MEPS radiation report
— DRAFT —

REF: LGR-IS-KIE-AN-0002_iss1_rev0

Prepared by:	Jan Christoph Terasa, Scientist *Name, Job title*	Date:	9th January 2019
Checked by:	César Martín *Name, Job title*	Date:	10th January 2019
Approved by:	*Name, Job title*	Date:	
Authorised by:	*Name, Job title*	Date:	

Contents

1 Scope

This document outlines an assessment of the impact of the extra-terrestrial radiation environment on Medium Energy Particle Spectrometer (MEPS).

2 Documents

2.1 Applicable Documents

Ref.	Title	Doc ref. #	Iss.	Rev.
SO-01	Solar Orbiter Environmental Specification	TEC-EEDS-03	1.3	1
LG-01	Lagrange Mission (L5) Environment Specification	ESA-SSA-LGR-RS-0004	1	0

2.2 Reference Documents

Ref.	Title	Doc ref. #	Iss.	Rev.

2.3 Acronyms and Abbreviations

CAD Computer Aided Design

CCD Charge-coupled Device

CREME96 Cosmic Ray Effects on Micro-Electronics Code

EBox Electronics Box

EDAC Error Detection and Correction

GCR Galactic Cosmic Ray

GEANT4 Geometry and Tracking 4

LET Linear Energy Transfer

LVPS Low Voltage Power Supply

MEPS Medium Energy Particle Spectrometer

NIEL Non-ionising Energy Loss

PCB Printed Circuit Board

S/C Spacecraft

SBox Sensor Box

SEB Single Event Burnout

SEE Single Event Effect

SEL Single Event Latchup

SEU Single Event Upset

SEP Solar Energetic Particle

SPE Solar Particle Event

SSD Solid State Detector

TID Total Ionising Dose

TNID Total Non-Ionising Dose

3 Introduction

Space-borne equipment is subject to environmental conditions which are very different from those observed on Earth. Especially particle and electromagnetic radiation in space can affect the operation and survival of space-borne equipment. The main contributors to the radiation impinging on equipment are radiation from the Sun, the extra-heliospheric radiation, and radiation from or trapped close to nearby planetary bodies. Herein we will report on the studies and analyses done for MEPS aboard the Lagrange spacecraft. The mission will take the spacecraft and the sensor from Earth to Lagrange point 5 during a 3-year cruise phase. During the 5-year operational phase, the spacecraft will stay at or around Lagrange point 5. Both Earth and Lagrange point 5 have an average distance of 1AU (=150 million km) from the Sun, so that the radiation environment is very similar at both positions. The environment at Lagrange point 5 is especially comparable to that at Lagrange point 1, which is close to Earth, and has several spacecraft orbiting it, so that a lot of reference data for other space-borne equipment is already available.

4 Radiation Effects

The section is intended to introduce the different types of radiation effects that can observed in space, and the impact that they can have on electronic components.

4.1 Total Ionising Dose (TID)

Ionising radiation are high energetic charged particle, which effect degradation of electronics components, and thus limit the lifetime of equipment. Ionising radiation can create unwanted glitches, which can lead to severe malfunctions of the equipment. They can create defects, or can destroy the structure of the solid. Accumulating a high amount of TID can lead to unwanted electronic effects, or even complete malfunction of the equipment. Thus, the more TID is accumulated by equipment during the lifetime of the mission, the more likely an electronic failure of the equipment becomes. Usually for space-borne equipment, radiation-hardened electronics are used, which are specifically designed to have a lower susceptibility to TID damages than commercial ground-based electronics.

Space plasmas, like the solar wind and Solar Energetic Particles (SEPs), are a source of high energy charged particles contributing to the TID. Particles from the Galactic Cosmic Rays (GCRs) also can also contribute to the TID.

4.2 Total Non-Ionising Dose (TNID)

Non-ionising radiation is less energetic than ionising radiation, but can still create glitches and malfunctions in equipment. Since the energy is not sufficient to ionize material, it will rather be heated. This heating can lead to displacement damages in the equipment, which can lead to defects in the solid. TNID mostly affect diodes, electro-optical elements and solar cells. The relevant quantity to analyse is the Non-ionising Energy Loss (NIEL)

4.3 Single Event Effects (SEEs)

SEEs are effects which result from heavy ions losing their kinetic energy very fast when passing through matter, and thus a large amount of energy is transferred to the equipment in a very short path. Thus, in contrast to TID, the relevant quantity to assess is not the total dose, but rather the Linear Energy Transfer (LET) $\frac{\mathrm{d}E}{\mathrm{d}x}$. SEEs can manifest themselves as Single Event Upset (SEU), which leads to corruption of data in memory registers, or in form of Single Event Latchups (SELs) or Single Event Burnouts (SEBs), which can lead to malfunction of the affected component.

5 Radiation Environment

The radiation environment we will consider for this report is the one specified in Sec. 4.3 of [LG-01]. For the cumulative mission proton fluence, the NASA GSFC ESP model is used., which models the SEP environment measured at 1 AU (Fig. 1).

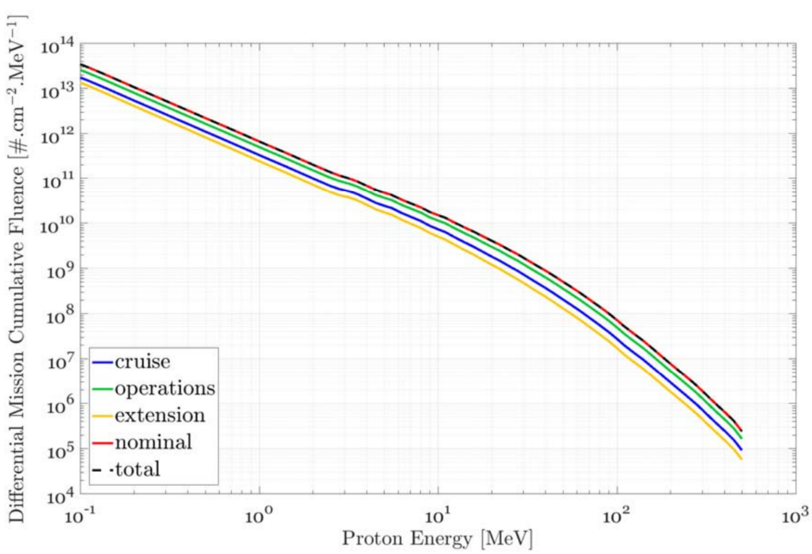

Figure 1: Differential mission cumulative solar proton spectrum for SSA-L5 mission. Taken from [LG-01]

In addition, for analysing the contributions of heavy ions, the relative abundances are given in the model. Assuming the same spectral shape as for the protons, one can thus also asses the contribution of heavy ions from SEP. A more detailed description of the model can be found in Sec. 4.3.2.1 of [LG-01].

To asses the contributions of singular high-flux SEPs, we will also consider using the CREME96 data set, which provides energetic particle flux at 1AU for the 5-minute peak of the worst SEP event recorded on October 1989, as well as data for the worst day and worst week of data. This data is very useful to assess the cross-sections for SEEs (Sec. 4.3).

We will also consider the contributions from GCRs. Even though GCRs have a relatively small flux compared to SEPs, they can still contribute to the TID or to SEEs, due to their higher relative abundance of very high energy particles above 1GeV/nuc..

Contributions of electrons will be negligible for TID or SEEs.

6 Equipment Description

A more thorough description of MEPS can be found in TODO. For assessment of the susceptibility of the sensor to radiation effects the relevant components are the Solid State Detectors (SSDs), the Printed Circuit Boards (PCBs), and the installed electronic components.

6.1 List of Electronic Parts

Here we will provide a table of the electronic parts affected by radiation effects, including their radiation hardness, SEE-thresholds. We will also list in which sub-assemblies those components are used.

6.2 Subassembly #1

Here we will have sections describing the different sub-assemblies (detector heads, power board, digital FPGA board, etc.)

7 Analysis

For the analysis of the radiation effects on MEPS we perform Monte-Carlo simulations using the GEANT4 toolkit. We create a model of the sensor, including sensitive volumes for the PCBs and electronic components. We then perform simulations shooting in energetic particles from hydrogen up to iron, in the energy range given by the models mentioned in Sec. 5, with a power-law spectrum with an index of $\gamma = -1$. This will give us similar statistics logarithmically across the whole energy range. We can then easily re-normalize the results to the spectra provided in [LG-01].

We will use the simulation results to calculate the TID in the sensitive volumes, and map those volumes to the respective components in Sec. 6.1.

Thus we can evaluate the TID for each relevant component. Ultimately we will provide a likelihood that MEPS will not exceed the TID in the most affected part during the mission time, based on assumptions about the solar activity during the mission.

We will also use the tracking results from the simulations to determine the LET, and thus the probability of a SEE in the individual susceptible components.

8 Conclusion

8.1 Total Ionising Dose

Based on the analysis, we will either confirm that the design is sufficient to survive the mission, or propose changes to the design. The effects of TID can only realistically be mitigated by increasing the shielding of the electronic parts, or selecting higher rated rad-hard parts.

8.2 Total Non-Ionising Dose

We will not perform a dedicated study of TNID. The parts which can be affected are the SSDs, but we will choose a sufficiently bias voltage, to mitigate the effect of increasing leakage current, due to aging and radiation effects.

8.3 Single Event Effect

Based on the analysis. we will present the expected SEU rate. The current MEPS design already uses Error Detection and Correction (EDAC) in its FPGA, which is able to fully correct single bit-flips, and notify about multiple bit-flips, due to SEUs.

Document Changes Record

Iss.	Rev.	Date	Modified by	Section mod.	Change implemented
1	0	January 2, 2019	Terasa	All	Initial release