- V_{\text{CC}} &amp; \Delta t_{\text{max}} = 10 \mu s$</td>
</tr>
<tr>
<td>Opto-coupler</td>
<td>Susceptible to SET $+/- V_{\text{cc}} &amp; \Delta t_{\text{max}} = 100$ nanoseconds</td>
</tr>
</tbody>
</table>

Table 8: nature of SET as a function of device type

(*) In this table, pulse durations to be taken into account are at device level, application circuit influence on SET duration to be added.

REQ SEP13: in case no SET ground test data on device under analysis is available, SET nature that would result in severe degradation of the operational capability of subsystem under consideration has to be determined by the equipment supplier and submitted to EADS ASTRIUM project for approval before use through preliminary radiation analysis (or FMECA). SET test data in the concerned application is required.

REQ SEP14: for complex devices like PWM, PLL, DAC and ADC, SET effect may be of multiple nature (see Table 9) and some of them may be critical for application; consequently, test data is required.

<table>
<thead>
<tr>
<th>Device type</th>
<th>SET nature at device output</th>
</tr>
</thead>
<tbody>
<tr>
<td>PWMs</td>
<td>Double Pulses, two missing pulses, multiple missing pulses in a row, device shut off…</td>
</tr>
<tr>
<td>PLL</td>
<td>Transients and permanent changes in output voltage. In synthesiser circuits can cause phase, amplitude and frequency transients with duration determined by loop response.</td>
</tr>
</tbody>
</table>

Table 9: nature of SET for some complex devices

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REQ SEP15: Memory circuits shall have sufficient error detection and correction capability (EDAC, scrubbing…) for protection against SEU such that the circuit performance goals are not affected by these errors.

8.4 Heavy ion and proton induced SEE test method

REQ SEP16: for SEE sensitivity determination or validation on a specific part type, the SEP test method shall comply with the following rules (listed 1 to 5):

1- Test shall be performed in accordance with European ESA/SCC25100 [RD 10] or possibly with US JEDEC JESD57 [RD 11] SEE test procedures, with a minimum sample size of 2 irradiated parts,

2- Test devices shall be unambiguously identified: the following information is required: part number; electrical function; manufacturer; Date Code; diffusion lot; wafer plant; device technology; mask set; quality level; procurement specification.

3- Input: typical conditions of use for application.

4- Task:
   - heavy ion and proton (if necessary) irradiation at minimum over the LET range of 0 to 60 MeV.cm²/mg and proton energy range of 30 to 200 MeV, except if saturation can be obtained for lower LET than 60 MeV.cm²/mg or proton energy lower than 200 MeV.
   - Irradiation performed under the worst case bias, temperature and frequency.

5- Output: Accurate measurement of SEE hardness.

Californium test: Heavy ion test performed using natural radio-activity of Cf-252 source.

Such a test gives only a qualitative and partial estimate of SEE sensitivity and cannot be used in order to predict in orbit behaviour of tested part type.

For silicon based EEE parts, the proton cross section is negligible when threshold LET as measured using heavy ion is larger than 15 MeV.cm²/mg; no proton testing is required in this case.

8.5 Acceptance criteria for previous SEE test reports

REQ SEP17: for SEP sensitivity estimates on a specific part type, used SEP test report shall comply with the following rules:

- Test to be performed in accordance with European ESA/SCC25100 [RD 10] or possibly with US JEDEC JESD57 [RD 11] SEE test procedures, with a minimum sample size of 2 irradiated parts,
and,

- The tested parts shall be similar (subcontractor to provide EADS ASTRIMUM project team with evidence of similarity for approval) to FM parts (except if any changes are proven not to alter SEE hardness).

and,

- Test pattern worst or equivalent to the application.

**REQ SEP18**: The following information is specifically required for SEGR and SEB test report acceptance:

- Worst case Vgs used in application

and,

- Case temperature range used in application

and,

- Evaluation data shall ensure to enclose cross section measurement up to a minimum LET of 38 MeV.cm²/mg, with particles range ≫ device sensitive depth, at ambient temperature.
9. QUALITY ASSURANCE

REQ RAD03: for any equipment, an Equipment Radiation Analysis is required. The final version of the radiation analysis shall be delivered before CDR for a new development and before EQSR for a recurring unit. The required minimum information to be included in the Equipment Radiation Analysis Document (ERAD) is listed here below. For the detailed required content, the reader will refer to the previous sections.

ERAD content:

1. Identification of all applicable and reference documents used in ERAD.

2. Identification of all relevant parameter for TIDL and TNIDL/DDEF calculation: radiation environment, software used, methodology, shielding used…

3. List of active parts (extracted from the DCL) used in the equipment with identification of manufacturer and date code,

4. Type by type on all active devices, TIDL, part hardness (TIDS) and dose group.

5. Type by type on DD sensitive devices, TNIDL/DDEF to be received, part hardness (TNIDS/DDSF) and displacement damage group.

6. For each relevant and predictable SEE, type-by-type on all active devices, the SEE group and error rate with method used.

7. Maximum rating used for devices potentially sensitive to SEB and SEGR.

8. Detailed SET analysis, including functional effects at interfaces and at equipment level (see REQ SEP12). In case such analysis is performed in another document (FMECA for example), this shall be referenced in the radiation analysis.

9. Status type by type for FM lot acceptance.

10. Identification and description of radiation countermeasure used by the subcontractor, if any.

11. Worst case analysis and reliability analysis demonstrating that equipment performance and reliability will be fulfilled considering dose, displacement damage and SEE effects. If not provided in ERAD, reference to the appropriate document(s).

12. RADLAT test results; if they are not available at the time the radiation analysis is completed, they shall be provided in a separate document not later than the CDR of the considered equipment.
10. ANNEX: NIEL TABLES FOR PROTONS AND ELECTRONS

NIEL values provided in Table 10 to Table 13 are extracted from Summers et al. publication[1] except the one used for protons in GaAs that comes from Barry's work[2].

10.1 NIEL for protons in SILICON:

<table>
<thead>
<tr>
<th>Energy [MeV]</th>
<th>200</th>
<th>100</th>
<th>70</th>
<th>50</th>
<th>30</th>
<th>20</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>NIEL [MeV.cm²/g]</td>
<td>1.94 10⁻³</td>
<td>2.6 10⁻³</td>
<td>3.16 10⁻³</td>
<td>3.88 10⁻³</td>
<td>4.78 10⁻³</td>
<td>5.36 10⁻³</td>
<td>7.86 10⁻³</td>
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</table>

10.2 NIEL for electrons in SILICON:

<table>
<thead>
<tr>
<th>Energy [MeV]</th>
<th>200</th>
<th>100</th>
<th>70</th>
<th>50</th>
<th>30</th>
<th>20</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>NIEL [MeV.cm²/g]</td>
<td>1.65 10⁻⁴</td>
<td>1.6 10⁻⁴</td>
<td>1.56 10⁻⁴</td>
<td>1.5 10⁻⁴</td>
<td>1.38 10⁻⁴</td>
<td>1.27 10⁻⁴</td>
<td>1.05 10⁻⁴</td>
</tr>
</tbody>
</table>

Table 10: NIEL values in Silicon as a function of proton energy

Table 11: NIEL values in Silicon as a function of electron energy


10.3 NIEL for protons in GaAs:

<table>
<thead>
<tr>
<th>Energy [MeV]</th>
<th>200</th>
<th>100</th>
<th>70</th>
<th>50</th>
<th>30</th>
<th>20</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>NIEL [MeV.cm(^2)/g]</td>
<td>(8.5 \times 10^{-4})</td>
<td>(1.25 \times 10^{-3})</td>
<td>(1.5 \times 10^{-3})</td>
<td>(2.1 \times 10^{-3})</td>
<td>(3 \times 10^{-3})</td>
<td>(4 \times 10^{-3})</td>
<td>(6.59 \times 10^{-3})</td>
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</table>

<table>
<thead>
<tr>
<th>Energy [MeV]</th>
<th>7</th>
<th>5</th>
<th>3</th>
<th>2</th>
<th>1</th>
<th>0.7</th>
<th>0.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>NIEL [MeV.cm(^2)/g]</td>
<td>(9.16 \times 10^{-3})</td>
<td>(1.25 \times 10^{-2})</td>
<td>(1.99 \times 10^{-2})</td>
<td>(2.89 \times 10^{-2})</td>
<td>(5.4 \times 10^{-2})</td>
<td>(7.44 \times 10^{-2})</td>
<td>(1.01 \times 10^{-1})</td>
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<table>
<thead>
<tr>
<th>Energy [MeV]</th>
<th>0.3</th>
<th>0.2</th>
<th>0.1</th>
<th>0.07</th>
<th>0.05</th>
<th>0.03</th>
<th>0.02</th>
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</thead>
<tbody>
<tr>
<td>NIEL [MeV.cm(^2)/g]</td>
<td>(1.58 \times 10^{-1})</td>
<td>(2.25 \times 10^{-1})</td>
<td>(4.09 \times 10^{-1})</td>
<td>(5.54 \times 10^{-1})</td>
<td>(7.34 \times 10^{-1})</td>
<td>(1.12)</td>
<td>(1.55)</td>
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Table 12: NIEL values in GaAs as a function of proton energy

10.4 NIEL for electrons in GaAs:

<table>
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<tr>
<th>Energy [MeV]</th>
<th>200</th>
<th>100</th>
<th>70</th>
<th>50</th>
<th>30</th>
<th>20</th>
<th>10</th>
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</thead>
<tbody>
<tr>
<td>NIEL [MeV.cm(^2)/g]</td>
<td>(1.75 \times 10^{-4})</td>
<td>(1.66 \times 10^{-4})</td>
<td>(1.6 \times 10^{-4})</td>
<td>(1.48 \times 10^{-4})</td>
<td>(1.37 \times 10^{-4})</td>
<td>(1.15 \times 10^{-4})</td>
<td>(1.03 \times 10^{-4})</td>
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</table>

<table>
<thead>
<tr>
<th>Energy [MeV]</th>
<th>7</th>
<th>5</th>
<th>3</th>
<th>2</th>
<th>1</th>
<th>0.7</th>
<th>0.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>NIEL [MeV.cm(^2)/g]</td>
<td>(9.15 \times 10^{-5})</td>
<td>(7.42 \times 10^{-5})</td>
<td>(6.14 \times 10^{-5})</td>
<td>(4.25 \times 10^{-5})</td>
<td>(3.45 \times 10^{-5})</td>
<td>(2.97 \times 10^{-5})</td>
<td>(1.85 \times 10^{-5})</td>
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</table>

<table>
<thead>
<tr>
<th>Energy [MeV]</th>
<th>0.3</th>
<th>0.2</th>
</tr>
</thead>
<tbody>
<tr>
<td>NIEL [MeV.cm(^2)/g]</td>
<td>(9.74 \times 10^{-9})</td>
<td>(9.74 \times 10^{-9})</td>
</tr>
</tbody>
</table>

Table 13: NIEL values in GaAs as a function of electron energy
INTENTIONALLY BLANK
DOCUMENT CHANGE DETAILS

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<th>CHANGE AUTHORITY</th>
<th>CLASS</th>
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DISTRIBUTION LIST

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