TECHNICAL NOTE

TITLE: **SVM RADIATION ENVIRONMENT COMPATIBILITY ASSESSMENT**

DRL Item No: E-6

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1. AIM AND SCOPE

The present technical note aims at providing with a system-level synopsis of the whole range of estimations and calculations performed during the activities of design and qualification of the radiation sensitive equipments of the Herschel-Planck SVM, integrating them with a whole-SVM-level assessment, despite it is not an Alenia's task to perform "true" system-level radiation analyses, in order to show compliance with the applicable radiation natural environment requirements, considering the three main areas of Effects due to Radiation Interaction with Materials:

- Ionisation Effects in Materials, evaluated in terms of Total Ionising Dose
- Non-Ionisation Effects in Materials, evaluated in terms of Displacement Damage
- Effects due to Single Event Phenomena, evaluated as Single Event Effect (*id est*: Upset, Transient, Latch-Up, Burnout, Gate Rupture, Hard Error, etc.) Probability Rates

The scope of the present evaluation and assessment encompasses the whole ensemble of the SVM SubSystem, and Units, where applicable, as better described in the following chapter 6, concerning item by item examination; this step is preceded by requirements review in chapter 4 and preliminary SVM level considerations about requirements consequences in chapter 5, and is followed by a global system level evaluation.

Despite it is almost complete in terms of the number of the units scrutinised, the present issue of the document has to be considered preliminary as far as the contents completeness and final status, due to the large number of subsystem / unit level CDRs open or even to be still performed, with all their implications on the evolution of the technical subjects. The latter units are being prepared for discussion, but not yet included in this document (with exceptions), while the former ones are fully reported, like the already "frozen" units, but their situation being not completely definite, they cannot be described in terms of a final, firm status: conversely an open situation is described, with illustration of all the point under discussion, in order to easily keep them under monitoring (and tracing) while full convergence of expected performances to requirements is addressed. This document will be finally updated, in order to witness that convergence, along with the closure of all the CDRs activities, and availability of the radiation analyses relevant information.

2. APPLICABLE AND REFERENCE DOCUMENTS

2.1 Applicable Documents

The following documents are applicable to this Technical Note and are quoted in the text as AD-xx or by their abbreviations in square brackets, in accordance with the list below:

AD-1. [RadReq] [RADREQ] "Radiation Requirements", H-P-1-ASPI-SP-0017, i. 1 (r. 0)
AD-2. [EnvTReq] [ENVTR] "Environment and Tests Requirements" Specification, H-P-1-ASPI-SP-0030,i. 4 r. 2
AD-3. [GDesIFReq] [GDIR] "General Design and InterFace Requirements", H-P-1-ASPI-SP-0027,Specification, i. 4 r. 2

2.2 Reference Documents

The following documents are references for this Technical Note and are quoted in the text as RD-xx or by their abbreviations in square brackets, in accordance with the list below:

RD-1. [SVM Conf] "{Herschel-Planck}SVM Configuration Requirement {sic}",
H-P-RP-AI-0003, i.3 , date:

RD-2. [SVM MICD] "Herschel / Planck SVM Mechanical Interface Control Document",
H-P-IC-AI-0001, i. 4 {→5}, date:

RD-3. [H-P RADSHAN] "Radiation Shielding Analysis of Herschel / Planck Satellites",
H-P-1-ASPI-AN-0321, i. 1, date: 20/06/2002

RD-4. [ACMS RADAN] "ACMS Radiation Analysis Overview",
H-P-4-DS-TN-044, i.1 r.0, date: 13/04/2004

RD-5. [ACC RADAN2] "ACC Radiation Analysis",
H-P-4-SES-NT-00008, i.2, date: 16/01/2004

RD-6. [ACC RADAN3] "ACC Radiation Analysis",
H-P-4-SES-NT-00008, i.3, date: 18/03/2004

RD-7. [CDMU RADAN2] "CDMU Radiation Analysis",
H-P-4-SES-NT-00005, i.2, date: 16/01/2004

RD-8. [CDMU RADAN4] "CDMU Radiation Analysis",
H-P-4-SES-NT-00005, i.4, date: 18/03/2004

RD-9. [AAD DESAN] "Herschel-Planck AAD - Design and Analysis Report",
H-P-4-TNO-RP-A004, i.3, date: 10/10/2003

RD-10. [CRS RADAN] "Coarse Rate Sensor Array (CRSA) Radiation Analysis",
H-P-4-LAB-AN-0003, i.1, date: 06/04/2004

RD-11. [GYR RADAN] "Herschel IRU E-4 Radiation Analysis",
[Northrop Grumman presentation without reference], i.=, date: 20/10/2003

RD-12. [RWA TIDAN] "[RWA] Shielding Analysis for RSI 20-215/18",
Teldix doc. 15179-323, i.1, date: 14/07/2003

RD-13. [RWA SEEAN] ""[RWA] SEE Analysis for RSI 20-215/18",
Teldix doc. 15179-324, i.1, date: 15/07/2003

RD-14. [SAS DESAN] "Herschel-Planck AAD - Design and Analysis Report",
H-P-4-TNO-RP-S004, i.3, date: 17/10/2003

RD-15. [STR RADAN] "ASTR Radiation Analysis for Herschel-Planck Mission",
H-P-4-GAF-AN-0004, i.2, date: 15/07/2003

RD-16. [HRN RADx] *Document To Be Issued*
TBD, i., date:

RD-17. [BATT RADAN] "Battery Equipment: Radiation Analysis Report",
HP4-AEA-PL-0024, i.1 r.-, date: 19/09/2002

RD-18. [PCDU RADAN] "Herschel-Planck PCDU - Radiation Analysis",
H-P-4-ETCA-AN-0055, i.1 r.1, date: 03/09/2003

RD-19. [PCDU SEEAN] "Single Event Phenomena Hardness Analysis",
MEDIA-ETCA-AN0036, i.1, date: 17/01/2003

RD-20. [RCS RADAN] "RCS Radiation Analysis",
H-P-RILAM-AN-0010, i.1, date: 10/03/2004

RD-21. [SA RADAN] "Herschel & Planck Photo-Voltaic Assembly - Radiation Analysis",
HP-2/4-GAMI-RP-0002, first issue r.-, date: 02/04/2003

RD-22. [LGAMGA RADCO] "[LGA, MGA] Statement of Compliance to Radiation Requirements for Herschel Planck",
HP-CO-RY-0055, i.1 r.0, date: ==/11/2002

RD-23. [RFDN RADAN] "Herschel Planck RFDN - Radiation Analysis",
H-P-4-AEO-AN-1003, i.2, date: 02/02/2004

RD-24. [TWTA RADAN] "Herschel Planck X-Band TWTAs - Radiation Analysis",
H-P-4-AEO-AN-1003, i.1 r.1, date: 16/02/2004

RD-25. [XPND RADAN] "Herschel Planck X-Band Transponder - Radiation Analysis",
H-P-4-AEO-AN-2003, i.2, date: 01/04/2004

3. ACRONYMS AND ABBREVIATIONS

H-P radiation assessment

AD	Applicable Document
CCD	Charge Coupling Device
CMOS	Complementary Metal Oxide Semiconductor
DDC	Dose-Depth Curve
DDEF	Damage Displacement Equivalent Fluence
DDEFC	Damage Displacement Equivalent Fluence Curve
EQFRUX	
ENVM-x	"Environment and Test Requirements Specification" Environment-related Requirement *number* x
ENVR-x	"General Design and Interface Requirements Specification" Environment-related Requirement *number* x
e^-	electron
I/F	InterFace
LET	Linear Energy Transfer
LET_{th}	threshold Linear Energy Transfer
HI	Heavy Ion
H-P	Herschel-Planck
LEOP	Low Earth Orbit Phase
L_2	2^{nd} Lagrange point for the Sun-Earth system
MEU	Multiple Event Upset
MeV	Mega electron-Volt
MOSFET	Metal Oxide Semiconductor Field Effect Transistor
N	neutron
N/A	Not Applicable
NIEL	Non-Ionising Energy Loss
NOVICE	
P/L	PayLoad
PLE	PayLoad Element
PLM	PayLoad Module
p^+	proton
RAD-x	Radiation Requirement *number* x
RD	Reference Document
RDL	Radiation Design Lifetime
RADLAT	RADiation Lot AcceptanceTests
RADHARD	RADiation HARDened
RR	Radiation Review
SEB	Single Event Burnout
SECDEC	Single Error Correction and Double Error Detection
SEE	Single Event Effect
SEGR	Single Event Gate Rupture
SEL	Single Event Latchup
SEP	Single Event Phenomenon
SET	Single Event Transient
SEU	Single Event Upset
SHE	Single Event Hard Error
SOCRATE	Single event upset Optimised Calculation RATE
SVM	SerVice Module
TBC	To Be Confirmed
TBD	To Be Defined
TBP	To Be Provided
TDT	Total Dose Threshold

TID	Total Ionising Dose
WCA	Worst Case Analysis

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H-P subsystems and units,
Non-H-P units ***(Customer Furnished Equipment, Instrument Warm Units, Cryostat Control electronic Unit)***

4CAU	4K Cooler Ancillary Unit
4CCU	4K Cooler Compressor Unit
4CEU	4K Cooler Electronic Unit
AAD	Attitude Anomaly Detector
ACC	Attitude Control Computer
ACMS	Attitude Control and Measurement Subsystem
AR5	Ariane 5
BATT	Lithium-Ion Battery
BEU	Back End Unit
BRKT	Bracket
CCU	Cryostat Control electronic Unit
CDMU	Central Data Management Unit
CDMS	Command and Data Management Subsystem
CFE	Customer Furnished Equipment
CRYO	CRYO Subsystem
CRS	Coarse Rate Sensor
DAE-CB	Data Acquisition Electronics Control Box
DCCU	Dilution Cooler Control Unit
DPU	Data Processing Unit
EPC	Electrical Power Conditioner
FDV	Fill & Drain Valve (N2H3)
FHFCU	Focal plane Control Unit
FHHRH	High Resolution spectrometer Horiz. Pol.
FHHRI	High Resolution IF-processor
FHHRV	High Resolution spectrometer Vert. Pol.
FHICU	Instrument Control Unit
FHIFH/FHIFV	Up Converter
FHLCU	Local oscillator Control Unit
FHLSU	Local oscillator Source Unit
FHWEH	Wide-Band Spectrometer Electronics Horiz. Pol.
FHWEV	Wide-Band Spectrometer Electronics Vert. Pol.
FHWOH	Wide-Band Spectrometer Optics Horiz. Pol.
FHWOV	Wide-Band Spectrometer Optics Vert. Pol.
FOG	Fiber Optic Gyro
FPBOLC	Bolometer/Cooler Control
FPDPU	Digital Processing Unit
FPMEC-DEC	Mechanism Control 1&2 + Detector Control 1&2
FPSPU	Signal Processing Unit
FVV	Fill & Vent Valve (N2)
GYR	GYROscope
HeTANK	Helium Tank
HFI	High Frequency Instrument (Planck)
HIFI	Heterodyne Instrument for First
H/P	Herschel and Planck
HSDCU	Detector Control Unit
HSDPU	Digital Processing Unit
HSFCU	FPU Control Unit
HTANK	Helium Tank
ICD	Interface Control Document

LF	Propellant filter
LFI	Low Frequency Instrument
LGA	Low Gain Antenna
LV	Latch Valve
MGA	Medium Gain Antenna
OSR	Optical Solar Reflector
PACS	Photo-conductor Array Camera Spectrometer (Herschel)
PAU	Pre-Amplifier Unit
PCDU	Power Conditioning & Distribution Unit
PT	Pressure Transducer
PTANK	Propellant Tank
PWR	Power Subsystem
RCS	Reaction Control Subsystem
REBA	Radiometer Electronics Box Assembly
REU	Readout Electronics
RFDN	Radio Frequency Distribution Network
SA	Solar Array
SAS	Sun Acquisition Sensor
SCC	Sorption Cooler Compressor
SCE	Sorption Cooler Electronics
SPIRE	Spectral Photometer Imaging Receiver (Herschel)
SREM	Standard Radiation Environment Monitor
STR	Star Tracker
SVM	Service Module
TCS	Thermal Control Subsystem
THR1N	Thruster (1 N)
THR20N	Thruster (20 N)
TP	Test Port
TT&C	Telemetry and Tracking and Control
TWTA	Travelling Wave Tube Amplifier
VMC	Visual Monitoring System
XPND	Transponder

4. HERSCHEL AND PLANCK MISSIONS RADIATION ENVIRONMENT REQUIREMENTS

4.1 Herschel and Planck Missions Radiation Environment Description

The Herschel and Planck spacecrafts will conduct their scientific missions during their operative lives when orbiting around the L_2 point (second Lagrange point) of the Earth/Sun system, where they will be substantially exposed only to energetic protons and heavy ions coming with the solar wind and the galactic cosmic rays. After launch, however, during their transfer orbits, the spacecrafts will be exposed also to Van Allen belts trapped particles (electrons, protons). Despite the quite benign radiation environment seen by the two satellites, it is necessary to evaluate their degradation and possible damages and failures due to the previous environment, that is: to assess the radiation damage risk and verify the design hardness against it.

In general, radiation related damage mechanisms to which the satellites will be subjected include:

- radiation damage by ionisation due to passage of electrons and protons into electronic devices, expressed as a function of the Total Ionising Dose (TID)
- radiation damage due to microscopic displacements (Non Ionising Energy Loss - NIEL), induced mainly by protons, and affecting Solar Cells, CCDs, and optocouplers and bipolar electronics, expressed as a function of the Displacement Damage Equivalent Fluence (DDEF) of particles
- effects from single event phenomena generated into electronic devices due to the charge left by heavy ions and protons from cosmic rays and solar wind (including "flare" phenomena), and trapped protons, which pass through the devices themselves.

In the following, the Radiation Requirements applicable to Herschel and Planck spacecrafts SVMs will be reviewed and analysed, so as to collect / perform, in the following chapters, the appropriate system and subsystem / unit level assessments, in order to demonstrate compliance to the requirements themselves.

4.2 Herschel and Planck Missions Radiation Environment Requirements

The Radiation Requirements applicable to Herschel and Planck spacecrafts SVMs are organically displayed and specified by [GDIR] and [ENVTR] specifications, and by [RAD REQ], which in turn reflects (or calls) the appropriate qualitative requirements or quantitative figures, tables and curves of [ENVTR] and [GDIR].

In particular, [GDIR] makes it applicable [RAD REQ], at least for SEEs, equipped with the ([ENVTR]) data and procedures, which are displayed in its para 3.4.4.2.

(note: the original text quoted from mentioned specs is in brown, and paragraphs are right-shifted)

[GDIFReq] applicable section is para. 3.14 – **Radiations**:

> The radiation environment is defined in the Environment Requirements Specification (AD-1) [id est: the [EnvTReq] specification]. Due to the specificity of the mission around L_2, the spacecraft will only cross the Earth's radiation belts once during LEOP.
> However, it will still be exposed to energetic protons and heavy ions from solar flares and cosmic rays.
> The principal anticipated radiation effects are:
> – Degradation of electronic components, detectors and materials (dose effect),
> – Interference with detector operation (background)
> – Cosmic rays induced upsets
> – Latchup
> – Electrostatic charging
>
> #----------- Reference **ENVR-005** ------------------------------
>
> The contractor shall be responsible for performing radiation analyses as required using the nominal mission scenario and taking into account the data from the Herschel L_2 Radiation Environment document (AD-1). The in-orbit case with a beginning of mission in February 2007 shall be taken into account.

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In particular, the figures related to the Silicon Solar cells, Gallium Arsenide cells, single dose/depth, non-ionising dose/depth and raw particle spectra shall be taken into account.

In sub-detail:
para. 3.14.1 is for Radiation Dose:

#----------- Reference **ENVR-010** -----------------------------

The satellite shall be designed to withstand the doses predicted for a 2 times the nominal lifetime of the spacecraft except for the solar array sizing.

(here it is proper to quote para 3.6 about Lifetime**:**

#----------- Reference **GDGE-210** -----------------------------

For the Herschel mission, the spacecraft shall have a nominal lifetime of 3. 5 years. This duration is counted from the launch to end of mission. This duration includes an allocation of 6 months for the transfer to the L-2 Lissajous orbit.

#----------- Reference **GDGE-220** -----------------------------

For the Planck mission, the spacecraft shall have a nominal lifetime of at least 21 months. This duration is counted from the launch to end of mission.
This duration shall allow two full sky surveys (with a coverage of at least 95% of the full sky) at the operational Lissajous orbit around L-2, and includes an allocation of 6 months for the transfer to the L-2 Lissajous orbit.

). Getting now back to para. 3.14.1:

#----------- Reference **ENVR-020** -----------------------------

The components and their shielding shall be compatible with the above requirement such that the radiation dose will not cause failures or produce unacceptable changes in performance.

#----------- Reference **ENVR-030** -----------------------------

For the design of the solar array and the determination of its degradation during the mission, the total equivalent fluence of 1 MeV electrons shall be taken into account for the extended lifetime.

#----------- Reference **ENVR-040** -----------------------------

Components shall be qualified (either based on existing or new test data) to withstand the doses predicted according to ENVR-010. Radiation testing shall be included in the lot acceptance testing, if the margin is small and if the variation of radiation resistance between lots is large or insufficiently known. An exception to this requirement is the solar cells, which shall be qualified according to AD- 21 [id est: ESA PSS-01-604, Jan 1988] for Silicon Solar Cells and AD- 22 [id est: SPA-TS-0006, Jul 1977] for Gallium Arsenide Solar Cells.

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para. 3.14.2 is for Radiation Induced Background:

Radiation impinging onto a detector or its associated electronics can produce an increase in noise, which in turn can produce a significant decrease of performance. Such changes can last until well after the radiation dose has stopped (remittances).

#----------- Reference **ENVR-050** -----------------------------

The spacecraft design and component selection shall be such as to minimise these effects, including any necessary means to ensure the most rapid restoration of nominal performance.

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para. 3.14.3 is for Single [and Multiple] Event Effects:

Single event effects are due to heavy ions and protons from galactic and extra galactic sources and solar flares protons. Its effects on electronic components may be destructive (latch-up) or non-destructive (bit flips).
The applicable environment curves are given in AD-1[*id est*: the [EnvTReq] specification].
The methodology to be applied for single events (SEL, SEU) rate prediction is provided in AD- 6 [*id est*: the [RadReq] specification].

[para.] 3.14.3.1 Single event latch-up

Cosmic rays may cause latch-up in certain technologies, primarily CMOS. Latch-up is permanent and potentially destructive.

#----------- Reference **ENVR-060** -----------------------------
Devices which are known or proven to be susceptible to latch-up shall not be used.

#----------- Reference **ENVR-070** -----------------------------
Components of technology sensitive to heavy ions or protons shall be submitted to evaluation in order to qualify their latch-up occurrence rate.

#----------- Reference **ENVR-080** -----------------------------
In the case where technical demands can only be met using latch-up sensitive technologies, a de-latching device shall be implemented so as to avoid loss of the unit upon latch-up.
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[para.] 3.14.3.2 Single event burn-out and single event gate rupture
N channel power MOSFETs are sensitive to single event burn-out and single event gate rupture, while P channel ones are only sensitive to single event gate rupture.

#----------- Reference **ENVR-090** -----------------------------
Appropriate derating rules shall be applied as per AD- 40 [*id est*: the [RadReq] specification].
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[para.] 3.14.3.3 Single event upset (SEU) [and MEU]

#----------- Reference **ENVR-100** -----------------------------
When components sensitive to SEU are selected, the design shall take care that solutions to prevent the effects of SEU on the mission are implemented into the equipment as hardware solutions (particularly through component selection) or as software solutions.

#----------- Reference **ENVR-110** -----------------------------
The availability computation shall account for possible SEU effects and shall demonstrate that the availability requirement is fulfilled.

#----------- Reference **ENVR-120** -----------------------------
SEU shall not cause permanent failure or degradation either directly or as a consequence.

#----------- Reference **ENVR-130** -----------------------------
All computers shall be protected against the effects of SEU.

#----------- Reference **ENVR-140** -----------------------------
The computers memory architecture shall be such that a MEU inducing a flip of more than two (2) bits in the same word shall not lead to the loss of the mission. MEU: Multiple Even Upset, i.e. the consequence of a heavy ion causing more than one simultaneous bit flip in the same chip.

#----------- Reference **ENVR-150** -----------------------------
The rate of uncorrectable errors in spacecraft memories shall be better than 1E-11 (error/bit/day).

#----------- Reference **ENVR-160a** -----------------------------
All spacecraft processor semiconductor memories and registers shall implement Single Error Correction and Double Error Detection (SECDED) for each smallest addressable unit in memory.

#----------- Reference **ENVR-170** -----------------------------
The processor design shall ensure that the processor internal registers are refreshed at a rate sufficient to avoid cumulation of deposited charges leading to errors.
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All these requirements are furtherly expanded in **[RadReq]**.

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The prescriptions of the ([RadReq]) specification
(" The unit shall be designed to survive the space radiation environment during the Radiation Design Lifetime (2 times the nominal lifetime). The purpose of this document is to provide Space Radiation Requirements to follow during program in order to prove that the equipment will continue to perform its function throughout its Radiation Design Life…. The major factors that will effect the design of the electronic systems are total dose

ionisation damage, single event phenomena and displacement damages. The present document presents the analyses and procedures that will be used to ensure that the equipment will be designed to survive these environments. " – from chapters 1 and 2)

shall be understood on this basis.

Since indeed chapter 6 tells:

" The ~~radiation~~ Space Radiation Environment applicable for this mission is given in Applicable Document 1 [*id est*: **[EnvTReq]**] ",

then the applicable section of the latter, which is para. 3.4.4.2, will be examined first.

Para. 3.4.4.2.1 is dedicated to

Space Radiation Environment description,

with the radiation hardness minimum requirement

#----------- Reference **ENVM-370** -----------------------------

The minimum allowable radiation level for active parts shall be :

- Minimum Total Dose Behavior : 10 krad (*Si*)
- Minimum Displacement Damage Equivalent Fluence (Si) : $6 \cdot 10^9$ p^+ (*@10 MeV*) /cm²
- Minimum Displacement Damage Equivalent Fluence (GaAs) : $5 \cdot 10^9$ p^+ (*@10 MeV*) /cm²

#---,

and the applicable

- average-on-the-(transfer-)orbit energy-spectral values of trapped electrons and protons fluxes,
- mission energy-spectral values of fluence of solar protons (including the worst case peak flux),
- average-on-the-mission LET-spectral values of integral flux of galactic cosmic rays.

Para. 3.4.4.2.2 is dedicated to

Space Radiation Effects ,

stating that

If the Sub-Contractor don't use advanced particle/matter interaction simulation tools, the following 'between in' curves shall be used, instead of using directly particle fluxes and fluences as an input.

and brings the applicable Dose-Depth Curve to determine TID:

#----------- Reference **ENVM-430** -----------------------------

…Dose-Depth Curve, … calculated for an Aluminium Solid Sphere Shielding, with a Silicon Detector located in the centre of the sphere … shall be used to perform Ray Tracing Analysis to calculate Deposited Dose [due to Ionising effects of Radiation]. The mission Dose-Depth Curve takes into account particle fluxes. This curve is given in Table 3.4-8 and in Figure 3-26.

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the applicable methods and data to calculate Single Event Phenomena Effects:

#----------- Reference **ENVM-440** -----------------------------

Heavy Ions Induced SEU:

For Single Event Upset calculations, the SEU rate, normalised to a device cross section of 1 cm², is calculated for various LET threshold. This SEU Rate versus LET_{th} curve is given in Figure 3-28 and Table 3.4-9.

This curve shall be convoluted with the experimental Device Cross Sections versus LET curve, in order to get the Galactic Cosmic Rays SEU rate for the device.

#----------- Reference **ENVM-450** -----------------------------

Protons Induced SEU:

For Single Event Upset calculations, the SEU rate, normalised to a device cross section of 10^{-8} cm², is calculated for various LET threshold. This SEU Rate versus LET_{th} curve is given in Table 3.4-10 and Figure 3-30

#----------- Reference **ENVM-460** -----------------------------

For other effects (Latchup, Burnout, Gate Rupture, Hard Error, Transient, ...), the particle fluxes and fluences shall be directly used.

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and the mission "Displacement Damage Equivalent Fluence" versus Depth curves related to the Non-Ionising Energy Loss:

Both protons and electrons can induce displacement damage in semiconductor devices. The part of deposited energy involved in displacement defects creation is called NonIonizing Energy Loss (NIEL). The particles fluxes spectra are converted into a fluence of monoenergetic particles producing the same amount of defects (10 MeV protons).

#----------- Reference **ENVM-470** -----------------------------

The Displacement Damage Equivalent Fluence (10 MeV protons) is calculated using the NOVICE code. This curve is calculated for an Aluminium Solid Sphere Shielding. The mission Displacement Damage Equivalent Fluence Depth Curves are given in Figure 3-32 and Table 3.4-11 for Silicon and GaAs detectors.

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as well as the Solar Cells degradation equivalent fluences curves:

#----------- Reference **ENVM-480** -----------------------------

The Solar Cells degradation equivalent fluences of 1 MeV electrons as a function of cover glass thickness are calculated with the EQFRUX code (JPL) for the mission (5 years). Infinite cell back shielding is assumed and a 10 MeV proton to 1 MeV electron equivalence ratio of 3000 is used for maximum power degradation.

The results are provided in:

– Figure 3-34 and Table 3.4-12 for P_{max}-V_{oc} in Silicon
– Figure 3-36 and Table 3.4-13 for I_{sc} in Silicon
– Figure 3-38 and Table 3.4-14 for V_{oc} in GaAs
– Figure 3-40 and Table 3.4-15 for P_{max} in GaAs
– Figure 3-42 and Table 3.4-16 for I_{sc} in GaAs

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=*=

On this basis, the **[RadReq]** specification provides the approach and methods to be mandatorily followed:

- the **total ionising dose evaluation** and related hardness assurance is dealt in **ch. 7**;
- the **single event phenomena** hardness assurance is dealt in **ch. 8**;
- the **non-ionising effect** of radiation**, as displacement damage,** and related hardness assurance is dealt in **ch. 9.**

Ionising effect of radiation**, as total ionising dose** (ch. 7).

About this, it is prescribed that

RAD-01 The Equipment unit shall be designed to account for the Total Dose Effect, during the Radiation Design Lifetime (RDL) equal to 2 times the nominal lifetime, as specified in Applicable Document 2 [id est [GDIFReq]]**.**

The Space Radiation Hardness activities will proceed through these non-chronological tasks :

- Parts selection, characterisation and Radiation Lot Acceptance Testing
- Radiation Review at sub-contractor facility **(RR)**
- Deposited doses calculations
- Equipment worst case analysis **(WCA)**
- Corrective actions.

Para. 7.1: parts selection

Parts shall be selected in order to survive the on-orbit space radiation environment for the specified mission time as well as still permitting the units in which they are installed to meet all their performance specifications. The minimum allowable radiation level is the Total Dose Threshold **(TDT)** level defined behind 4 mm of Aluminum of a Solid Sphere shielding, according to Reference Document 6 [id est: "Product Assurance Requirements for FIRST/Planck Satellite", ref SCI-PT/RS/MPAO4683 i. 2, r. 1].

RAD-02 All parts need to meet the Total Dose Threshold (TDT) of 10 krad(Si), as specified in Reference Document 6 [id est: Product assurance Req's, see above].

The subcontractor shall justify the use of EEE parts, according to Total Dose Evaluation data provided by the procurement authority:

RAD-03 Total Dose Degradation Database shall be submitted, during the Radiation Review (see para. 10), to ALCATEL SPACE for validation

Para. 7.2: radiation lot acceptance tests

Due to the lot-to-lot variability in Total Dose effect, all active parts, who are not in Radiation Hardened (RADHARD) technology, shall be submitted to Radiation Lot Acceptance Tests (RADLAT) according to the following table[s 1 and 2, omitted as outside the scope of the present assessment].

Some device technologies are inherently hard to total dose ionising dose effects. The following classes of parts are considered as total dose insensitive :

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

Calculated deposited dose levels shall be lower than 300 krad (Si). If not, experimental data shall be provided during the Radiation Review for review and approval.

RAD-04
RAD-05
RAD-06
concern modes and conditions about RADLAT performance, which are outside the scope of the present assessment.

Para. 7.3: deposited dose calculations

The subcontractor shall perform an accurate deposited dose calculation on the equipment. The subcontractor is required to perform a 3D modelling of the equipment, including part case models as detector points. The subcontractor shall describe the calculation method used for these deposited doses calculations. The subcontractor will use the following preliminary simple 3D spacecraft model. The satellite structure will be modelled by an aluminium cubical box of 2 meters size. Thicknesses to take into account are as follows :

Equipment Location	Mounting Surface *mm (Al)*	Other Surfaces *mm*
Inside	0.8	0.8
Outside	1.6	0.1

[Table 3]: Preliminary Satellite Radiation model

In case of mass out of specification, a more detailed ray tracing analysis at spacecraft level will be provided to the subcontractor in order to optimise the mechanical design, and deposited dose calculation shall be re-issued.

Two Deposited Dose calculation methods are allowed :

- **Ray Tracing** : In order to carry out Solid Angle Sectoring Analysis, particle fluxes are converted into Dose Depth Curves for Solid Sphere Shielding. If necessary, Dose Depth Curves for other target material could be provided. This calculation method is based on the straight ahead approximation. **Solid Angle Sectoring Analysis** are performed taking into account the angle of incidence between the ray and the shielding **(Slant Path**). The Dose Depth Curve for a **Solid Sphere** shielding shall be applied. A minimum sectoring resolution of 800 elementary solid angles is required.
- **3D Monte Carlo** : This accurate calculation method may be used, but taking into account the problem to have an accurate resolution versus the complexity of the model, the ALCATEL approval [is] required before calculation.

RAD-07 To perform Deposited Dose calculations on active parts, using either Ray Tracing or 3D Monte Carlo technics.

Para. 7.4: Worst Case Analysis

Circuit WCA is needed to evaluate susceptibility to the radiation environment. The specific details describing the objectives, methods, and requirements need to be described. WCA includes the effects of temperature, aging, and radiation degradation. This equipment WCA is a valuable tool to identify clearly critical parts. Because there is a ‘ within one lot variability’ , it is necessary to use statistical tools in order to estimate the Post-Rad parameters values. This Post-Rad value, for each electrical parameter shift, will either be calculated using one of the following tools :

- **3 sigma approach :**

  Delta X_L = <delta x > + 3 . σ For increasing total dose shift

  Delta X_L = <delta x > - 3 . σ For decreasing total dose shift
- **One sided tolerance limit statistical tool could be used, based upon RD-4** [id est: “Single Event Effects Test Method and Guidelines’, ESA/SCC Basic Specification N°25100, Draft A, February 1995.]. Confidence Level as well as Lot Quality factors shall be submitted to ALCATEL for approval.

RAD-08 To perform Equipment according to the Evaluation Total Dose Database* validated during the Radiation Review.

** radiation tests reports used as input for the WCA*

RAD-09 Equipment Worst Case Analysis shall be updated according to RADLAT results, if necessary

Single event phenomena … - ch. 8;

Cosmic rays, solar flares and high energy trapped protons can induce various effects, caused by the energy deposited by a high energy particle as it interacts with the sensitive portions of an electrical device.

These effects are :

- Single Event Upset **(SEU**) : SEUs are any disturbance of a circuit. The response could be a soft error (a bit flip that can be reset). This is a non destructive effect.

SEU is considered in para 8.1.1 (LET characterisation and usage requirements), 8.2 (SEU rate calculation) and 8.3 (SEU effects analysis).

- Single Event Latch-Up **(SEL**) : This phenomena can occur in CMOS BULK or EPI parts. It turns out that the CMOS fabrication process results in parasitic PNPN paths that are well known and have been studied for conventional radiation induced latchup. This is a destructive effect.

SEL is considered in para 8.1.2 (LET characterisation and usage requirements) and 8.5 (rate acceptability compared with intrinsic failure rate).

- Single Event Burnout **(SEB**) : This phenomena can occur in power MOSFET N-channel transistors. The parasitic bipolar NPN transistor is switched on, and induces a short circuit between drain and source. This is a destructive effect.

SEB is considered in para 8.1.3 (LET characterisation and usage requirements) and 8.5 (rate acceptability compared with intrinsic failure rate).

- Single Event Gate Rupture **(SEGR**) : This phenomena can occur in power MOSFET. This is a destructive event.

SEGR is considered in para 8.1.4 (LET characterisation and usage requirements) and 8.5 (rate acceptability compared with intrinsic failure rate).

- Single Event Transient **(SET)** : This phenomena can occur on Linear Bipolar devices and Digital Optocouplers. This is a non destructive effect.

SET is considered in para 8.1.5 (characterisation and usage requirements), and 8.4 (SET effects analysis).

- Single Event Hard Error **(SHE)** : This is a permanent bit flip, due to a local micro-dose deposited by the ion within the memory cell. Not destructive effect for the device, but permanent damage for the memory cell.

SHE is considered in para 8.1.6 (characterisation) and 8.5 (rate acceptability compared with intrinsic failure rate)

Para. 8.1: parts selection and characterisation

8.1.1 Single Event Upset

Taking into account that the SEU is a nondestructive effect, there is no requirement in terms of minimum LET threshold or maximum cross section. The subcontractor is requested to analyze the effect and the criticality of SEU for the equipment.

For digital technologies, the subcontractor shall use parts with a well known SEU sensitivity in terms of LET threshold and cross section (refer to paragraph « Single Event Phenomena (SEP) Rate Calculation »). If no data is available, the subcontractor is responsible to perform a Single Event Upset test :

- An **Heavy Ions testing** shall be performed in order to determine the Device Cross Section versus LET response of the device,
- If the orbit is exposed to proton environment and if the Heavy Ions LET threshold is lower than 15 MeV.cm2 /mg, then a **Proton induced SEU testing** shall be performed Test plans and the use of these parts requires express approval from ALCATEL.

There is no lot-to-lot variability, there is no lot testing requirements. Data collected for ‘ equivalent parts’ (see para. 5 [Definitions]) will be acceptable.

8.1.2 Single Event Latchup

RAD-10 As a preferred baseline approach, only Single Event Latchup Free parts shall be used.

RAD-11 Single Event Latchup sensitive parts could be used upon a case by case basis and requires ALCATEL approval.

Single Event Latchup sensitive part use shall be justified with a technical report providing : full device cross section versus LET curve (up to LET of 60 MeV.cm2 /mg), risk assessment, detection/correction circuitry, impact on reliability analysis, etc ..... The sub-Contractor shall demonstrate the compliance to mission requirements in terms of reliability.

8.1.3 Single Event Burnout

RAD-12 As a preferred baseline approach, only Single Event Burnout free parts shall be used.

In order to prevent permanent damage, bias requirement is as follows :

RAD-13 For N-Channel Power MOSFETs from Harris & International Rectifier, design requirements are as follows :

VDS < 50 % BVDSS @ BVDSS < 200 Volts

RAD-14 For VDS above 50% or BVDSS > 200 Volts or other manufacturers, Heavy Ions data shall be provided in order to demonstrate SEB free behavior

POWER MOSFET P-CHANNEL and BIPOLAR POWER transistors are SEB free.

RAD-15 Single Event Burnout sensitive parts could be used upon a case by case basis and requires ALCATEL approval.

Single Event Burnout sensitive part use shall be justified with a technical report providing : full device cross section versus LET curve (up to LET of 60 MeV.cm2 /mg), SEB risk assessment, detection/correction circuitry, impact on reliability analysis, etc ..... The sub-Contractor shall demonstrate the compliance to mission requirements in terms of reliability.

8.1.4 Single Event Gate Rupture

RAD-16 As a preferred baseline approach, only Single Event Gate Rupture free parts shall be used.

RAD-17 For Power MOSFETs from Harris & International Rectifier, design requirements are as follows :

N Channel : VG > 0 Volt

P Channel : VG < 0 Volt

RAD-18 Single Event Gate Rupture sensitive parts could be used upon a case by case basis and requires ALCATEL approval.

Single Event Gate Rupture sensitive part use shall be justified with a technical report providing : full device cross section versus LET curve (up to LET of 60 MeV.cm2 /mg), SEGR risk assessment, impact on reliability analysis, etc ..... The sub-Contractor shall demonstrate the compliance to mission requirements in terms of reliability.

8.1.5 Single Event Transient

This includes such devices as Linear integrated circuits that do not suffer logic upset as such, but may produce a large output spike that can appear as a false command. Design analysis shall be performed in order to assess the sensitivity of applications using sensitive devices. In case of sensitive application, experimental data shall be provided in order to justify the use of selected parts, and SET frequencies shall be determined.

8.1.6 Single Event Hard Error (stuck bit)

These hard errors are due to total dose effects from a few ions impinging on the gate oxide of sensitive transistors. Up to date, hard errors have been seen only in commercial SRAM cells as well as in DRAMs.

Para. 8.2: SEU rate calculation

For a given phenomenon, the part cosmic rays response is a curve of Device Cross Section versus LET of incident ions.

8.2.1 Heavy Ions Induced SEU

The Heavy Ions SEU rate thi shall be calculated for each active part. The sub-contractor shall submit its SEU rate calculation method to ALCATEL ESPACE for approval. If no tools are available to the subcontractor, the SOCRATE (Single Event Upset Optimized Calculation RATE) EXCEL macro-sheet will be provided to the sub-contractor.

8.2.2 Protons Induced SEU

The Proton SEU rate tpr shall be calculated for each active part having an Heavy Ion SEU LET threshold lower than 15 MeV.cm2 /mg, and if the orbit is exposed to proton environment. The sub-contractor shall submit its SEU rate calculation method to ALCATEL ESPACE for approval. If no tools are available to the sub-contractor, the SOCRATE (Single Event Upset Optimized Calculation RATE) excel macro-sheet will be provided to the sub-contractor.

8.2.3 Total SEU Rate

The Total SEU rate will be $\tau_{seu} = \tau_{hi} + \tau_{pr}$

RAD-19 The subcontractor is required to calculate SEP rates for all parts sensitive to cosmic rays and protons effects.

Para. 8.3: SEU effects analysis

RAD-20 The subcontractor is required to perform a SEU effects analysis in order to identify the SEU effects and criticality.

Para. 8.4: SET effects analysis

RAD-21 The subcontractor is required to perform a SET effects analysis in order to determine the effects of SET on equipment performance.

It is required to determine the following effects on performance :

OP-amps	Vmax = ± VCC & .tmax =15 µs
Comparators	Vmax = ± VCC & .tmax =10 µs

Voltage Regul	Vmax = ± VCC & .tmax =10 µs
Voltage Ref.	Vmax = ± VCC & .tmax =10 µs
PWMs	Double Pulses, two missing pulses, multiple missing pulses in a row, device shut off. Assess impact in specific application.
PLL	Transients and permanent changes in output voltage. In synthesiser circuits can cause phase, amplitude and frequency transients with duration determined by loop response.
Digital Optocouplers	.Vmax = ± VCC & .tmax =100 µs

For those applications, demonstrate that a SET will not produce an out of specification.

Para. 8.5: destructive single events effects

All Destructive Single Event Effects (Latchup, Gate Rupture, Burnout, Hard Errors, ...) could be acceptable only if the equivalent Destructive Single Event Failure Rate is 10 times lower than the intrinsic reliability failure rate of the part (@ 25°C).

RAD-22 The calculation rate method shall be submitted to ALCATEL for approval.

Non-ionising effect of radiation**, as displacement damage - ch. 9.**

Para. 9.1: environment to be resisted

NIEL effect is evaluated by conversion of electrons and protons energy spectra fluxes (integrated over mission time) into an equivalent 10 MeV proton fluence causing the same displacement damage in the target material, after passing a variable thickness of shielding material (aluminium). The curve is calculated and provided in [EnvTReq]

Para. 9.2: parts selection

Parts shall survive the lower Displacement Damage Equivalent Fluence calculated for the mission. At the DDEF level to be considered for the Herschel/Planck mission, only Optoelectronic devices (CCD, LED, Optocoupler,…) are displacement damage sensitive. For Bipolar and MOS devices, this effect can be ignored because the sensitivity threshold is high enough. The acceptance of the parts will be based on displacement damage test data. The data will be taken from neutrons testing databases and protons test results.

Equivalence between protons and neutrons will be deduced from NIEL values in the target material. If no data are available, protons irradiation evaluation tests shall be performed. The test plan will be submitted to ALCATEL for approval.

Displacement Damage tests shall be performed using the following sources :

- Protons @ energy > 50 MeV
- Neutrons @ 1 MeV

The electrical parameters drifts induced by displacement damage must be added to Total Dose drifts in the Worst Case Analysis.

RAD-23 All designs must account for the Displacement Damage produced by the Equivalent Fluence (DDEF), as specified in Applicable Document 1 [*id est*: [EnvTReq]]**.**

The subcontractor shall justify the use of EEE parts, according to Displacement Damage evaluation data.

RAD-24 Displacement Damage Degradation Database shall be submitted, during the Radiation Review, to ALCATEL SPACE for validation.

RAD-25 Equipment Worst Case Analysis shall be performed using this Displacement Damage Database.

Radiation Review - ch. 10.

A Radiation Review shall be held, at Preliminary Design Review time frame (PDR, EQSR, ...) in order to address the following points :

- To review total dose test reports, in order to validate the subcontractor radiation database These data will be used for equipment circuit WCA

- To determine part types that shall be submitted to a characterization and/or a RADLAT, selected parameters to be measured and to review radiation test plan for such parts
- To review proposed packaging design approach to achieve maximum inherent shielding.
  To review preliminary shielding analysis
- To review preliminary circuit design analysis.
- To review SEU parts data, in order to validate the subcontractor radiation database. These data will be used for equipment SEU effects analysis
- To determine part types that shall be submitted to a Single Event Upset testing, and to review radiation test plan for such parts
- To review circuit SEU effects analysis.
- To review the assessment on displacement damage on electronics if significant.
- ......

RAD-26 As a minimum, one Radiation Review meeting will be held at sub-contractor facility.

4.3 Radiation Environment Requirements “Sift”

To each unit or subsystem, an essentially homogeneous (within limits of single item applicability) conceptual “sift” was
devised and used, in order to organically monitor and report about the radiation analyses status, results and design impact, having considered applicable (as far as they indeed are to the individual items, of course), the requirements quoted and synthesised above. The results are reported in chapter 6.
Concretely, the following points have been observed:

- Applicability and presence – as individual document(s) or not – of a radiation analysis, comprehending the following broad areas:
  - the ionising effects of the radiations (TID analysis and shielding evaluation by means of the DD curve),
  - the non-ionising effects of the radiations (NIEL analysis and shielding evaluation by means of the DDEF curve, or, if applicable, the photovoltaic cell damage and degradation due to radiation),
  - the SEP effects, for short: SEEs (analysis of the various types of SEEs and calculation of their rates and consequences).
- Methodology, coherence, completeness, accuracy and correctness (as far as possible, as seen from system level) of the analyses scrutinised
- Coherence of the analytical results facing the environmental requirements
- Coherence of the actual reported qualification status and levels of hardness to radiations of the parts / components w.r.t. the minimum environmental / design requirements and, anyway, vs. the actual radiation level actually seen.
- Acceptability of radiation effects, also as damage / degradation, to unit and to general SVM design, as well as acceptability of design consequences necessary to counter the radiations input (shielding, …) or effects (redundancy, …)

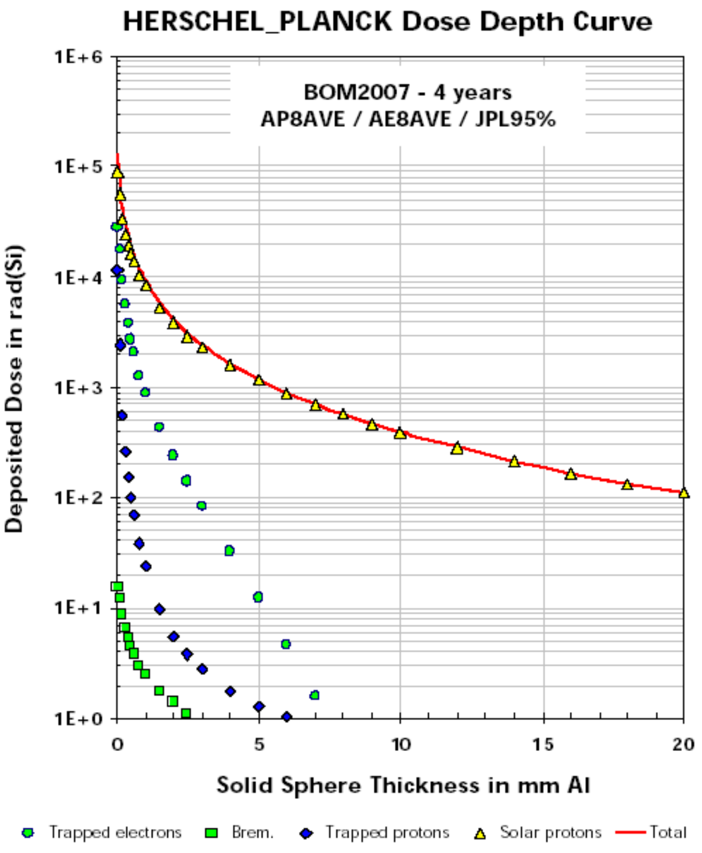
The taxonomic approach followed is intermediate between the extensive verbose description, on one hand, and the bare tabulated “one-word” synthesis, on the other one; id est: a short description is provided for every point to be evaluated, in the most common and commonly ordered way possible by using a formal scheme obtained enveloping the aspects of all the units.
Before screening of subsystem and units radiation analyses in chapter 6, chapter 5 provides with generally applicable considerations derived by the environmental boundary conditions, that may help assisting / deriving the related merit assessments.

5. PRELIMINARY SVM SYSTEM-LEVEL RADIATION EFFECTS ASSESSMENT

5.1 Total Ionising Dose Damage

In figure 5.1-1 the Herschel-Planck Total Ionising Dose versus Depth curve is reported from [ENVTR], where also there is the related table.

Considering the minimum acceptable TID hardness level of 10 krad (Si) for the active parts and the required Radiation Design Margin of 2 [RAD REQ], the aluminium solid sphere that guarantees a sufficient shielding has a thickness of 1.86 mm. Also not considering the Payloads shield, the shielding effect of the closure panels, the platforms, and the units' boxes should protect the SVM electronics by the total dose ionisation damage. For the electronic units mounted on the external side of the SVM assembly an adequate box thickness, shielding or proper devices will be used, if needed.



.Figure: 5.1-1: Total Ionising Dose versus Depth curve

To be noted the "maximum limit" (@ shielding = 0 mm(Al)) value of (4 years) TID of ~ 150÷200 krad for a "naked" Silicon detector.

Actually, this curve may help estimating the TID level for 1mission lifetime (to be then multiplied by two), to get a conservative assessment at unit ("equipment box") level, simply entering it with the thickness seen from inside of the box by every face, obtained by summing the constant thickness per face (constant over solid angle) value of 0.8 mm(Al) valid for each side of the 2-meter-sided cube (equivalent satellite for an equipment mounted inside SVM – [RAD REQ] para 7.3) plus the actual "Al-thickness" of each of the box sides; the resulting 6 doses will be summed after multiplying them by their solid angle fractions (id est: doses per face will be summed up). Even more conservatively, and if sufficient: the minimum thickness between the box sides ones will be added to the satellite's 0.8 mm(Al), and the corresponding dose extracted from the curve.

This value is to be compared and to result lower than the component minimum TDT of 10 krad, or its possible higher ionising dose hardness.

A first, immediate, assessment valid for any item mounted internally to SVM, in a closed-compartment way, can be derived by the 0.8 mm(Al) "thumb" rule: TID can never exceed 11.7 krad, over 4 years, that is: 23.4 krad over the full RDL. As a matter of fact, [HP RADSHAN], chapter 4, shows that 0.8 mm(Al) are the very minimum value of the actual satellite shieldings provided for each face of the equipments inside the SVM, both for Herschel and for Planck.
Even more, in [HP RADSHAN] chapter 5, a 1 mission lifetime dose calculation (preliminarily made assuming a uniform thickness of 0.8 mm(Al) for the all the boxes' wall) shows that the margin of 2 w.r.t. the TDT of 10 krad is always satisfied for all the equipments, , even those mounted outside the satellites, exception made only for the Planck focal plane unit (TID = 10 krad).

5.2 Non-Ionisation Displacement Damage

In figure 5.2-1 the Herschel-Planck Displacement Damage (induced from Non Ionising Energy Loss Dose) Equivalent Fluence versus Depth curve is reported from [ENVTR], where also there is the related table.
Considering the minimum level of acceptable hardness in terms of DDEF of $6 \cdot 10^{+9}$ $_{10MeV}$ p^+ / cm^2 for Silicon detectors for the active parts, and the required Radiation Design Margin of 2 [RAD REQ], the aluminium solid sphere that guarantees a sufficient shielding has a thickness of 4.53 mm. For GaAs detectors, the minimum level of acceptable hardness in terms of DDEF is of $5 \cdot 10^{+9}$ $_{10MeV}$ p^+ / cm^2 , and the corresponding aluminium solid sphere shielding has a thickness of 4.63 mm. The shielding effect of the closure panels, the platforms, and the boxes' units should protect the SVM semiconductor by the displacement damage. For the electronic units mounted on the external side of the SVM assembly an adequate box thickness, shielding or proper devices will be used, if needed.

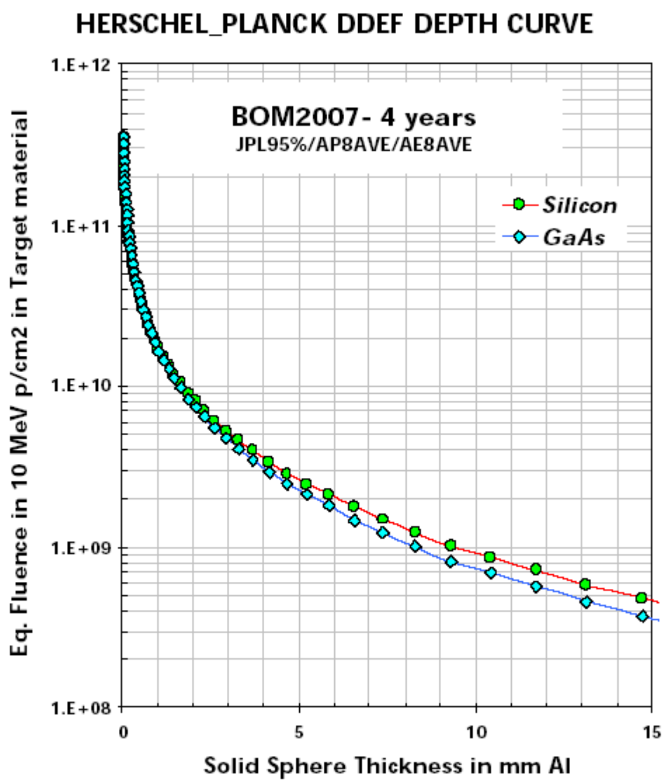


Figure 5.2-1: Displacement Damage Equivalent Fluence versus Depth curve

To be noted the "maximum limit" (@ shielding = 0 mm(Al)) value of (4 years) DDEF of ~ $(5 \div 6) \cdot 10^{+11}$ $_{10MeV}$ p^+ / cm^2 for a "naked" either Si or GaAs detector.

Actually, in a way completely similar to TID case, this curve may help estimating the NIEL-DDEF level for 1mission lifetime (to be then multiplied by two), to get a conservative assessment at unit ("equipment box") level, simply entering it with the overall thicknesses seen by each of the faces from inside of box, and deriving an overall DDEF value, more or less conservative, as for TIDs.
This value is to be compared and to result lower than the component minimum DDEF of $6 \cdot 10^{+9}$ $_{10MeV}$ p^+ / cm^2 for silicon detectors (or of $5 \cdot 10^{+9}$ $_{10MeV}$ p^+ / cm^2 for Gallium Arsenide detectors), or its possible higher non-ionising dose hardnesses.
A first, immediate, assessment valid for any item mounted internally to SVM, in a closed-compartment way, can be derived by the 0.8 mm(Al) "thumb" rule: DDEF can never exceed, for Silicon items, the value of $2.26 \cdot 10^{+10}$ $_{10MeV}$ p^+ / cm^2, over 4 years, that is: $4.53 \cdot 10^{+10}$ over the full RDL; respectively: the value of $2.21 \cdot 10^{+10}$ $_{10MeV}$ p^+ / cm^2, over 4 years, that is: $4.41 \cdot 10^{+10}$ over the full RDL for Gallium Arsenide detectors.

A similar comfortable consideration, as per ionising radiation dose, holds as a matter of fact from [HP RADSHAN] results consideration, again both for Herschel and for Planck.

5.3 Single Event Effects Damages

As baseline [RAD REQ] only parts insensitive to the following destructive events will be used:

Single Event Latch-up	(SEL),
Single Event Burnout	(SEB),
Single Event Gate Rupture	(SEGR),

for which parts a minimum LET_{th} value of 60 MeV/(mg/cm^2) is required to state insensitivy; in the opposite case, knowledge of the relevant full device cross section σ (LET) is requested, and risks, impacts, detection and correction analysis, as well (see previous requirements chapter).
On the contrary, no minimum LET_{th} or maximum σ values are specified for the non destructive events:

Single Event Upset	(SEU),
Single Event Transient	(SET),

however for sensitive devices, frequencies of events and analysis of effects and criticality on design are requested.

5.3.1 Single Event Upset (SEU)

In particular, for SEU, determination of **SEU rate** t_{SEU}, is required, by means of a suitable applicative programme, starting from the environmental boundary conditions of the mission as per [ENVTR], and availing of the device's cross section σ (LET). If no other calculation tools are available, SOCRATE, then OMERE, is to be used, provided by Alcatel.
If the Heavy Ions threshold LET is lower than 15 MeV/(mg/cm^2), the total rate τ_{SEU} is to be calculated adding the effect of (galactic and solar) protons:

$$t_{SEU} = t_{HI} + t_{p} .$$

Even in a conservative way, it is possible to estimate SEU rate(s), instead that from the environment, directly from the curves / tables with provided by [ENVTR] for the Herschel-Planck missions environment.

In figure 5.3.1-1 the [ENVTR] Heavy Ions induced SEU rate as a function of the LET threshold of the device is reported.
It may be used, by entering even just the threshold LET and the saturation cross section of the critical device characteristic, the "single upset rate" t_{HI} in upsets/day related to heavy ions.

In figure 5.3.1-2 the [ENVTR] Protons induced rate curve as a function of the Proton energy threshold A of the part is reported.
It may be used in a similar way, to compute (estimate) a "single upset rate" in upsets/day related to protons.

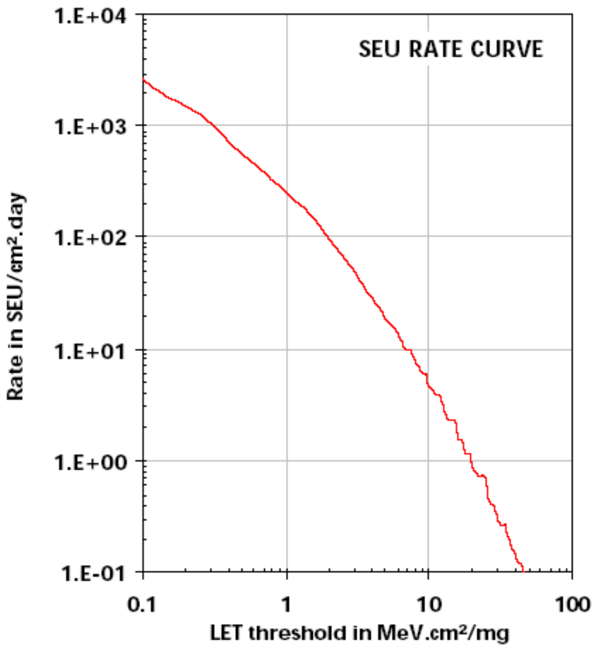


Figure 5.3.1-1: Heavy Ions Induced SEU Rate

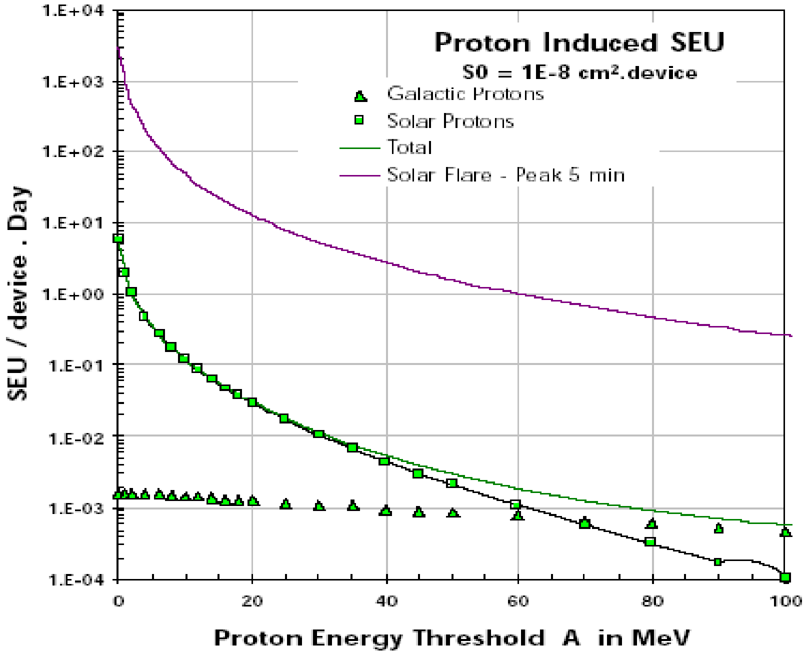


Figure 5.3.1-2: Protons Induced SEU Rate

6. SVM SUBSYSTEMS AND HOSTED UNITS RADIATION ANALYSES

The radiation analyses produced in the course of the design activity of the SVM units and subsystems listed hereafter were looked for, screened, and their methods and results evaluated in order to assess their compliance to the relevant requirements directly concerning them and already illustrated in the previous para.s ___; indeed, also the effects of their output into the units design was evaluated, so that the designs themselves can be considered adequate to the aims of surviving the operational environment of the Herschel and Planck missions.

SubSystems and Units Considered

- **ACMS**, at subsystem level, as well as, at unit level (ACC is shifted by homogeneity to CDMS group):
  - AAD
  - CRS
  - GYR (Herschel only)
  - RWA (Herschel only)
  - SAS
  - STR
- **CDMS**, at unit level:
  - ACC
  - CDMU
- **HRN**, at subsystem level
- **PCS**, at unit level:
  - BATT
  - PCDU
- **SA** (Planck only)
- **RCS**, at unit level (only radiation sensitive ones):
  - Pressure Transducer
  - Latching Valve
  - Tank Diaphragm
- **TCS**, at subsystem level
- **TT&C**, at unit level:
  - LGA/MGA
  - RFDN
  - (EPC+) TWTA
  - XPND

6.1 ACMS

ACMS Radiation Analysis is contained into **[ACMS RADAN], iss. 1,** examined in occasion of ACMS CDR, as commented in the following.
The CDR review was performed at subsystem level, considering all the units as all radiation sensitive: AAD, CRS, GYR, RWA, SAS, STR (see details reported accordingly in the following paragraphs).
1 **Radiation RID** was submitted:

ACMS_CDR rid n. 10689 "Missing Radiation Hardness Analysis in Design Reporting" (major, dated 16/04/2004) then changed (after late arrival of the [ACMS RADAN]) in:

"Radiation Analysis Overview Open Points" , sent on 26/04/2004 .

After the CDR MoM H-P-MI-AI-0497 dated 27-29/04/2004, the first issue was closed as superseded by the second, and the second accepted by DS/SEN as comments, to which answer within 28/04/2004 by action item AI#03 DS as per page 4, but AI#197 DS within 31/05/2004, on page 23. Its status is to-date: <u>open</u>.

Since actually the open points in the RID are addressed to unit level contents, being [ACMS RADAN] only a synthesis plus a discussion of the units radiation analyses, they will be discussed in the following unit paragraphs.

<u>Synthetic evaluation</u>:
The unit dedicated paragraphs in chapter 3 of [ACMS RADAN] should be considered for the time being "on-hold", since the evaluation of analyses of radiations effects have been made as seen directly at units level, and in case of discrepancies or missing points from subsystem level, the unit level "reading" is now considered prevailing.

<u>Conclusions</u>:
The conclusive chapter 4 of [ACMS RADAN] should be considered for the time being "on-hold", since the unit level open points and the related conclusions in this document chapter synthesised prevail until RID answer is get.

<u>Status</u>:
Open, awaiting for ACMS CDR successful conclusion.

6.1.1 AAD

A self-standing AAD Radiation Analysis does not exist as such, but is contained into **[AAD DESAN], iss. 3,** which was examined and commented, and comments indirectly addressed to AAD as inserted in the submitted upper level **ACMS CDR Radiation RID 10689**, to-date status being: <u>open</u>, whose AAD section concerned: NIEL effects.

<u>Synthetic evaluation</u>:
radiations effects related to AAD are only felt as silicon photodiode degradation, which is dealt considering it "like a solar cell". Degradation effect is linked to decay in I_{sc}, and increase in Tempco, whose impacts on AAD design and performance are considered acceptable.

<u>Details:</u>

➢ **<u>NIEL</u>** (see RID, bullet AAD-1):
Quoting from page 8 of [AAD DESAN]: "Each detection module consists of an optical head and a single-chip photo voltaic light detector. The latter is a silicon photodiode with a nominal active area of 10 x 10 mm, which in size, appearance and performance is identical to the chips of the dual-chip detector in the SAS", and from page14: "The AAD is a passive unit, i.e. it does not need power from the system and there are no power lines to or from the CSS unit. Its electronics is limited to p-n junction silicon diodes, which produce currents of typical 0.26mA at 1 Solar Constant (see section 4.37)".
Therefore only **NIEL effects** are to be **evaluated**, as degradations of the silicon photodiode performances**, vs its tested hardness**: the equivalent fluence of 1 MeV <u>electrons</u> for I_{sc} in Si, is calculated by [AAD DESAN], para 4.23, page 36, as $1.5\cdot10^{+14}$ $e^-_{@ 1 MeV}$ /cm^2 under a 300 μm thick cover glass, and then compared to test values ($1\cdot10^{+15}$ $e^-_{@ 1 MeV}$ /cm^2) with a margin factor of 7.
Actually, use of <u>correctly quoted [ENVTR] table 3.4-13 data for Silicon solar cells I_{sc} degradation</u> (variable front glass cover, infinite back shielding) for **5 years**, leads – **by Alenia assessment** – to a value of $1.12\cdot10^{+14}$, to be scaled down to a **4 years** value of $8.96\cdot10^{+13}$, and, considering, eventually, 2 times 4 years, as the radiation design lifetime, to the final value of $1.79\cdot10^{+14}$ $e^-_{@ 1 MeV}$ /cm^2 . The margin is then ~ 5.6 , however widely satisfactory since >> 2.

The resulting detector degradation by NIEL, conservatively assumed at test level:

I_{sc} from 100 % to 97 %,

Tempco from 0.06 %/°C to 0.12 %/°C,

are acceptable, and entered in **worst case analysis** and **FMECA** in order to verify the compliance with functional performance and interface electrical requirement.

Conclusions:
AAD radiation (NIEL) analysis results are acceptable.
Status:
Closed. (**Open**, only formally, awaiting for ACMS CDR successful conclusion).

6.1.2 CRS

A self-standing CRS Radiation Analysis for Herschel Planck missions was provided at beginning of April 2004: **[CRS RADAN], iss. 1,** which was examined and commented, and **comments** addressed to LABEN in occasion of the QSR closure as such, dated 19/04/2004,
concerning TID, NIEL, SEE, the comments status being: closed by action item "LABEN #1", due date not defined, to-date: open.
(besides, it was included in the submitted upper level **ACMS CDR Radiation RID 10689**, to-date status being: open).

Connected Document:
[CD CRS] "Coarse Rate Sensor Assembly (CSRA) Detailed Design Report",
TL 20107, issue 2, H-P-4-LAB-RP-0001, dated 06 Apr 2004

Synthetic evaluation:
The document is not exhaustive (uncertain elements in TID analysis, NIEL analysis not mentioned, open areas in SEE), and despite confidence exists above all for item TID behaviour vs. hardness, it needs to be revised and integrated, after discussion of the following comments.

Details:

➢ **TID** :
Analytical verification is made by means of **ESABASE/RADIATION/DOSRAD;** it lends itself to some comments:

- in [CRS RADAN], para.s 6.1 and 6.2, the simplified model of CRSA is described, but not justified by recalling the sources of selected walls thicknesses (drawings, …): the latter (materials and thicknesses shall be provided); aluminium as a material or equivalence to it shall be explicitly given;
- clarification about panels qualifiers like "left", "top", "front" and the like should be linked to {x,y,z} frame in fig. 6.1 (without looking to target labels in appendix A);
- clarification about "worst case panels thickness" meaning is requested: in which sense is it a "worst case", does that include also electronic boards thickness ? ;
- definition of T1 to T4 as "most exposed locations" shall be explained.

Furthermore, in the previous point subject, the **selection of 2 mm(Al) as simplified** (2 m sided cubical) **satellite wall** thickness is not coherent with [RAD REQ] (para 7.3) requirements (correct value is 0.8 mm(Al)), as derived by local "AD 4" (e-mail from SENER, 19 Feb 2004, closure of BR-06 of H-P CRSA-QSR 2nd, H-P-4-SEN-MoM-0036). Clarifications as first are needed, "AD 4" shall be validated and, in case, attached to the document.

This point is discussed in QSR close out session, but a conclusion is not drawn.

What it will be the precise result in case of 0.8 mm instead of 2 mm?
Alenia rough assessment with 3.8 mm(Al) (SVM sides + minimum (top panel) of CRS sides) leads to a worst case estimate of 1.79 krad, which becomes 3.58 krad for full RDL of 8 years, so nothing dangerous occurs.

TID degradation input to Worst Case Analysis ([RAD REQ], para. 7.4) is **not found** and has to be provided.

To be reminded [CRS RADAN], para. 5.1: the applicable requirement which states that **Radiation Design Lifetime (RDL) = 2 times the nominal mission lifetime** is from local AD 3 - [RAD REQ] (ch. 1) and AD 2 (ENVR-010), not AD 4.
TID radiation hardness of 10 krad as minimum for all items is reported and vs. it all the actual level show a margin larger than 2. However, these results will be frozen after the previous points revision.

In QSR close out session minutes,point n. 16 reports a missing value (acceptable, as as minimum 20 krad) concerning item AD670,which was due, but this open point did not appear in [CRS RADAN] .

- **NIEL** :

NIEL aspects are completely **missing** in the document; if no components sensitive to Displacement Damages caused by NIEL are found, this shall be stated explicitly

- **SEE** :

SEU (Para 7.1)
On the **analytical side**, [RAD REQ] para. 8.1.1 and 8.2 require to perform **calculations of SEU rate** due to Heavy Ions in any case (for each active component), and to calculate, and add to the former one, the SEU rate due to Protons in case of LET threshold lower than 15 MeV/(mg/cm^2). These calculation require to know the devices LET thresholds and spectra and phenomenon cross section in order to calculate HI-SEU rate and PR-SEU rate according to requirements ENVM-440, ENVM-450, and to submit to Alcatel the proposed calculation method.
This **remains to be performed** (considering also threshold values in [CD CRS] pages 25; 104 & 105 (converter)), despite in [CRS RADAN] para 4.2 the (mere) environmental boundary conditions are recalculated in terms of integral directional flux of galactic cosmic rays (fig. 4-2 equivalent to [ENVTR] fig. 3-24 for solar minimum).
A check is suggested for fig. 4-3 and –4, showing growth of LET-spectrum of integral directional flux of "galactic cosmic rays" when solar activity increases: the contrary would be expected (see also req. ENVM-420 text): would not it refer to "solar particle cosmic rays" ?

Furthermore, the results of an analysis, component by component, showing compliance with electrical / functional requirements, including [GDIR] requirements ENVR-100 to -170, is missing.

On EEPROM, in which way is $\overline{WE}$ pin connected?

SET (Para 7.2)
An assessment of compliance vs. electrical requirements due for example to SET effect (required by [RAD REQ] para. 8.1.5 and 8.4) is missing.

Narrow Band filtering is mentioned: where is this filter, and what does it mean in terms of frequency ?

What is the effect of SET on DC/DC converter? reference to RMU is not enough. Was a SPICE simulation performed and an effect estimated?

OP400AY: in which way was +/- 10 deg/s found out ? The reference is +/-Vcc (+/-12V) for t=15 μs .

SEL
[RAD REQ] para. 8.1.2 requires to perform analysis of SEL impacts in case non-SEL-free parts are used.
Most of the components (see list on [CRS RADAN] page 15) are not explicitly mentioned in SEL paragraph (Para 7.1) but they are defined "all SEL free" (considering also QRS sensor in [CD CRS] on page 21; DC/DC converter in [CD CRS] on page 104). EEPROM on the contrary is reported, with a (high) LET threshold.
Was the LET threshold of [RAD REQ] para. 8.1.2 considered ?

SEB, SEGR
SEB and SEGR non consideration due to absence of power MOSFETs shall be declared.

SHE
Missing consideration of SHE for mentioned components (for example EEPROM) needs to be explained. If the components are SHE tolerant, it shall be written.

General
Diode Switching 1N6640 is not considered. Why? If not necessary it shall be written.

Issue: some components are only considered for one effect, why the other effects are not considered? For example: SEU effect on DAC or on ADC.

For component AD670, considered in para 7.1, it is necessary to progress beyond the "not enough information to give a SEE analysis" level.

This point is not covered by data on TID hardness on point 16 of QSR close out session minutes.

Conclusions:

The document shall be modified and updated according to all points raised above, so that compliance to requirements and acceptability of design do become complete. If about TID behaviour essential confidence exist about requirements fulfilment, SEE is open point.
LABEN (see HP-4-SEN-MoM-0043, on 20/04/2004, point 14), closed formal reply to comments with a **commitment (**by action item "LABEN #1") **to provide answers to comments themselves to the Radiation Analysis;** point 16 of same MoM provided (only) the TID qualification test data for item AD670, requested by previous action item, not the SEE data requested in present comments.

Status:
Open, awaiting for comments discussion, feedback, and successful implementation (apart point on AD670 TID hardness, already achieved).

6.1.3 GYR (Herschel only)

A GYR Radiation Analysis, for Herschel only mission, was provided as **[GYR RADAN], iss. ==,** which was examined and commented, the first comment being that unfortunately it is not a fluent, self-standing text, but a presentation, featuring a lot of synthetic statements, and a lot of missing logical links and explanations among them. **Comments** were indeed indirectly addressed to GYR as inserted in the submitted upper level **ACMS CDR Radiation RID 10689**, to-date status being: open, whose GYR section concerned: TID, NIEL, SEE effects.
besides, a Radiation Hardness Assessment was found in the

Connected Documents:
[CD GYR LIF] "Scalable SIRU Life Analysis Report for Herschel Scalable Space Inertial Reference Unit (SIRU)", Northrop Grumman Doc. 295230, revision April 2002.
[CD GYR RADH] "Standard Radiation Hardness Program Plan", Northrop Grumman Doc. PAP-SPACE-5-NSD, revision December 2002.

Synthetic evaluation:
Despite the intuition of extensive and complete dealing of all the aspects related to the analyses versus the requirements, and the expected satisfactory results, a clear understanding of the premises, hypotheses and flow of calculation, and applicability of results obtained versus the qualification status in terms of radiation hardness is not possible due to the mentioned excess of synthesis of the "slide-like" kind of prose. See the details hereunder, including also open point and comments.

Details:
The initial discussion, defined "Radiation Analysis", on pages 1 to 32, on accepted / rejected requirements and design status of the art is not well described, in the light of what generally ascertained before, and a general framework, top level intention explanation is missing; leading to doubtful interpretation even of some points the applicable general, environment and radiation requirements.

➢ **Radiation Hardness**
On page 11of the subsystem level [ACMS RADAN], a general Standard **Radiation Hardness** Program Plan [CD GYR RADH] is quoted, applicable to GYR.
Concerning **displacement damage**, it is observed that qualification levels are quoted from it, and actually given in [GYR RADAN] as equivalent 1 MeV neutron fluence levels (actually: $4 \cdot 10^{+11}$ neutrons / cm^2 in [CD GYR RADH]), while is requested by H-P specifications in equivalent 10 MeV proton fluence levels. Since not present in the quoted [ENVTR] fig. 3-20, **an equivalence factor has to be provided** to prove the previous statement, also taking into consideration that, the actual equivalent 10 MeV proton fluence levels are provided by the [RAD REQ] fig. 3-32 vs. the shielding thickness in Al, and rise up to ~ $5 \cdot 10^{+11}$, for zero shielding.
A similar assessment is found also in [CD GYR LIF], appendix D, where 3 types of scalable SIRU™ Radiation Hardness Levels are illustrated: type A is the low(er) total dose one, featuring TID hardness till 10-20 krad, displacement damage till $1 \cdot 10^{+12}$ neutrons (at which energy ?) / cm^2 (become $2 \cdot 10^{+11}$ neutrons / cm^2 for types B and C), immunity from SEL until 100 MeV/(mg/cm^2), SEU rate , 1 in 10 years for GCR.
Thus: the **actual radiation hardness levels** ought to be indicated clearly and in the right measurement units just in the [GYR RADAN].

RLAT analyses on pages 61 to 69 need, at least, a top-level introduction and detail explanations.

➢ **TID**

TID analysis is mixed up with NIEL analysis, in the section titled "Permanent Damage Analysis" on pages 33 to 60 of [GYR RADAN] – a document that is a presentation, not a true report, so, despite the favourable TID results reported, as expected, the **analysis description is difficult or impossible to follow**, as only "bullets" and short statements without explicit introduction and most of logical connections are quoted, and **TID analysis execution (made by Excel calculation sheet) is impossible to understand and verify**: in fact, TID calculation method illustration (pages 34 on) cannot be considered neither self-explanatory, nor explained enough.
3 different analyses were performed, with very limited explanations, only 1 with the correct 0.8 mm(Al) equivalent satellite shielding, their aims remaining undisclosed…
The meaning of data on pages 40-41 (no satellite shielding) is not understood.
To summarise: **a more complete and understandable explanation document** (including breakdown, aims, names of devices, symbols and variables, intentions of tables, meaning of colours, etc.) **shall be provided, before a solid evaluation may be given**, despite results on page 39 report large margin for 1 lifetime maximum TID accumulated, vs. radiation hardness.
(Anglo-saxon units (mils) were neither to be expected nor welcome in the document.)

WCA input is not clearly evidentiated.

➢ **NIEL**

DDEF analysis is in [GYR RADAN], spread in the same page of TID one, and similar comments to the above made can be repeated. A difference is that for DDEF, no explicit conclusion is drawn neither vs. actual nor vs. minimum hardness.
An equivalence factor 3× was considered (pages 21, 22) from equivalent 1 MeV neutron fluence levels to equivalent 10 MeV proton fluence levels: it must be explained and justified.

The meaning of data on pages 40-41 (no satellite shielding) is not understood, also for NIEL.
Some optical components (optocoupler) are considered in [GYR RADAN], but are not referred in [ACMS RADAN]. Are other ones present?

WCA input is not clearly evidentiated.

➢ **SEE**

Similar comments as above is applicable for SEE section – pages 70 to 86 – too, in terms of **very difficult understanding** of logical flow of **physics**, **methodology** and of **hypotheses** and **results – SEU rate calculation method is not even declared at all**. **Verification of results is impossible, if not by attempts**. For instance, which is the physical meaning of "Upset Critical Factor" and how is it calculated, and against which requirement ?

SEU

Pages 74 to 78 cannot be accepted as such, but must be clearly explained and results testable vs. [RAD REQ] methods of para. 8.2 and or using data in [ENVTR], para. 3.4.4, as well as SET calculations in the following pages.
More in detail:
After having provided the cross section value and the SEU error/per day, the demonstration that a SEU cannot induce a catastrophic event is missing. Then, SEU effect shall be included inside FMECA analysis and should be referred into GYR documentation (as well as ACMS documentation).
SET immunity or tolerance shall be clearly demonstrated inside the documentation.
Permanent Damage Protection values for Power MOSFET devices against SEB/SEGR must be explained vs. [RAD REQ] RAD-13 and RAD-17.
Another question is when will IRHF9130 and IRHF7230 compliance with requirements be demonstrated, and if an additional test is foreseen or if a RFW to cover the requirement not fulfilled will be issued?

Tolerance to SHE effect on memory is not reported.

Conclusions:

Open points to be clarified and uncertain interpretation of document [GYR RADAN] suggest to wait for reading an issue logical and verbose enough, and to receive answers to levied comments. If TID and NIEL hardness is felt as seeming to be sufficient, SEE areas are above all unclear, as linked to design features.

Status:

Open, awaiting for comments discussion, provision of answers, and successful upgrading of document from presentation to text level.

6.1.4 RWA (Herschel only)

A self-standing RWA Radiation Analysis for Herschel mission was provided as composed by the two documents: **[RWA TIDAN], iss. 1, [RWA SEEAN], iss. 1,** which were examined and commented, and comments indirectly addressed to RWA as inserted in the submitted upper level **ACMS CDR Radiation RID 10689**, to-date status being: open, whose RWA section concerned: TID (and NIEL) and SEE effects.

NOTE: this unit is expected to be reviewed at RWS CDR.
Since RWS documentation is still under evolution, a final assessment shall be provided just with CDR documentation examination.

Synthetic evaluation:
Radiations analyses – even preliminarily examined – showed large dark areas hampering a complete and suitable understanding of hypotheses, models, and results: before estimating an assessment on radiation impacts on RWA design and acceptability of RWA performances, a deeper screening, possibly after timely removal of foggy spots, as outlined in the following, is necessary.

Details:

➢ **TID**

[RWA TIDAN] quotes **TID analysis results**, which are considered compliant to requirements "as such", despite it is not clear whether they are referred to 1 or 2 mission lifetimes. However, a careful reading of the mentioned document highlights that its reporting features are inadequate to permit a third party to achieve a complete and satisfactory independent verification of its goals, as in general **too poor of contents and links among them**, and in detail leads to the following comments (ref. is to [RWA TIDAN]).

Para. 2.1: among the applicable documents also the RWA specification, and the [GDIR] and the [RAD REQ] specifications must be added, as well as the Declared Component List.

Ch. 3: there is no picture that correlates names and numbers of the considered items (table 3.2.1-a) with their position in the obscure drawings on pages 9, 10, 11, 12, 13, as well as with the list in ch. 4 (table 4.1-a).
Since no element about the used materials (only equivalence to aluminium thickness) is given (not to speak of their geometry), **no verification is possible** also for this reason. Does the model represent the **worst case values?** The hypothesis on **equivalent Al thickness** is said to be in agreement with [RAD REQ], Para 7.3; explicitly: **which value was used?**
The **time considered** to calculate the **integrated radiation dose** has to be reported.
No data or statement is present about the **qualification status** and level of the analysed components (as well as their data mentioned in para. 3.2.5).

Despite actual confidence in the fulfilment of actual TID levels exists, the **previous open points must be closed**.

As a shielding analysis, also **NIEL displacement damage ought to be considered**, at least to explicitly state that no components subject to it are present in RWA, if so.

➢ **SEE**

On [RWA SEEAN] a comment similar to the previous one is made on requirements AD to be mentioned in its para. 2.

Then, since in general, as said, this unit is expected to be detailedly reviewed at RWA CDR, and a deeper evaluation shall be performed at CDR time, - and in particular evaluation and assessment of qualification data and following uncertain points a b c. – NOW, ONLY PRELIMINARY CONSIDERATIONS ARE PROVIDED, sufficient to initially highlight a quite poor analysis status.
The more general points affected by uncertainty are:
Para. 1.6, p. 6:
with SEU considered as SET, and
Para 3, page 8:
where some more clarification has to be provided on which effects are considered under points:
a : seems quantitative evaluation for rates etc for SEU=SET in para 5.1, SEL in para 5.2, SEGR in para.5.3).
- Why is SEB not considered?

b : seems SEU=SET functional evaluation at local (part) level in para 6
c : seems SEU=SET functional evaluation at global level in para 3.2.1.

Furthermore,
Page 9, para 3.1.4:
SEB requirements (first line) are mixed up with SEGR's:

Page 10: para 3.2:
third line of SET requirements has an error as ΔV_{max} = +/- V_{cc} , not 5 V

Page 10: para 3.2.1:
SET induced Latch Up leading to loss of function with probability = (2.24 $\cdot 10^{-6}$ per hour ± other two unknown value addenda) is evidently an open point to close.

Page 11, : para 3.3: page 12 onwards (ch. 4 to 6):
all these sections are to be evaluated in detail with relation to the design for the unit CDR.

Page 12: para 4.1: N1, N2, V28, V29 references are not understood.

Page 12: para 4.2:
origin of requirement on SEL / SEB of immunity until 80 MeV/(mg/cm^2) (not MeV/(cm^2 / mg)) instead of 60 has to be explained; SEGR immunity reported only till 37 MeV/(mg/cm^2).

Page 12: para 4.3:
Whether protons insensitivity be related to negative tests or to missing tests, has to be clarified.

On ch. 5:
were SEU=SET rate calculations with CREME96 approved by Alcatel (as per [RAD REQ] para 8.2.1 (and 8.2.2)) ?
A clarification about "numbers" is necessary: a check made by Alenia with data of component HCC40106BD about LETth and (saturation ?) cross section σ from TELDIX, and use of table 3.4-9 of [ENVTR] led to SEU=SET rate per hour = $9.5\cdot10^{-10}$, vs TELDIX result of (<) 398 (or 3.98 ?)·10-12 . Other values are OK, again if no missing decimal point exists…

On ch 6:
calculation details are missing ! Correlation to ch. 5 has to be provided.

In general:
are in RWA present only International Rectifier Components or Harris components?

Conclusions:
CDR evaluation necessary before a final assessment can be given, preliminarily: scarcity of contents and logical links observed.

Status:
Open, awaiting for CDR comments, discussion, feedback, and their successful implementation.

6.1.5 SAS

A self-standing SAS Radiation Analysis does not exist as such, but is contained into **[SAS DESAN], iss. 3,** which was examined and commented, and comments indirectly addressed to SAS as inserted in the submitted upper level **ACMS CDR Radiation RID 10689**, to-date status being: open, whose SAS section concerned: NIEL effects.

Synthetic evaluation:
radiations effects related to SAS are only felt as silicon photodiodes detectors degradation, which is dealt considering them "like solar cells". Degradation effect is linked to decay in I_{sc}, and increase in Tempco, whose impacts on SAS design and performance are acceptable.

Details:
- **NIEL** (see RID, bullet SAS-1):

Quoting from page 8 of [SAS DESAN]: "The detectors are n on p type silicon photodiodes with a nominal active area of 10 x 10 mm^2. The detectors are mechanically grouped to pairs, bonded to a substrate. Each pair contains a nominal and a redundant active area. Four of such pairs are attached to the four sides of a truncated pyramid (part of the SAS-housing), located at the centre front-side of the structure. The pyramid angle chosen for Herschel Planck is 22°.", and from page12: "Another aspect of electrical lay-out concerns the type of output. The detector chips applied in the SAS are current sources which produce photo currents up to about 33 mA for I solar constant illumination. The SAS is a passive unit without active pre-processing of these detector currents. It is technically feasible to convert photo currents passively into voltages."
Therefore only **NIEL effects** are to be **evaluated**, as degradations of the silicon photodiode performances**, vs its tested hardness**: the 1 Mev (**electrons**) equivalent fluence for I_{sc} in Si, first calculated by [SAS DESAN], para 4.2.16, page 29÷30, as $1.5 \cdot 10^{+14}$ $e^-_{@ 1 MeV}$ /cm^2 under a 300 µm thick cover glass, and then compared to test values ($1 \cdot 10^{+15}$ and $3 \cdot 10^{+15}$ $e^-_{@ 1 MeV}$ /cm^2) with a margin factor of 7 in the first case.
Actually, use of correctly quoted [ENVTR] table 3.4-13 data for Silicon solar cells I_{sc} degradation, data for **5 years**, leads – **by Alenia assessment** – to a value of $1.12 \cdot 10^{+14}$, to be scaled down to a **4 years** value of $8.96 \cdot 10^{+13}$, and, considering, eventually, 2 times 4 years, as the radiation design lifetime, to the final value of $1.79 \cdot 10^{+14}$ $e^-_{@ 1 MeV}$ /cm^2 . The margin is then ~ 5.6 , however widely satisfactory since >> 2.

The result of NIEL detector degradation, conservatively assumed at test level:
I_{sc} from 100 % to 97 %, id est –3% (@$1 \cdot 10^{+15}$; becomes –7% @ $3 \cdot 10^{+15}$ $e^-_{1 MeV}$ /cm^2),
Tempco from 0.08 %/°C to 0.12 %/°C,
are acceptable and entered in **worst case analysis** and **FMECA** in order to verify the compliance with functional performance and interface electrical requirement.
In particular, a clarification is pending: since the effect of Radiation Displacement Damage on SAS should act as a Differential Effect w.r.t. the receiver, it shall be clarified why it is considered as a common mode effect to be rejected by the system, and, anyway, the verification of CMRR requirement verification shall be provided.

Conclusions:
SAS radiation (NIEL) analysis results are acceptable, despite the pending clarification.
Status:
Closed. (**Open**, only formally, awaiting for ACMS CDR successful conclusion).

6.1.6 STR

STR Radiation Analysis contained into **[STR RADAN], iss. 2,** examined in occasion of STR CDR hold on 04 and 05 May 2004.

Radiation RID CDR-AI-STR-ENG-021 (major), dated 03/05/2004, submitted, accepted as comments, see pages 1 and 2 of CDR minutes HP-DS-MN-128 rev. 1, dated 17/05/2004, action taken by GAL to provide answers; likely, the closure is related with action item AI GAL 03, closure date:13/05/2004, to-date status being: open.
The RID was concerning:
- general aspects,
- TID aspects,
- NIEL aspects,
- SEE aspects.

(besides, the RID contents were also included in the submitted upper level **ACMS CDR Radiation RID 10689**, to-date status being: open).

Synthetic evaluation: all involved questions are dealt in document, but: several topics inadequately reported, part of components not submitted to analyses, open areas existing, id est: TID model invaluable, insufficient confidence about CCD hardness vs. NIEL damage (RFW to follow?), SEU calculation insufficiently explained, SEE analysis not including all the components and hardness situation not conclusive, consequences on design not highlighted enough.

Details:

➢ **TID** (see RID, bullet 2):
Total Ionising Dose calculation performed (ch.3), results (ch. 7) are difficult to refer to parts / components, and uncertain in their validity, due to obstacles to understanding and verification of model and results.

Used method:

- ray-tracing sectoring analysis, by means of **RADIATION** module of **ESABASE** (no disclosure of used parameters), and Dose-Depth curve of [ENVTR] as input,
- geometrical model and its physical features (materials, thicknesses) largely unexplained, or unclear, implying unverifiable model and results. Remarkably, STR position w.r.t. both Herschel and Planck configuration not given explicitly, and hypothesis of "no satellite shielding" (even though conservative) is not justified and certainly in contradiction with the unit TID analyses instructions in [RAD REQ] para. 7.3
- nominally (RDL requirement of 2 missions lifetime converted in "safety margin = 2" on 1 missions lifetime dose results) TID results at part level are satisfactory

Radiation hardness:
one component (LM137H) violates req. [ENVTR] ENVM-370, or [RAD REQ] RAD-02 , as qualified @ 9 krad[(Si?)] < TDT = 10 krad(Si), despite apparently rad-hard enough to withstand the worst calculated TID = twice 4.228 krad.

WCA input data: missing .

➢ **NIEL** (see RID, bullet 3):
NIEL analysis requested by [RAD REQ] para 9.1 and using DDEF data provided as per [ENVTR] ENVM-470 missing; ch. 4 including only reporting of flight and test results of CCD components, not compared to actual H-P environment to STR.

Radiation hardness:
Radiation hardness of TH7890M is claimed, as missing elements of item TH7890M are "covered" with (some) ones of TH6863. Anyway:

- a): The comparison between TH7890M and TH7863 doesn't consider the possible differences in the density of the materials and the densities of their dopants.
- b): Data sheets of both components (TH7890M and TH7863) shall be provided in order to assess the similarity of the two components, including the number of pixels and their sizes.

Information sub a) and b) shall then be evaluated in order to grant similarity between TH7683 and TH7890, otherwise [RAD REQ] para. 9.2 about testing shall be followed.

Furthermore, the considered item shows a value of 10 MeV proton fluences, mentioned in ISO tests (up to $3.6\cdot10^{+9}/cm^2$) that violates mandatory req. ENVM-370 of minimum fluence of $6\cdot10^{+9}$ p^+/cm^2 for Si-items, since lower than the requirement itself.

WCA input data: missing .

➢ **SEE** (see RID, bullet 4) - SEEs are dealt in [STR RADAN] ch.s 5 and 6:

Ch. 5 - electronics
SEE consequences analysis on all the components and unit (including AACAD and ATFAD conditions) restricted to ASIC only.

Calculation method behind **SEU/SET, SEL rates** data obtained in table 5.1-1 not made explicit, to be done (preliminary checks following [RAD REQ] para 8.2 for SEU(/SET) rate and using [ENVTR] tables 3-28, 3-30 (ENVM-440, -450) only partly confirming the results), part of data missing, clarifications requested, not all components considered.
SEU/SET event rates (e.g.: for EEPROM, SRAM, etc) – after provision (as per RAD-19) and verification – remain to be correlated to and accepted vs. FMECA, in order STR to be granted immune from either critical or catastrophic events (RAD-20) for all components, and **SEL** analysis remain to be completed (as per RAD-11, RAD-22) for all components.
Requirement ENVR-150 for memory (uncorrectable errors < $1\cdot10^{-11}$ error/(bit·day) **not considered (fulfilment of requirement is missing)**, as well as requirements **ENVR-100 to ENVR-170** for all µController, memory, and in general for all the registers and buffers.

SEB and SEGR requirements interpretation under trimming, **hardness demonstration** not conclusive (analysis missing), and not present for all the items.

SHE consideration missing.

Ultimately: **results are uncertain**, also affecting conclusions.

Ch. 6 – SEU in CCD.
Hypotheses and calculations are on hold: clarifications requested both on particles transport features and on actual CCD interaction modes and aspects (including traceable CCD data), complementary explanations for AACAD and ATFAD submodes expected; **derivation of numeric values referred to SEU/frame for AACAD and ATFAD submodes not understood**.

Conclusions:
Removal of signalled obstacles to understanding and adequate dealing of deviations from guidelines or matching of design requirements necessary prior to reaching a satisfactory judgement for all radiations aspects for STR.
Status:
Open, awaiting for CDR successful conclusion.

6.2 CDMS (CDMU, ACC)

The CDMS units: CDMU and ACC, present very large elements of commonality. They will be therefore discussed here considering them collectively, unless differences arise, which will be signalled . Suitable distinctions will be set to evidence when necessary, since, at least different locations are foreseen for the two units in Herschel as well as in Planck.
Two distinct reviews were performed of the dedicated documents **[ACC RADAN2] and [CDMU RADAN2]**. Both (**Issues 2**) were commented for the units' CDR, by issue of RIDs :
CDR-ALS-ACC-CDMU-ENG-026 (minor), concerning editorials
CDR-ALS-ACC-CDMU-ENG-027 (major), concerning CDMU TID, NIEL, SEE analyses
CDR-ALS-ACC-CDMU-ENG-028 (major), concerning ACC TID, NIEL, SEE analyses

They were discussed and agreed, as per MoM: H-P-MI-AI-0439, dated 16 to 18/04/2004 (which is annex 1 to CDR MoM: H-P-MI-AI-0442), and action was taken (AI#08, AI#09, closure date 19/03/2004) by SES to update the documents implementing also answers to Alcatel RIDs on similar subjects:

CDR-ASP-ACC-CDMU-ENG-012, concerning SEFI,

CDR-ASP-ACC-CDMU-ENG-017, concerning SEU,

CDR-ASP-ACC-CDMU-ENG-018, concerning SET,

CDR-ASP-ACC-CDMU-ENG-019, concerning SEB/SEGR,

CDR-ASP-ACC-CDMU-ENG-020, concerning Displacement Damage.

Then, after the limited progress obtained, the newly prepared issues **[ACC RADAN3] (issue 3)** and **[CDMU RADAN4] (issue 4)**, as a closure of AI#08, AI#09**,** were again commented with a new issued RID of almost the same contents, with very limited modifications (for instance NIEL missing in the first run, was commented in the second one…), and a newly structured layout .
The new RID is:
CDR-ALS-ACC-CDMU-ENG-507 (major):
"INADEQUATE DEMONSTRATION OF RADIATION REQUIREMENTS MATCHING",
concerning **both ACC and CDMU** TID, NIEL, SEE analyses.
Similar RIDs from Alcatel are:

CDR-ASP-ACC-CDMU-ENG-504, concerning SET,

CDR-ASP-ACC-CDMU-ENG-505, concerning Displacement Damage.

The latter, detailed, Alenia RID was discussed in view of the deltaCDR, SES proposing its closure with no or very little new feedback, as deemed already closed at CDR. Alenia disagreed and the subjects were debated in a teleconference which was hold during the deltaCDR and is reported in deltaCDR MoM: H-P-MI-AI-0491, dated 22 and 23/04/2004, so the RID points were agreed and closed by replies on RID close-out and actions taken by SE to update the CDMU/ACC Radiation Analysis documents according to the action items AI#12, AI#13, due date being: 15/05/2004, to-date status being: <u>open</u>.

To the sake of brevity only the last (deltaCDR) run will be illustrated hereafter, including SE replies.

<u>Synthetic evaluation</u>:
Several of the analytical as well as qualification (e.g.: testing) aspects due to demonstrate CDMU / ACC design compliance with the requirements as per [RAD REQ], [ENVTR], [GDIR] for all the items, as applicable, were missing in the respective documents or inadequately explained or reported, so that the fulfilment of Radiation Requirements was considered not completely demonstrated for CDMU / ACC (or just demonstrated by making <u>implicit</u> reference to documents not provided in the data package).
TID requirements fulfilment demonstration by analysis was inadequate, and ionising effects hardness not even stated.
NIEL analysis was not explicitly complete (CDMU I/O section), and for ACC I/O section (optocoupler) dark areas were pinpointed in the radiation hardness demonstration, while actual DDEF analysis was not performed at all.
In both case **WCA input data are limited or missing at all**.
SEE analysis, too, was found affected by a **general weakness of methodology application** – statements of intentions of analysis not followed by true analyses indeed, with insufficient design impacts consequence enlightenment – and, on the other hand, SEE hardness data are often scarce and unreferred.

Details:

➢ TID

(Chapter 3 "Radiation Environment" and Chapter 4 "Total Dose Analysis" of [CDMU RADAN4] and of [ACC RADAN3] are intended to correspond to [RAD REQ] chapter 7 "Total Dose Evaluation and Hardness Assurance")

Total ionising dose evaluation is correctly addressed, in order to fulfil RAD-01, with the following exceptions, **but the final requirement of 10 kRad hardness for all the parts** (RAD-02, ENVM-370 **) is just quoted**, **while its fulfilment is not adequately demonstrated**.

- **(1)** [RAD REQ] para. 7.3 (**Deposited Dose Calculation**) looks to have been followed, but (RAD-07) choice between the 2 methods proposed, was only implicitly made, by selecting **ray tracing**, and its (conceptual) application **is not clearly exposed**.
  It is intended (and explanation / confirmation awaited) that, being CDMU and ACC mounted inside the Satellite, a radiation ray exiting the representative point of any component (target representative point), traverses as a minimum travel (normal ray to 3 equally oriented parallelepipedic shapes):
  0.6 mm of component (half-thickness of the shortest thickness),
  then 1.6 mm of CDMU /ACC box side,
  then 0.8 mm of satellite structure;
  it is requested to prove the point above, better with a (even sketchy) drawing, demostrating dimensions from design data, showing clearly which are materials and thicknesses considered.
  Therefore, a clear **demonstration that mm in ch. 4 are of equivalent aluminium** is **needed for the actual design materials**.
  Besides:
- **(2)** An explicit **statement that all procured parts respect the TDT minimum 10 krad dose is necessary**, since missing, as well as consideration of requirements under AD 2 para. 7.2 (Radiation Lot Acceptance Tests) and their related activities.

(1) and (2): SE accept to update §4 with a sketch giving graphical evidence of a certain number of mm Aluminium. A table will be included in §5.2 when all data are available from Tecnologica. The table will include total dose.

- **(3) No** explicit **values related to TID degradation to be used in Worst Case Analysis** is found for CDMU, and for ACC this concerns only the optocoupler in para 5.4.

(3): SE will clarify that the values in the WCA takes radiation into account.

➢ NIEL

(portion of Chapter 5.4 "IO System Analysis - Radiation Effects on Optocouplers" of [ACC RADAN3], and Chapter 5.3.4 "Displacement Damages" of [CDMU RADAN4] and [ACC RADAN3], are intended to correspond to [RAD REQ] chapter 9 "Displacement Damages")

NIEL effects analysis is excluded for core sections of ACC and CDMU, and performed, for I/O section of ACC only, however **discrepancies emerge if the applicable requirements are remembered** :

[RAD REQ] para 9.2 states:

"Parts shall survive the lower Displacement Damage Equivalent Fluence calculated for the mission. At the DDEF level to be considered for the Herschel/Planck mission, only Optoelectronic devices (CCD, LED, Optocoupler,…) are displacement damage sensitive. … The acceptance of the parts will be based on displacement damage test data. The data will be taken from neutrons testing databases and protons test results.
Equivalence between protons and neutrons will be deduced from NIEL values in the target material. If no data are available, protons irradiation evaluation tests shall be performed. The test plan will be submitted to ALCATEL for approval.
Displacement Damage tests shall be performed using the following sources :
• Protons @ energy > 50 MeV
• Neutrons @ 1 MeV "

- **(4)** ACC radiation displacement damage analysis is performed for "IO System" / "Radiation Effects on Optocouplers" in para. 5.4, but for the MicroPac 66099 taken as representative of the 66179:

the **displacement damage test data** (to which compare the actual one) **were not given**, **if not quoting performances as**:

<> "The 66099 performs very well at neutron levels up to about 2 · E12 neutrons/cm^2 . CTR degradation is 65%.; and

<> The 66099 was evaluated for proton radiation tolerance up to 61MeV. CTR degradation is appr. 77% at 10mA IF."

"Because of the lack of detailed information concerning the relevant proton / neutron fluence we add a total CTR degradation due to particle shower of 75%, which is referred as "Displacement Damage" ".

Actually, there is a missing point in the loop: the equivalence criterion between test fluences in neutrons and that in 10 MeV protons in the requirement; besides, test fluence in protons is <u>missing</u> (only the maximum threshold energy is given).

→ Therefore the **actual qualification test fluence cannot be defined by the available data and, as no evidence of displacement damage immunity exists, it has to be defined by tests as per quoted requirements**, or, at least, adequate reference to a respected centralised EEE parts procurement policy for radiation hardness be given. These values must also **match the minimum required level** (Req. RAD-23, ENVM-370).

(4): SE/AAe will investigate for the opto-coupler, the equivalence of the neutron flow used during the qualification test with the requirement of proton radiation (10MeV).

- **(5.1)** The **actual** (for Herschel and for Planck) **DDEF values out of the applicable curve** (by ENVM-470) of fig. 3-32 / table 3.4-11 of [ENVTR] **were not calculated**, by entering the appropriate value of abscissa (solid sphere shieldings in mm of Al), then to be multiplied for 2 (radiation lifetime = 2 mission lifetimes, ENVR-010, [RAD REQ] para. 1), or by a complete analysis from scratch.
- **(5.2)** The previous point was evaluated by Alenia by entering the DDEF curve with the overall Al-equivalent thickness seen by the ACC /CDMU units ("Radiation Shielding Analysis of Herschel and Planck Satellites", H-P-1-ASPI-AN-0321, iss. 1, for TID evaluation), when all the true satellites are considered, including 0.8 mm(Al) per side of each subsystem box. The resulting values for full radiation lifetime are around $7{\cdot}10^{+9}$, quite higher than the requirement GaAs limit of $5{\cdot}10^{+9}$ p^+ @10MeV/ cm^2 (RAD-23, ENVM-370), and therefore these values need an appropriate verification with a more accurate model / calculation.

(5.1) and (5.2): Analysis will be completed showing the actual flow at the sensitive components (opto-coupler).

- **(6) Non ionising radiation effects on CDMU IO section is not considered** in para 5.4 it has to be done (as it is for ACC), unless clarification is given about absence of optocouplers in CDMU.

(6) SE will insert a statement that CDMU does not include displacement damage sensitive parts.

- **(7) WCA** overall minimum CTR coefficient **calculation mechanism is not explained**.

(7) SE will provide a clarification.

- **(8)** No hue exists about the Displacement Damage Database for Worst Case Analysis (RAD-25), .

(8) A reference to the WCA will be included.

➢ SEE

<u>Chapter 5 "Single Event Analysis" (apart Displacement Damages in para. 5.4) of [CDMU RADAN4] and of [ACC RADAN3is intended to correspond to [RAD REQ] chapter 8 "Single Event Phenomena Hardness Assurance"</u>

<u>In general</u>,
compliance with requirements about SEP effects is not explicitly demonstrated for the considered items, and, when a reference to further SES documentation was given in the previous issue, this was not available for review in the CDR Data Package and now is no more even quoted (exception made for the "CDMU Technical Design Report" P-HPL-NOT-00021, quoted on page 8 of CDMU radiation analysis).
In more detail:

- **(9)** In para 5.1 "General", only 5 out of the 6 Single Event Phenomena (SEP) considered in AD 2, ch.8 were considered**, letting aside the Single Event Hard Error (SHE)**, as in the following para. 5.3 "Core Analysis". If deemed as events not applicable to the considered parts, at least such a statement ought to be given; if SHE is dealt as part of other effects (e.g. SEL) this shall be declared and justified.

(9): A chapter on single event hard errors to be included.

- **(10)** In para. 5.2 a TBW exists.

(10): A table will be included in §5.2 when all data are available from Tecnologica (see point 1).

- **SEU**:

  [RAD REQ] on para. 8.1.1 clearly requests that:

  "Taking into account that the SEU is a non-destructive effect, there is no requirement in terms of minimum LET threshold or maximum cross section. The subcontractor is requested to analyse the effect and the criticality of SEU for the equipment.

  For digital technologies, the subcontractor shall use parts with a well known SEU sensitivity in terms of LET threshold and cross section (refer to paragraph «Single Event Phenomena (SEP) Rate Calculation»). If no data is available, the subcontractor is responsible to perform a Single Event Upset test :

  - *An Heavy Ions testing shall be performed in order to determine the Device Cross Section versus LET response of the device,*
  - *If the orbit is exposed to proton environment and if the Heavy Ions LET threshold is lower than 15 MeV.cm^2 /mg, then a Proton induced SEU testing shall be performed. Test plans and the use of these parts requires express approval from ALCATEL.*

  There is no lot-to-lot variability, there is no lot testing requirements. Data collected for ' equivalent parts' (see para. 5) will be acceptable."

  In addition, [RAD REQ] RAD-19 in para 8.2 – *"The subcontractor is required to calculate SEP rates for all parts sensitive to cosmic rays and protons effects"* – needs to be fulfilled, including the prescriptions on the calculation methods (both for cosmic rays and for protons effects) and relevant rate curves in [ENVTR] .

  [RAD REQ] RAD-20 – *"The subcontractor is required to perform a SEU effects analysis in order to identify the SEU effects and criticality"* – need to be fully matched, since presently the effects analysis depth level is unsatisfactory and the criticality is not put to evidence.

- **(11) Therefore: demonstrated compliance to the above quoted SEU requirements has to be provided,** while, on the contrary:

  in para. 5.3.1, some components are declared as SEU sensitive and SEU rate is reported, other as non sensitive and not requiring detailed analysis, however in both cases **no demonstration or supporting documentation is attached**, so as to explain environmental conditions for those data, and **without distinguishing between heavy ions and protons contributions**.

  in para. 5.4, items are divided in: considered susceptible or not susceptible to SEU (with no demonstration, simple statement) and their SEU impact to functionality / performance is briefly reported into tables 2 and 3 (in common to SET effect). **No SEU rate is reported** as "if not explicitly quoted, there was no SEE data available". Which is not acceptable: **since a SEU effect exists, its rate must be known, to be discussed and possibly accepted**.

  In both para.s **no reference to further detailed analysis**, even if unavailable in the CDR Data Package, is made, so to assess if SEU rates are acceptable in design.

(11): The MTTF value given shall be recalculated to equivalent errors/bit/day in order to allow comparison with the requirement on 10e-11.

- **(12)** In para 5.3. 1, **<u>SRAM</u> SEU rate calculation was not understood**; 1 LET value ought to lead to 1 SEU rate not to a "range" with a width factor 100. [ENVTR] used values are not specified, however they are understood as integral flux values per unit solid angle. SEU rate was calculated by Alenia from curve of fig. 3-28 / table 3.4-9, entering the threshold LET= 10 MeV/(mg/cm^2). It is observed that since LET < 15 MeV/(mg/cm^2) also protons contribution to SEU rate has to be considered.

  Clarification w.r.t. the above points and **complete calculation chain has to be provided**, and any number shall be connected to a physical variable. In the MTTF calculation, any physical variable shall be connected to its numeric value.

- **(13)** Clarification w.r.t. the **missing MARS ASIC**, as well as to the fact **that not all the active components have been considered** has to be given.

- **(14) Evidence is missing** and must be provided **for any type of memories** (incl. Processor registers, asic, fpga…) that **no MEU** (multiple event upset) **leads to unit malfunction that can cause the mission loss** (ENVR-140) and in particular that :
  - **SECDEC** algorithms **are foreseen** (ENVR-160a)
  - The occurrence probability of **uncorrectable errors is < 10^{-11} errors/bit.day** (ENVR-150)

(12), (13), (14)): Agreed by SE.

- **SET**:

  [RAD REQ] on para. 8.1.5 clearly requests that:
  "This [SET] includes such devices as Linear integrated circuits that do not suffer logic upset as such, but may produce a large output spike that can appear as a false command. Design analysis shall be performed in order to assess the sensitivity of applications using sensitive devices. In case of sensitive application, experimental data shall be provided in order to justify the use of selected parts, and SET frequencies shall be determined".
  In addition, AD 2 requirement RAD-21 in para. 8.4 – *"The subcontractor is required to perform a SET effects analysis in order to determine the effects of SET on equipment performance"* needs to be taken into full consideration, within the following specific cases and values, including *demonstration "that a SET will not produce an out of specification".*

- **(15) Therefore: demonstrated compliance to the above quoted SET requirements has to be provided,** while, on the contrary, **presently, quantitative analyses are not given** in the available documentation:
para. 5.3.1 states that SET effects "are taken into account in the design. Outputs from sensitive components are filtered so that the transient does not propagate**". SET-analysis is shown in the table of para. 5.3.1, but it was referred for details to documents unavailable** in the CDR Data Package (and no more mentioned in new issues of doc.s for delta-CDR):

[PMWCA]	P-PU-NOT-00010-SE	"PM board Analysis Report"
[RMWCA]	P-PU-NOT-00006-SE	"RM board Analysis Report"
[PAAHCA]	P-PU-NOT-00105-SE	"PAAH board Analysis Report"
[PCSEE]	P-HPL-NOT-00036-SE	"PCDH SEE Analysis Summary"

in para. 5.4, items are divided in: considered susceptible or not susceptible to SET (with no demonstration, simple statement) and their **SET impact to functionality / performance is briefly reported** into tables 2 and 3 (in common to SEU effect).
No reference to further detailed analysis, even if unavailable in the CDR Data Package, is made.
Hence: demonstrated compliance to the above SET requirements has to be provided, in particular in para 5.4 where missing conclusions are noted for functional effects due to SET (in table 3) and lack of demonstrations is noted (for example: what does it mean "wrong acquistion" ?). Clarifications are needed, and addition of schemes / figures may help understanding.

(15) Column addressing the relevant failure case in the FMECA shall be added.

- **(16)** In para 5.3.1 clarification w.r.t. the **missing MARS ASIC**, as well as to the fact that **not all the active components have been considered** has to be given.

16) MARS is included in the table according to point 1).

- **SEL**:

  For SEL, [RAD REQ] **RAD-11** applies (which **does not appear fulfilled**):
  "SEL sensitive parts could be used upon a case by case basis and requires Alcatel approval";
  furthermore the following requirement does not appear completely fulfilled:
  "Single Event Latchup sensitive part use shall be justified with a technical report providing :
  full device cross section versus LET curve (up to LET of 60 MeV.cm^2 /mg), risk assessment, detection/correction circuitry, impact on reliability analysis, etc .....
  The sub-Contractor shall demonstrate the compliance to mission requirements in terms of reliability",
  including the principle ([RAD REQ] para. 8.5) that
  "All Destructive Single Event Effects (Latchup, Gate Rupture, Burnout, Hard Errors, ...) could be acceptable only if the equivalent Destructive Single Event Failure Rate is 10 times lower than the intrinsic reliability failure rate of the part (@ 25°C)"

and the [RAD REQ] requirement RAD-22:

"calculation rate method [for destructive events] shall be submitted to Alcatel for approval" .

- **(17)** On the contrary,
  para 5.3.2 states compliance with [RAD REQ] req. RAD-10, but demonstration is not given;
  para. 5.4 reports that some items are, or are assumed, as immune to SEL, but no demonstration is given;

  however, for the other items, a protection and failure recovery analysis is made, concerning SEL sensitivity, and in this case
  "calculation rate method [for destructive events] shall be submitted to Alcatel for approval" .clarifications are needed and demonstrated compliance to the above sel requirements has to be provided (including cross section vs. let data when applicable), in particular, in para 5.4 (in table 3) as far as cmos, power mosfet, bipolar transistor are considered. Design impacts have to be clearly stated.

  (17): LET values for latch up are included in the table according to point 1).

- **SEB, SEGR**:
  - **(18)** Para 5.3.3 states **compliance with** [RAD REQ] RAD-12 (**SEB free parts preferably used**) **and** RAD-16 (**SEGR free parts preferably used**): SEB and SEGR "removed by selection of rad-hard FET's and by that they are operated in conditions ("Safe Operated Area" , SOA) in which they are immune to single event effects", but **demonstration is not clear and not all required data are given**.
    Since SEB and SEGR are indeed subjected to requirements of LET analysis and compliance demonstration fully equivalent to that for SEL, and to [RAD REQ] para. 8.5 and RAD-22, **SEB- and SEGR-freedom requirements cannot be considered FULLY matched** (see [RAD REQ] para. 8.1.3 and 8.1.4), but only until a certain LET threshold.
    Para. 5.4 brings SEB and SEGR consideration ("analysis"), but **no consequence comes for the assessment of impact on design**.

    Clarifications are needed and **demonstrated compliance to the above SEB / SEGR requirements has to be provided** (including cross section vs. LET data, risk assessment, etc).
    When V_{DS}<50%VBDSS is stated, not only $V_{DS\ MAX}$ **, also VBDSS ought to be reported;**
    Guaranteed V_{DS} tolerance needs explanation, as well the restriction to **"**V_{DS}<50% AND LET > 60 MeV /(mg/cm^2)" for component FSGYE033.
    Design impacts have to be clearly stated.

    18) EM parts will be removed from the document.
    The 2N7445 (36MeV) component will be reviewed
    and if needed a RFD will be issued. (AI#14).

Conclusions:
Clearly, such an extensive dearth of analysis and radiation hardness reporting implies to wait for a full closure of any pending action item before declaring acceptable the ACC / CDMU design status and the related performances.

Status:
Open, awaiting for actions closure, after comments discussion, and successful implementation.

6.3 HRN

Evaluation is performed at subsystem level.

Presently no HRN Radiation Analysis was provided by NEXAN.

Synthetic evaluation – about TID :
Despite **radiation sensitivity** concerning HaRNess **items** was highlighted, by NEXAN declaration of non-compliance vs. requirements at HRN PDR (see doc. H-P-NXH-LI-0011 "A0 Design Verification Matrix"), over which situation the RID PDR-AI-HRN-ENG-048 led to the definition by Alenia / Alcatel of an expected TID level for both internal / external harness items of 10 krad, to be matched by the used materials hardness, to date no reporting of analyses or assessments were received on the subject.

Conclusions:
None, for the time being.

Status:
Open, awaiting for relevant further information from NEXAN.

6.4 PCS

Evaluation is done at unit level: BATT and PCDU.

6.4.1 BATT

A self-standing BATT Radiation Analysis for Herschel Planck missions was provided as: **[BATT RADAN], iss. 1,** which was examined and commented. **Comments**, concerning only TID, are hereafter reported (not submitted as a CDR Radiation RID).

Synthetic evaluation:
Pure **TID**, as due, was analysed, and the resulting TID hardness is such to withstand the expected environment, despite the analysis was imperfect. Alenia assessment covers the latter point.

Details:
A part missing quotation of [GDIR] among the applicable requirements documents (para 1.2), the correct [ENVTR] and [RAD REQ] are considered.
Chapter 2 addresses the radiation analysis subject: NIEL is implicitly and SEUs is explicitly excluded ("There are no components with digital functionality or otherwise susceptible to SEUs"); a nominalistic point could be the exclusion of any kind of SEE.
Only TID has to be considered, anyway, and all the component except the battery cells are either not susceptible to radiation or have a minimum tolerance of 1 Mrad, greater than the bare exposure to unshielded environment for the full RDL.
The cells are reported (chapter 3) having been **tested and being unaffected in their performances at TID levels up to 100 krad, largely greater than TDT**.
Chapter 4 concludes that:
" The battery is hard to a minimum of 100 krad of radiation. According to the dose-depth curve of [AD4] – *id est: [ENVTR]* – , 100 krad is the maximum dose seen with no shielding. The spacecraft structure will provide a level of shielding for the battery, therefore the radiation dose seen by the battery will be well within the qualification level. Consequently, no specific radiation design measures are required for the battery. "
The first sentence is agreed, the second no, since after [ENVTR] curve dose-depth (also in fig. 5.1-1 of this note) the maximum dose seen with no shielding is 129 krad for 1 mission time, and at behind a shielding of 0.05 mm(Al), thus at least twice for the full RDL of 2 mission lifetimes, and somewhat more with bare 0 mm(Al), say some 300 krad.
Anyway, a positive assessment, in line with the third sentence, is easily derived by the consideration of the mounting of BATT inside the spacecraft (not to speak of the BATT structure itself): according to [RAD REQ] instructions of para. 7.3, 0.8 mm(Al) have to be considered for the spacecraft, therefore the dose is lowered to twice 11.7 krad, that is 23.4 krad for the true RDL << of radiation hardness of 100 krad. "Consequently – with the words of the last sentence – , no specific radiation design measures are required for the battery."

Conclusions:
Despite the few comments raised, the status of the documentation and the results provided are satisfactory and the design performances acceptable.

Status:
Closed.

6.4.2 PCDU

NOTE: this unit is expected to be reviewed at the next-to-come PCDU CDR:
Since PCDU documentation is still under evolution, an evaluation and an assessment shall be provided just with CDR documentation examination.

A self-standing PCDU Radiation Analysis for Herschel Planck missions was provided as [PCDU RADAN], but on its page 14 a recall is given that, in turn, some components' SEE behaviour is analysed in [PCDU SEEAN].

Synthetic evaluation:
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Details:
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Conclusions:
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Status:
Open, awaiting for CDR.

6.5 SA (Planck only)

NOTE: this unit is expected to be reviewed at next-to-come SA CDR:
Since SA documentation is still under evolution, an evaluation and an assessment shall be provided just with CDR documentation examination.

A self-standing SA Radiation Analysis for Planck mission was provided as [SA RADAN].

Synthetic evaluation:
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Details:
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Conclusions:
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Status:
Open, awaiting for CDR.

6.6 RCS

RCS Radiation Analysis is contained into **[RCS RADAN], iss. 1,** examined in occasion of RCS CDR, as commented in the following.
The CDR review was performed at subsystem level, considering only radiation sensitive units: Pressure Transducer, Latching Valve, Propellant Tank Diaphragm (see details reported accordingly in the following paragraphs).
2 **Radiation** RIDs were submitted:

CDR- RCS- ALS-ENG-058 "Open points in RCS Radiation Analysis" main part (major, reclassified minor),
CDR- RCS- ALS-ENG-059 "Open points in RCS Radiation Analysis" supplement (major, reclassified minor),.

Since actually they constitute one only RID, their comments will be dealt commonly.
Also, after their discussion at CDR, they were accepted and closed together, with commitment of EADS to implement answers to points raised into an updated Radiation Analysis, whose due date is undefined, to-date: open.

Synthetic evaluation

A number of aspects, concerning both analyses and component qualification / selection activities due to demonstrate RCS design compliance with the requirements as per the applicable requirements, concerning the **Ionising And Non-Ionising Radiation Effects** as well as the **Radiation Single Event Phenomena Effects,** are found in the document as inadequately explained, or reported, or actually as open/missing points, preventing form acceptance of design under radiation environment compatibility for the time being, as detailed later on.
Note:
since **[RCS RADAN]** was configured as a "sandwich" report, incorporating, into a RCS-level main part of the document, the subcontractors' radiation analyses into attachments as per the following list:

attachments I, IV and V: Pressure Transducer (by Ametek , plus NASA's SEE test results),
attachment II: Latching Valve (by Moog) ,
attachment III: Propellant Tank Diaphragm (…, item to be provided),

then one overall introduction and overall synthesis and conclusion will be provided here at RCS level, while details (preceded by a local synthesis) will be splitted downwards at unit level in the following paragraphs, exception made for RCS level considerations.

Details

- In para 3.1 column 3 of table Requirements Tracking… "**Radiation Requirement**", the values for pressure transducer and for latching valve are not correctly referred: they are **1** krad in the respective para.s of [RD03] and [RD04], not 10 krad as reported, and so they do not respect at RCS level the **minimum dose level to be mandatorily matched** (requirement of TDT of 10 Krad (Si) ([ENVTR] ENVM-370, [RAD REQ] RAD-02).
- All the other aspects TID / NIEL / SEE are dealt at unit level (even para. 4.1 and subpara.s are identical with para. 4.2 of attachment I and subpara.s).

Conclusions:

The document, showing a number of weak areas, at least as far as demonstration and reporting of a successful analysis versus qualification / testing hardness levels for all the three main radiation areas, shall be modified and updated according to the points raised above, so that compliance to requirements and acceptability of design is achieved. In fact, EADS **accepted the comments**, during the interactive RID discussion at CDR (see H-P-MI-0507, on 11&12/05/2004), closing RIDs with a **commitment for an updated Radiation Analysis**, according to the provided comments (action item, without number, on EADS). Details to be still discussed.

Status:
Open, awaiting for CDR action successful conclusion.

6.6.1 Pressure Transducer

Pressure Transducer - attachments I, IV and V of [RCS RADAN]

Synthetic evaluation
In general applicability of Herschel-Planck requirements was found limited, which is a negative point to remove. Besides, **TID analysis is not satisfactory** both in terms of requirements understanding and of hardness, as well as of (non) calculated dose.
NIEL Displacement Damage possibility was **excluded.**
SEE are generally not dealt as per applicable requirements, or not dealt at all.

Details

General
[GDIR], [ENVTR], [RAD REQ] must be considered as **applicable documents** at RCS level (as per "RCS Requirement Specification" H-P-SP-AI-0002, iss. 3, dated 17 Dec. 2003) despite they are not at Pressure Transducer level (see the applicable documents list, in Ametek Radiation Analysis, ch. 2);
since in ch. 1 it is said that Ametek Radiation Analysis is performed in accordance with space environmental conditions specified in the Pressure Transducer Procurement Specification (EADS doc. MBST-RILAM-PS-1656-01, iss. 3, dated 15 Dec 2003), which does not recall [GDIR], [ENVTR], [RAD REQ], actually, deviations from those requirements that are observed, and signalled in the following, shall be covered at RCS level;

Appendix pictures to be improved (figure 5 not readable).

➢ **SEE** (para 4.2)
SEP effects has to be **classified and treated according to applicable [RAD REQ] requirements et alii, which is not presently, in general**.

- Para 4.2.1.1:
  LET thresholds: Heavy Ions SEU threshold not to consider proton induced SEU rate is not 12 but **15** MeV/(mg/cm^2) as per [RAD REQ] para 8.2.2.
- Para 4.2.1.1:
  it is written: "error rate should be calculated according to the method described in 2.2.1 [Pressure Transducer Specification] and compared to the acceptable error rate of the equipment" (see (#) below). Anyway, references shall be methods and data according to [RAD REQ] para. 8 and [ENVTR] para. 3.4.4.2.2, to which EADS is requested to upgrade accordingly, see (*****) below (← "if the Sub-Contractor don't use advanced particle matter interaction simulation tools the following 'between-in' curves shall be used, instead of using directly particle fluxes and fluences as an input").
- Para 4.2.1.2:
  EADS to clarify where the use of Safe Operating Area, defined in Pressure Transducer Specification (ref. 2.2.1), is shown.
- Furthermore, in para 4.2.2:
  the intention of performing calculations of para 4.2.1.1 (#) is not executed, and in attachments IV and V, just the test data in terms of LET thresholds and saturation cross sections are reported, and in certain cases not for all the effects (SEU / SET, SEL).
  Indeed: **SEP rate analytical calculations** (depending on the actual environment) **are not carried on,** as they are to be done, according to [RAD REQ] para 8.2. (*)
- Para 4.2.2.1 (and 4.1):
  The quantitative values of "relatively immune to latch-up effect" / ">> upset effects" are to be clarified.
  Such a demonstration about the verification of SEL tolerance requirement cannot be acceptable as explained. To demonstrate SEL immunity additional test value or additional analysis shall be provided.
- Para 4.2.2.2:
  RH07H (identified in "Appendix E" (identified as: para E of chapter III of appendix A 4 / attachment IV) as number 7: OP07AJ) (Please, EADS to provide evidence of similarity between OP07 and RH07. Note: in Ametek design it has been used component RH07H) has no test data for SEU cross section, and no well defined SEL testing at least over LET = 50 MeV/(mg/cm^2), while [RAD REQ] para 8.1.2 asks until 60. [RAD REQ] para 8.1.2 and requirements RAD-10 and -11 have to be applied. SEU / SET have to be analysed as per [RAD REQ] para 8.3 / 4.
- Para 4.2.2.2:
  LM117HVH (in "Appendix E" (identified as: para E of chapter III of appendix A 4 / attachment IV) is found at

number 12, and has no test data for SEU. [RAD REQ] para 8.1.1 and requirements RAD-10 and –11 have to be applied. SEU / SET have to be analysed as per [RAD REQ] para 8.3 / 4.
Furthermore, if LM117HVH is realised as a Power MOSFET technology switch, evaluation of SEB and SEGR effects shall be performed as per [RAD REQ] para.s 8.1.3, 8.1.4, 8.5..

- Para 4.2.1.1:
  SET tolerance shall be better explained: it could enough to have a spice simulation with the introduction of a "SET" pulses according to requirement of [RAD REQ].
- SHE occurrence possibility was not considered, it has to done, even just to exclude it.

➢ **TID** (para. 4.3)

para 4.3.1:
The **requirements for TID Radiation Hardness Assurance** are in [RAD REQ] para.s 7.1 and 7.2, to which Ametek shall comply.
para 4.3.1 to 4.3.3:
The followed approach is to compare a Total Dose Sensitivity (TDS) for each component (qualification tests…) with the actual Total Dose Level (TDL) seen by the component. Actually, in para 4.3.2 the estimation of TDL is reported for the active items in table 2, as "lifetime expected TID", equal to 1.0 krad(Si) for each item, and it is said that "TID information is given in [ref.?] 2.2.1 for an orbit with 4 year operational life and a 12 year design life".
Indeed, **this cannot be considered correct: instead, 10 krad is the minimum dose level to be mandatorily matched** (requirement of TDT of 10 Krad (Si) ([ENVTR] ENVM-370, [RAD REQ] RAD-02)), and despite the "operational life" of "4 years in orbit", the **requirement for radiation is to survive a RDL of 2 times the nominal lifetime** ([GDIR] ENVR-010, [RAD REQ] para 1 and RAD-01).
As a matter of fact**, the actual mission dose ("TDL") has to be analytically computed (then doubled to match the mentioned RAD-01) by SubContractor according to para 7.3 of [RAD REQ] and [ENVTR] ENVM-430, and detailedly reported, and compared to the "TDS".**

Tables 3, 4, 5, 6 and 7 (as summary) report the considered TDS for the 4 items, as 100 krad for the operational amplifier, 2 krad (equivalent to twice the TDL of 1 krad) for the current limiter and the voltage regulator, and $2 \cdot 10^3$ krad (to be intended likely 2 krad, see table 7) for the transistor; these values are used for characterisation of radiation induced worst case post-radiation performance change.
(Is 2 Krad the qualification value of every active components or they are supposed to be tolerant to higher values of TID? EADS ought to clarify whether reference to 2 Krad test results is maybe just compliant with the radiation expected value). EADS ought to clarify/confirm the previous values/interpretation in relation with the fact, that,

On the other side, in table 8 a synthesis of the TDS for the 4 items in the previous order shifts up the previous values to >100 [krad(Si)], >200 [krad(Si)], >200 [krad(Si)], >100 [krad(Si)], respectively.

Facing those **TDS estimations** (the last ones), but it has to be pinpointed that references are a "2.3.2" not existing in the reference document list, or an unquoted / unexplained "Appendix C" (therefore the **values need to be confirmed and their sources clarified**), presently **no actual TDL calculation is performed**. Despite at least a ray tracing analysis is requested in [RAD REQ] para 7.3, an actual analysis per item is not performed, and the not calculated TID per item is substituted with a common value of "Lifetime expected TID" of "1 krad [(Si)]", which is not "expected" as such, and not acceptable as a methodology result as not coherent with physics if considered as the actual levels of TID (since they must depend on shielding thickness); in addition, the TID must be considered for the overall RDL of 8 years, versus the "Total Dose Capability".

Given the well known position of RCS items into Herschel / Planck configuration (denied in ch.1 "location of the valve within the spacecraft is unknown"), [RAD REQ] para. 7.3 instructions can be followed, and **Preliminary Satellite Radiation Model shall be considered**.

In conclusion, the (defective) demonstration provided by the previous chapters shall be upgraded.

The **actual input data** for performed radiation dose degradation / damage **WCA** and its results cannot be accepted. Those corresponding to the analysis in para. 4.3.3 cannot be considered corresponding to the actual environmental conditions, as however are not the result of a correct analysis . EADS to clarify which is the maximum acceptable value of every electrical parameter for active components in table 2 to table 8, as a function of value in column "Test TID Krad": this value shall be compared with the results found after radiation test. If a non compliance it will be raised, it shall be taken into consideration inside the worst case analysis.

➢ **NIEL**
No item subject to **Displacement Damage** was evidentiated.

6.6.2 Latching Valve

Latching Valve - attachment II of [RCS RADAN]

Synthetic evaluation
In general applicability of Herschel-Planck requirements was found limited, which is a negative point to remove. Besides, **TID analysis is not satisfactory** both in terms of requirements understanding and of hardness, as well as of (non) calculated dose.
NIEL Displacement Damage possibility was **not considered.**

Details
General:
[GDIR], [ENVTR], [RAD REQ] must be considered as **applicable documents** at RCS level (as per "RCS Requirement Specification" H-P-SP-AI-0002, iss. 3, dated 17 Dec. 2003) despite they are not at Pressure Transducer level (see the applicable documents list, in Radiation Effects Analysis, ch. 2);
since in ch. 1 it is not said that MOOG Radiation Effects Analysis is performed in accordance with defined space environmental conditions – to H-P are those specified in [GDIR], [ENVTR], [RAD REQ] – not even to the Latching Valve Procurement Specification (EADS doc. MBST-RILAM-PS-1652-01, iss. 3, dated 22 Feb. 2004), which does not recall as **applicable** documents [GDIR], [ENVTR], [RAD REQ] (they are recalled only as "documents"), actually, **deviations from those requirements that are observed, and signalled in the following, shall be covered at RCS level.**

➢ **TID**
In para. 4 it is said that "the valve assembly will be exposed to a **maximum** of 1E4 rad (Si)": indeed, **this is not a maximum requirement to be matched or a calculated, analytical maximum level to comply with. Instead, 10 Krad is a minimum dose level to be mandatorily matched** (requirement of TDT of 10 Krad (Si) ([ENVTR] ENVM-370, [RAD REQ] RAD-02)), and despite the "operational life" of "4 years in orbit", the **requirement for radiation is to survive a RDL of 2 times the nominal lifetime** ([GDIR] ENVR-010, [RAD REQ] para 1 and RAD-01). As a matter of fact**, the actual mission dose has to be computed by SubContractor according to para 7.3 of [RAD REQ] and [ENVTR] ENVM-430, and detailedly reported**.
Presently, despite at least a ray tracing analysis is requested in [RAD REQ] para 7.3, **the actual analysis** in ch. 6, announced in para 5.1, gives **only estimated shielding equivalent aluminium millimetres**, reported per item. Moreover, **TID per item is not calculated** and is substituted with a common value of "total dose exposure" of "1E4 rad [(Si)]", which is not acceptable as such, and not coherent with physics if considered as the actual levels of TID (since they must depend on shielding thickness); in addition, the TID must be considered for the overall RDL of 8 years, versus the "Total Dose Capability".

For instance:

- In para 6.2, it is not understood by which dose-depth curve "average shielding of 1.1 mm[(Al)] would allow exposure to 4E7 [rad(Si)] total dose" – dose-depth curve for H-P brings to ~2 times (for RDL=8 years) 1E4 rad(Si), id est ~2E4 rad(Si).
- Also, on the contrary: if really 0 mm ought to be considered for the first and second item in the table of para 6.2, then the dose-depth curve for H-P would bring to ~2 times (for RDL=8 years) ~ 2E5 rad(Si), id est ~4E5 rad(Si). It is stated that for those items that "all shielding for leadwires is to be provided at system level", which is not evaluated…
- In para. 6.3, there is a contradiction about the capability, announced in the first and second line, of the motor cap to provide 1.4mm(Al) of shielding: in the third it is said: "The cap is not designed…"; which is the conclusion?
- In para. 6.4, 3.1623 mm(Ti) would imply in H-P environment a TID for 8 years of 2.36 krad largely lower than the reported total dose capability of Teflon valve seat/seal.

Given the well known position of RCS items into Herschel / Planck configuration (denied in ch.1: "location of the valve within the spacecraft is unknown"), [RAD REQ] para. 7.3 instructions can be followed, and **Preliminary**

Satellite Radiation Model shall be considered.

In conclusion, the (defective) demonstration provided by the previous chapters shall be upgraded.

No mention of WCA input data for radiation dose degradation / damage.

➢ **NIEL**

Displacement Damage possibility, as per ([RAD REQ] para. 9 and RAD-23), was not considered, unlike for Pressure Transducer in para 4.4: it shall be so, for all items, even just to exclude it.

6.6.3 Tank Diaphragm

Propellant Tank Diaphragm - attachment III of [RCS RADAN]

Details

- Presently, Attachment III (diaphragm radiation test) is quoted but actually not issued.

6.7 TCS

Evaluation can be performed at whole subsystem level.
Actually, **no item** was signalled to date as **radiation sensitive** in the overall TCS, also due to the low TID level inside the SVM to be withstood.

Status:
Closed.

6.8 TT&C

Evaluation is performed at units level.

6.8.1 LGA/MGA

No actual Radiation Analysis as such was provided by RYMSA, since antennas were considered immune to radiations environment effects of Herschel – Planck missions. Conversely, a Statement of Compliance **[LGAMGA RADCO], iss. 1,** was provided. It was examined and commented hereafter.

Synthetic evaluation – about TID / NIEL :
Radiation insensitivity concerning the antennas (**LGA, MGA**) **items** was declared on page 3, despite a "N.A" as marker. Indeed, it should be "C", if, as said: "The antennas manufactured by RYMSA are no susceptible to be damaged by radiation [intended: of Herschel-Planck mission requirements]. Materials shall be resistant to radiation."
Under a formal point of view, the declaration of compliance vs. requirements should have been accompanied by actual **radiation hardness** levels, which are missing, on the contrary, splitted for TID / NIEL, in case.
(Also a statement of absence of any parts potentially sensitive to SEEs is missing, just under formal point of view).

Conclusions:
No effects of radiations on the antennas, therefore: compliance to requirements; design acceptable.
Status:
Closed.

6.8.2 RFDN

A short document titled "Radiation Analysis" was provided for RFDN, **[RFDN RADAN], iss. 2**, which was examined and commented hereafter.

Synthetic evaluation – about TID / NIEL / SEE :
Considering the diode SM1918 as the sole radiation sensitive component in RFDN, with the implicit **exclusion of NIEL sensitivity** and related displacement damages (coherently with [RAD REQ] para. 9.2 instructions), and the explicit **exclusion of SEE** sensitivity (but a look to the kind of diode usage (for possible SET) into the design has to be given), only the ionising effects of radiations are evaluated. **TID hardness** is reported up to 100 krad (after testing), and vs. such a level, even a very conservative ("more-than-worst" case) analysis turns on green lights to the diode's usage. The diode's case equivalent Aluminium thickness is quoted equal to 0.5 mm, corresponding, as correctly written, to 19 krad, for 1 mission lifetime, from the [ENVTR] Dose - Depth curve. Considering a RDL of twice the previous time span, the **accumulated TID** would be limited to 38 krad, still greatly lower than the hardness level. Anyway, the extra shielding of the RFDN box and of the satellite itself will curb the actual level, as confirmed by [H-P RADSHAN] – some 3.5 mm added for Herschel configuration, and almost 4.0 mm for Planck configuration.

Conclusions:
RFDN shows no deviations form requirements; design is acceptable.
Status:
Closed.

6.8.3 (EPC+) TWTA

"TWTA" ((EPC+) TWTA) Radiation Analysis is contained into **[TWTA RADAN], iss. 1 rev. 1,** examined in occasion of TWTA CDR, as commented in the following.

Radiation RIDs CDR-AI-TWTA-ENG-nnnn , dated 03/05/2004, were submitted, concerning:

- RID …-nnnn = -0013: (minor), general aspects,
- RID …-nnnn = -0014: (major, reclassified minor), TID / NIEL aspects (*),
- RID …-nnnn = -0015: (major, reclassified minor), SEE aspects (*).
  - (*): See also similar RID CDR-**ASP**-TWTA-ENG-008 (major) on absence of analyses for TWTA (EPC only).

All the previous RIDs status is: closed by action item "AEO#6", due date 20/05/2004, to-date: open.

Synthetic evaluation:
Document looked like not well structured to easy understanding and verification of the three different radiation effects analyses, including missing equipment reference in terms of devices electrical sketches, configuration schemes, items topological identification.
Even more, despite all involved questions were dealt, the document itself looked like inadequate to its goal, since several of the analytical as well as qualification aspects due to demonstrate TWTA design compliance with the "Radiation Requirements", concerning the **Ionising And Non-Ionising Radiation Effects as well as the Single Event Phenomena Effects,** were missing in the document or inadequately explained or reported, id est: TID / NIEL models invaluable, with part of components apparently not submitted to analyses, and hardness situation not conclusive, SEU calculation insufficiently explained, SEE analysis unclear and not including all the components, consequences on design not highlighted enough.

Amendment and/or completion of the document was required in such a way that the TWTA fulfilment of related Radiation Requirements, considered not completely demonstrated to that date, could be so.

Details:
General
In general, it was suggested to get easier the understanding of the radiation analyses, by **reorganising and grouping the chapters** as corresponding to the 3 main areas of analysis, as dealt with into [RAD REQ], and by making explicit reference to a design description document, by providing some **figures and other data necessary to understand the position of considered devices and components**, such as schematics, and adding an acronym list.

➢ **TID**
Total dose evaluation was correctly addressed, **as a used method**, in order to fulfil RAD-01, (including applicable [ENVTR] dose-depth curve) with the following exceptions, but the **minimum requirement of TDT = 10 krad radiation hardness** for all the parts (RAD-02, ENVM-370) **was not even quoted**, **while its fulfilment** was **not clearly demonstrated**. Even more: **qualification values** for parts TID (to be intended as ≥ to the mentioned concept of "Design Dose") are **neither reported nor their** related **qualification tests mentioned**.

[RAD REQ] para. 7.3 (**Deposited Dose Calculation) instructions** were followed, by selecting the **ray tracing option of NOVICE**, but while its (conceptual) application was exposed, the EPC **model** (nothing is said of the TWTAs) was **not described** in terms of selected elements (geometry, position, materials, thickness…), targets.

In [TWTA RADAN] (para. 4.1) **TID results** "tables … show the total dose analysis results", results defined as "extremely summarised due to lack of criticality as far as cumulated doses are concerned."
While acceptable that "The calculation with NOVICE has been done on a limited but well-chosen number of devices " (for instance: the weakest and most exposed of them), on the other hand, clearly the selection process ought to be transparent and fully justified, so as to be understood and agreed, which was not possible for the time being. The presence of too generic (and therefore vague and potentially misleading) used terms like "hybrid", "BT", "HT1", etc. (to be better justified and explained, or, rather: re-selected). So, **actual TID results** are **reported** on table of page 7, but **precise links with EPC components names is not provided**, (lacking pictures addition might help); furthermore, it is **not possible to track the calculation path and check the results**, even if it is intended that EPC components, being EPC mounted inside the SVM, were calculated as shielded by:

- equivalent satellite structure = 0.8 mm(Al) para. 7.3 of Radiation Req.s (AD 2),
- EPC sides = ?? mm(Al);

- EPC internal elements and components sides = ?? mm(Al).

(Anyway, it is not possible to compare the actual with the above mentioned (missing) qualification values).

It is **not even stated whether the results are for the correct RDL** (Radiation Design Lifetime = twice the 4-year long mission lifetime, as per req.s RAD-01, ENVR-010) or for only 4 years.

A check was made by Alenia with the dose values (multiplied by 2 mission lifetimes) of Alcatel doc. H-P-1-ASPI-AN-0321, i. 01 - "Radiation Shielding Analysis for Herschel and Planck Satellites" ([H-P RADSHAN]), where actual satellites thicknesses (> 0.8 mm(Al)) are considered, and all the equipments as well (the latter ones, in first approximation, taken as thick as 0.8 mm(Al) per side constant), and these unit-level EPC references are higher (however within the minimum TDT) than the results under examination.

A table provided by **Alenia in the RID listed the components (after the parts list document) expected** to be affected by ionising radiation effects, versus the few ones in the results table. Actually, no one-to one comparison was possible since no ETCA items was doubtless identified.

No explicit mention of actual **values** to be used in **Worst Case Analysis**.

➢ <u>**NIEL**</u>

As for total ionising dose, similar points are highlighted for non-ionising radiation effects evaluation.
EPC (nothing about TWTA ?) **model and calculation flow** are **missing**, so resulting data (para. 4.3.3) are not traceable and directly checkable.
Evidence that **all components subject to NIEL** were **considered** for DDEF analysis was **not given**, in [TWTA RADAN], so in the RID the same Alenia table for TID **listed** also **all the components expected to be affected by non-ionising radiation effects**, compared to the few ones in the results table.

There was **no evidence of consideration of the correct RDL** = 2 mission lifetimes (ENVR-010).

Results in [TWTA RADAN], para. 4.3.3, were compared by Alenia with those <u>indirectly</u> derived from satellite level Alcatel [H-P RADSHAN] for TID. Into the DDEF curve for GaAs, were entered just those millimetres of Aluminium (corresponding to calculated TID levels: a probably conservative case, since considering 0.8 mm(Al) for the sides of EPC box and of the boxes of the other SVM units – whose presence, on the other hand, is very likely not considered in ETCA analysis for TWTA). As an output, the DDEF curve gives (both for Herschel and for Planck cases) higher data, in terms of equivalent fluence (per cm^2) of p^+ (@10 MeV), when the correct RDL of 8 years is considered, if compared with minimum level of hardness for GaAs components ($= 5{\cdot}10^{+9}$ p^+ (@10 MeV) / cm^2) (req. ENVM-370), (despite they are still lower than "design" (id est: qualification (?) levels).

Actual **qualification values** for the **components** (higher than minimum required) are only stated, not demonstrated (missing reference to tests, etc…).

No explicit mention of actual **values** to be used in **Worst Case Analysis**.

➢ <u>**SEE**</u>

Also in [TWTA RADAN] SEE paragraph 4.2, a limited number of components and unclear/partial analysis was found:

- (Names of the) components and the order in which they were reported were not clearly understandable
- Just **few components** vs total were **considered** (see part list and list in Alenia table included in the RID, with all the components (after the parts list document) expected to be affected by SEE, compared to those in paragraph and table with the results)
- Some **SEE effects seemed mixed up** (e. g.: "SEU analysis" table in para 4.2.6.1 with actual SET analysis)
- **SEE effect analysis per item was felt diffusely unclear, ambiguous, unexhaustive**: complete consideration and fulfilment of [RAD REQ] para. 8 is expected (as per Alenia table, pinpointing the aspects needing amendments, clarifications or progress)
- In some SEE analyses, requirements are not correctly considered, seem mixed up: (e g verification of SEB and SEGR in para 4.2.3)
- The (few) **(SEU) calculations present are not explained, so neither traceable nor verifiable** (e. g.: "Weibull parameter" table, without a recall of used formula and software programme used (as is assumed) to integrate cross section multiplied by fluence over LET); LET limit for SEL sensitivity in para. 4.2.2 is not coherent with its value in MeV.
- In SET table (para. 4.2.6.1), some little schematics (now missing) can help understanding & justifying the final effect of analysed transients.

Conclusions:
ETCA **acknowledged the missing/open points** during RIDs discussion at CDR (see H-P-MI-0480, 07/04/2004) closing RIDs with a **commitment for an updated Radiation Analysis**, the new issue providing an improved TWTA description, radiation analysis input elements and NOVICE model output extract, and "taking as much as possible care of comments" about SEE. These additions are felt necessary, since compliance to requirements and acceptability of design is not evident till now. Concerning the true TWTA analysis (not only EPC), it is replied (to ASPI RID) by ETCA that radiation analysis (TID / NIEL ?) is nor applicable to it, SEU/SET may give rise to short glitches to TWT output level, to be evaluated at quantitative level.

Status:
Open, awaiting for CDR action successful conclusion.

6.8.4 XPND

XPND Radiation Analysis is contained into **[XPND RADAN], iss. 2,** examined in occasion of XPND CDR, as commented in the following.

Radiation RID CDR-AI-XPND-ENG-0030 (major), dated 05/05/2004, was submitted, concerning TID, NIEL, SEE, the RID status being: closed by action item "AEO#23 (Radiation Analysis)", due date 21/05/2004, to-date: open.

Synthetic evaluation:
Document lent itself, already at a first reading, to a basic criticism founded on the tested intermittence in the logical flow of the reported information on the nominal subject, where the excessive relevance given to certain (however not well explained) theoretical insets did not counterbalance the speckles due to the diffuse lack of several minor and major necessary subject-related aspects.
Among them: the completely missing consideration of Radiation Displacement Damage by NIEL effect; dearth of quotation of duly applicable documents (XPND specification itself, [GDIR], [ENVTR] at least…); excess of synthesis in explanation of TID and SEE concretely used hypotheses, model parameters and components input data; absence of – at least – links and references to other documents, like WCA, FMECA, reporting about radiation effects on design.
Globally and looking from the end: no secure evidence – also based on the possibility to trace the analytical activity of AEO and verify / reproduce their results – can be get, from the report in subject, about the complete radiation requirements fulfilment versus the XPND design objectives, also considering part of components apparently not submitted to analyses, and hardness situation not conclusive.
Reconstruction and completion of the document in this direction was by RID general and pointwise requests, initaially not all and fully agreed by AEO – details are signalled below.

Details:

➢ **TID**
(dealt in [XPND RADAN] ch. 4 and para.s 6.1 and 7.1)
(In **ch. 4)** the described **TID analysis method** and logical flow is agreed, as well the **used NOVICE programme**, but: **none of the geometrical and physical properties of the elements of XPND considered in the mentioned NOVICE model was explicitly provided (nor were any of the programme parameters selected in the model run)**, and the drawing in picture 4.3 was irrelevant to its understanding since un-understandable and completely lacking of items indication and naming.
Therefore, on top of these missing elements, the **analysis is not verifiable at all**.
Radiation Design Lifetime (RDL), explicitly, is defined in [GDIR] ENVR-010 and [RAD REQ] para. 7 RAD-01: RDL is equal to 2 times the nominal mission lifetime and shall be explicitly recalled.
The **satellite shielding hypothesis** was as per [RAD REQ] para. 7.3 and **was agreed**, but in the following **para. 6.1** the **other shielding hypotheses were not understood**:

<< Due to the relatively benign radiation environment and the short duration of the mission, we have considered a pessimistic case, limiting the received dose estimated up to 10 Krad(Si) and the shielding equivalence (worst case) of 3 mm Al. No further analysis will be needed since we expect a significatif reduction of the total dose received in the real case. The following table shows the list of the sensitive components included in the equipment and its radiation estimated hardness in Krad. >>

Thus, the following comments are made:

It is neither possible "to limit" the "received dose", neither "to estimate" it, but simply to calculate it, by entering the equivalent item shielding in mm(Al) into the applicable H-P Dose-Depth curve ([ENVTR], fig. 3-26 / Table 3.4-8), then to compare the resulting Ionising Dose received in rad, multiplied by two to fulfil RDL requirement, with the qualification values of the items. This has to be clearly provided, including the equivalent shielding per item (missing in the following table). (In which sense the "case" "considered" is "pessimistic"?).
The "shielding equivalence of 3 mm Al" (of which part? Does it include the satellite?) is neither explained nor justified. In which sense is it a "worst case"? According to the applicable H-P Dose-Depth curve, it corresponds to 2.43 krad.
Moreover, the reference to 3 mm of equivalent Aluminium is not given in the proper way: this value shall be linked with mechanical design of the box.

The last-but-one column being the "total dose" (for 1 or 2 mission lifetimes?), the last one ("Design Dose") should be the be "radiation estimated hardness": in which sense is it "estimated"? It shall be determined by qualification / verification tests! Does they mean that a full compliance with requirement of minimum TDT of RAD-02 is achieved despite not declared? Anyway, 10 Krad tolerance shall be clearly written for every component, as per requirement RAD-02.
In the table itself, among the header names, "X", "Y", "Z" (co-ordinates in which reference frame?) shall be explained, and measurement units given.

It is expected ultimately, as per RID, that the referred, admitted "obsolete" paragraph 6.1 will be erased or updated (better: updated); above all, it is expected that all RID comments and questions are answered, and suggested improvements are implemented, in order to ***explain and make the TID analysis fully understandable, traceable, and verifiable****; simply stating: "The table reflects the real calculated values that are within the specifications: design limit + margins" is not sufficient, despite confidence on that exists.*

Dose calculation output for Worst Case Analysis is mentioned, but **input values to WCA are not evident**.

RID final request is to have at least a written link to "drift parameters due to received dose" that "are taken into account in the WCA".

- **NIEL**

Verification of Radiation Displacement Damage by **NIEL** effect was a **missing** chapter at all; since at least OL249 is an optical component, hence the **analysis shall be performed** – as per [RAD REQ] ch. 9 – and **input to worst case analysis** provided.

RID request is agreed by AEO.

- **SEE**

(dealt in [XPND RADAN] ch. 5 and para.s 6.2 to 6.6 and 7.2)
Concerning environment definition and particle transport analysis, and SEE phenomenology, ch. 8 of [RAD REQ] applies. In any case, the **LET spectrum of (solar + galactic) cosmic rays** mentioned in **ch. 5** as calculated by use of CREME, as well as **the Van Allen belts trapped particles and solar protons flux vs energy spectra, should be given**, to compare them with those of applicable environment in [ENVTR].
It is felt that all para. 5.2 **theoretical and methodological explanations** are very hardly understandable as they were provided and are now, and, **as they were taken as a basis for the following analysis**, that **they shall be improved** by clear and complete descriptions of hypotheses, theses, formulas – including validity ranges, used symbols and their physical meanings –, logical flow between passages and steps, and all used numerical values (e.g.: Weibull statistics parameters). Also, reference of quoted texts, handbooks shall be given.
<u>This is considered necessary to understanding and preliminary to evaluation of SEU rates results of table 6.3</u>, where contributions of heavy ions and galactic as well as solar protons shall be given separately.

RID objection is still valid after subcontractor's reply to access explanations "in all radiation standards (ESA SCC) or in the radiation expert community NSREC(IEEE) or RADECS(Europe)" What was requested was to have a clear explanation of the <u>selected</u> theory, without compelling the reader to resort to peruse a library, even to verify passages. Another possible solution, if preferred, is erasing the sequel of formulas and to quote – if demonstrated sufficient to the aim of the analysis description and results reporting – the user's manual of the used s/w programme, with a hue of the theory in background

It is observed that **SEU rates** may be, and were, also easily, even if quite conservatively (due to the statistical, non-linear cross-section profile versus LET – as replied by subcontractor, but that was already well known), calculated by Alenia according to [ENVTR] requirements ENVR-440 and -450 methods. A first check with these methods not always provide the same order of magnitude, as for component 54HC74 : if "SEUth" is LET_{th} = 34 MeV/(mg/cm^2), then entering it into [ENVTR] table 3.4-9 , a value of $(\tau/\sigma)_{HI} = 2.68\cdot10^{-1}$ SEU/cm$^2\cdot$day is found, which multiplied by

"XS" intended as $\sigma_{SEU,sat} = 3.5\cdot10^{-5}$ cm^2 , gives a $(\tau)_{HI} = 9.38\cdot10^{-6}$ SEU/device·day, a value largely greater than the reported $1.88\cdot10^{-9}$ SEU/device·day.

RID point stands still valid after the dogmatic reply of AEO:

"The calculations are correct.",

since the "calculations" cannot be received with such a fideistic behaviour, but are proposed for evaluation, and in order to evaluate them, they must be understandable; after that, they may be judged "correct", if demonstrated so. (As highlighted by the fact that, even if other $(\tau)_{HI}$ values are approximately found equal (some larger than) the results in table 6.3, the quoted one differs by almost 4 decimal orders of magnitude. This deserves, it is felt, some attention…)

As a matter of fact, more in general, at least **all that is behind the bare SEU rates calculations**, and that is necessary to its possible system-level repetition, including parameters of the cross sections distributions statistical fitting, **is expected to be provided** (as well as the other programme (CREME) parameters / physical parameters in the whole chain of calculations since the [ENVTR] environment data). Moreover, a clear **statement** in para 5[.0] that the **initial environment data** are actually **those in [ENVTR]**. The reference of **the reported values of LET_{th} and "XS" are also missing** and due.

Furthermore, pointwise discrepancies follow:

- **SEP,** Para 6.2
  After a cross checking with DCL H-P-4-AEO-LI-2003 of 16/04/04, issue 2, a **number of components were found completely missing** in table 6.2
  – the same holds for **SEU:** table 6.3, **SET**: table 6.4, **SEL:** table 6.5 ! ;
  besides, in table 6.2 only some effect per component are considered (and, for instance, DVC4619 and DVC4620 components are not included in DCL at all, as misnamed ("referred as VCXO with different frequencies" as clarified by AEO) (see RID for details):
  AEO reply to RID that"Only sensitive devices are included the analysis" is not completely satisfactory, due either to apparent errors, or to possible of component embedded part sensitivity to SEP, for example: Schmidt Trigger.
  Alenia ask for complete table lists after verifications component by component and explicit insensitivity statement, taking into account internal electronics.

- **SEU,** Para 6.3
  At the end of table 6.3, **no conclusion is reported** after the analysis. The reference to FMECA at the end of the document is not enough to grant that neither catastrophic nor critical consequences can occur due to a SEU event. Hence **a conclusive paragraph about the effect of SEU shall be added**.
  *AEO reply that "The radiation analysis does not report conclusions at equipment level but at component level. Refer FMECA and WCA for equipment level analysis", ergo at least a reference to every paragraph where the analysis is included is requested. It is underlined, for what concern **WCA**, that **SEP are not included at all**.*
  In table 6.3 some components use algorithms to reduce error probability. This shall be clearly written.
  AEO replies that"Design techniques are applied in order to reduce SEP in addition of TMR. Refer to specification/datasheet for more information". They are requested at least to provide reference to specific paragraphs of other AEO documentation, since this kind of information shall be part of XPND documentation and design, in order to demonstrate the fulfilment of XPND applicable requirements.

- **SET,** Para 6.4

Verification of Requirement RAD-21 is completely missing! An assessment of the effect of every transition shall be added to the document.

*AEO reply that "The radiation analysis does not report conclusions at equipment level but at component level. Refer FMECA and WCA for equipment level analysis", ergo at least a reference to every paragraph where the analysis is included is requested. It is underlined, for what concern **WCA**, that **SEP are not included at all**.*

Moreover, in table 6.4, the pulse duration suggested for all OP AMP is not in line with the requirement of [RAD REQ] para 8.4 ($\Delta V_{max} = \pm V_{cc}$ & $\Delta t_{max} = 15$ µs, NOT 40 µs as used), hence it shall be explained and justified in the document.

AEO agree.

- **SEB SEGR,** Para 6.6

Components TRANS 2N4392 and TRANS 2N6849 shall be added in the analysis.

The requirement reported is only for International Rectifier components or for Harris component: it shall be clearly written otherwise [RAD12], [RAD14] for SEB and [RAD16], [RAD18] for SEGR shall be considered.

AEO agree to updated the document to include both devices.

In para 5.1.3 (**SEB**), resp. in para 5.1.4 (**SEGR**), and in para 6.6 (**SEB, SEGR**), after the confirmation already received by AEO, a statement that only IR/Harris devices are used in the equipment is requested, in order to have [RAD REQ] RAD-13, resp. RAD-17, correctly applied.

- **Missing verification of GDIR requirements from [ENVR-100] to [ENVR-170]** is highlighted.
  It is not enough to reply to RID point with"Radiation analysis contains all the information about the parts sensitivity to radiation and their effects. Further information can be found in the FMECA".
  As first, for example: req ENVR-150 clearly reqests to have in spacecraft memories an uncorrectable error rate of less than 10^{-11} *error/(bit·day).*
  Anyway, if AEO want to refer to FMECA or other documentation for all verification, this shall be clearly written: number of document, issue and paragraph,(and of course the document shall be available).

- **SHE verification is missing (**[RAD REQ] Para 8.1.6).
  Since AEO opposes that there are no SRAM/DRAM (the only components sensitive to this phenomena) present in the equipmen, they shall add such a statement.

Conclusions:

The document shall be modified and updated according to all points raised above, since showing a lot of weak areas, at least as far as demonstration and reporting of a successful analysis versus qualification / testing hardness levels for all the three main radiation areas, so that compliance to requirements and acceptability of design is not evident till now.

AEO **acknowledged some of the missing/open points** during the interactive RID discussion at CDR (see H-P-MI-0513, on 11&12/05/2004), closing RID with a **commitment for an updated Radiation Analysis**, according to the provided comments (action item AEO#23).

Status:

Open, awaiting for CDR successful conclusion.

7. SVM SYSTEM-LEVEL RADIATION HARDNESS CONCLUSIVE ASSESSMENTS

At the time of writing this document issue, most of the units/subsystems are under review/revision (mainly under CDR), and the status of the several issues and open points raised about radiation sensitivity is generally **open**, waiting for reply/convergence and consequent updating of documentation/analysis/design; therefore it is not possible to come to a really conclusive assessment of compliance for all the units versus all the radiation environment requirements, also due to outlined areas of radiation design visibility by reporting.
Anyway, it is already possible, also on the basis of the suppletory assessments made by Alenia and reported in the relevant chapters, to enlarge the number of units radiation issues that are definitely close to those that can be considered essentially close, even if some answers and clarifications are still awaited.

In the first group, where **no problems at all** are found, we may list units whose situation is considered **closed**:

LCA/MGA: no sensitivity to radiation at all;
RFDN: TID hardness demonstrated (and revised by Alenia);
BATT: TID hardness demonstrated (and revised by Alenia);
AAD: NIEL hardness demonstrated (and revised by Alenia);
SAS: NIEL hardness demonstrated (and revised by Alenia);
TCS: no item sensitive to radiation found.

The most populated group encompasses **units**, whose situation is evidently **open,** which are characterised by a "mix" of **requirements not clearly matched** or **apparently not matched** and, even more, of **missing or unclear reporting aspects about analytical and/or qualification sides of hardness demonstration** (underlined points are to render immediately a perception of the areas provisionally felt as most critical) – a limited assessment is provided till now for them, since upgradings and amendments are due by CDRs:

CRS: TID analysis questionable (but Alenia assessment covers and closes its open points),
NIEL to be explicitly excluded,
SEE analyses and hardness data above all to completed
GYR: essentially uncertain under any aspect (generic, too synthetic slides), anyway no danger felt behind
TID / NIEL (but explanations necessary, above all NIEL neutrons-to-protons factor),
SEE to be understood and evaluated vs. design
STR: TID analysis needs explanations and discussions, even on hypotheses, before accepting it,
furthermore one component hardness is below minimum 9 instead 10 krad;
NIEL analysis missing, hardness of CCD not sufficiently demonstrated;
SEE analysis both in electronics and CCD needs wide explanations, as well as effects on design.
ACC/CDMU: TID analysis poor, despite hardness felt sufficient to actual dose, improvements accepted and awaited;
NIEL analysis not performed as per requirements and uncertain hardness for optocoupler reported;
SEE analysis very limited in basic data, extension, components and design effects.
HRN: TID analysis/statement versus the 10 krad level delayed and missing to-date.
RCS: TID analysis (for PT essentially) still to be provided as per requirements, and results to be compared
versus correct hardness levels; reporting on tank diaphragm still missing;
SEE analysis (for PT only) "based on" partly missing LET, cross section data, partly uncorrect requirements and with important lacks.
EPC/TWTA: TID analysis description too synthetic, even on hypotheses (e.g. design lifetime) and actual hardness;
NIEL analysis scarcely reported, even on used design lifetime, perhaps not all items considered;
SEE requirements doubtfully considered, analyses insufficient, and also consequences for design.
XPND: TID analysis insufficiently explained, like hypotheses (e.g. design lifetime); thus unverifiable;
NIEL analysis missing, unmotivatedly;
SEE analyses insufficiently explained, thus unverifiable, some devices not considered for design.

Provisional comments are quoted for **RWA** (this situation is considered **open**, too) since examined together all the other ACMS units, but not yet deeply scrutinised at the upcoming CDR

RWA: TID analysis impossible to evaluate, vs hardness statement (even the "10 krad" minimum) missing;
NIEL consideration missing;
SEE analysis featuring many aspects at least to be integrated, as per posed questions.

In the group of **units** whose situation is considered logically **open, since not-yet-evaluated,** there are:
PCDU: since CDR is next to come;
SA: since CDR is next to come.

Before proceeding further with the SVM system level assessment, it is felt reasonable to wait and receive from SubContractors within a reasonable time span, the reply to open RIDs and/or comments raised, or the missing documentation. After that, the complete evaluation will be provided.