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Radiation mitigation in the Particle Environment Package (PEP) sensors for the JUICE mission

S. Barabash (1), S. Karlsson (1), M. Wieser (1), P. Brandt (2), J. Westlake (2), P. Wurz (3), M. Fränz (4)
(1) Swedish Institute of Space Physics, Kiruna, Sweden; (2) John Hopkins University / Applied Physics Laboratory, Laurel, USA; (3) University of Bern, Bern, Switzerland; (4) MPI fuer Sonnensystemforschung, Götingen, Germany.
(stas.barabash@irf.se / Fax: +46-980-79025)

Abstract

PEP (Particle Environment Package) is a suite of 6 (six) sensors measuring ions, electrons, exospheric neutral gas, thermal plasma and energetic neutral atoms present in all domains of the Jupiter system. Mitigation of the Jovian penetrating radiation is the outstanding problem of all PEP sensors design. We present results of the radiation simulations and the main design solutions that allow us to reach signal-to-noise ratios sufficient to address the PEP science objectives and decrease the total ionization dose below 100 kRad over the whole mission.

1. PEP suite

PEP measures positive and negative ions, electrons, exospheric neutral gas, thermal plasma and energetic neutral atoms present in all domains of the Jupiter system over nine decades of energy from < 0.001 eV to > 1 MeV with full angular coverage. The six PEP sensors are:

- Jovian plasma Dynamics and Composition analyzer (JDC);
- Jovian Electrons and Ions analyzer (JEI);
- Jovian Energetic Electrons (JoEE);
- Jovian Energetic Neutrals and Ions sensors (JENI);
- Jovian Neutrals Analyzer (JNA);
- Neutral gas and Ion Mass spectrometer (NIM).

Mechanically the sensors are arranged in 4 units which are grouped in two groups PEP-Lo and PEP-Hi (Fig. 1).

As particle detectors PEP uses ceramic channel electron multipliers (CCEM) and microchannel plates (MCP). The detectors are sensitive to the penetrating radiation and measurements of the required particle fluxes to achieve the PEP scientific objectives require comprehensive radiation mitigation measures.

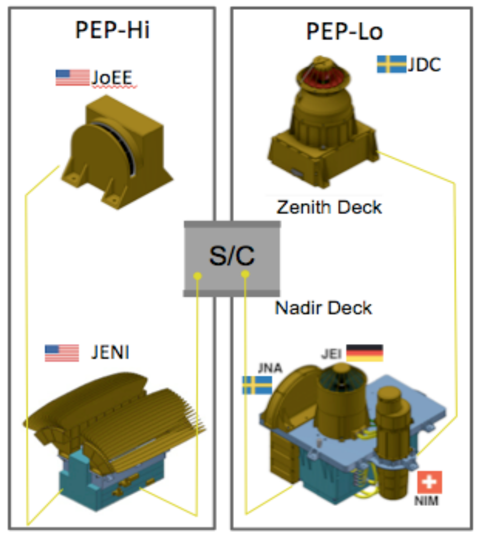

Figure 1: PEP suite and PEP sensors

2. Jupiter radiation

Jupiter possesses the strongest radiation belts in the solar system. The JUICE mission operating as close to Jupiter as Europa will experience significant fluxes of penetrating radiation, mostly electrons (Fig. 2).

The energetic electrons interacting with the instrument shielding and structure result in significant fluxes of secondary gamma rays in the energy range up to 10 MeV. The fluxes of gammas may exceed the fluxes of electrons at the detector locations by a factor of 10.

Fluxes of other particles, for example energetic protons, are significantly lower.

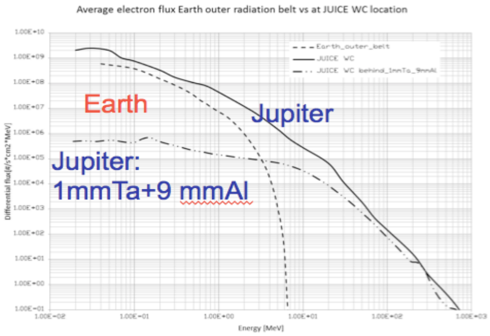

Figure 2: Comparison of energetic electrons fluxes at Europa and the Earth radiation belt.

3. PEP radiation mitigation

PEP radiation mitigation strategy includes *(1)* passive shielding to reduce total dose and backgrounds, *(2)* coincidence schemes to increase signal-to-noise ratio (SNR), *(3)* reduction of the detector sensitive area to reduce background rates keeping foreground sensitivity same by employing focusing electrostatic optics, *(4)* reduction of the sensor volumes to decrease the internal surface areas emitting not-valid secondary electrons, *(5)* monitoring instantaneous background rates to be subtracted, *(6)* where feasible, replacement of microchannel plates (MCP) by Ceramic Channel Electron Multipliers (CCEM), which are much less radiation sensitive,. MCPs are still used when imaging is required and the radiation can be mitigated by multiple coincidences.

The passive shielding includes spot shielding of individual electrical components and shielding elements shared by sensors and subsystems. Comprehensive radiation modelling was performed to optimize the shielding geometry and graded shielding design. The average doses achieved for electronics are below 100 kRad (including the Environmental Safety Factor that is equal to 2). The tools used in the analysis are: GRAS FMC (Geant4 Radiation Analysis for Space, Forward Monte Carlo), GRAS RMC (Geant4 Radiation Analysis for Space, Reversed Monte Carlo), SSAT (Sectoring Shielding Analysis Tool), FASTRAD, by TRAD, which includes ray-tracing, RMC and NOVICE interface.

The coincidence methods used in PEP sensors are based on *(1)* ToF coincidence, *(2)* anti-coincidence, *(3)* matching particle energy measured independently, *(4)* matching detector hit position measured independently (Table 1). The ToF coincidence is the most effective way to increase signal-to-noise ratio (SNR) because the probability of two non-correlated background events to occur within a short TOF window (from a few ns to 512 ns) is relatively low. Anti-coincidence schemes used in PEP rely on anticoincidence between valid events and background events recorded by anti-coincidence solid state detectors (SSD). PEP also uses the difference in pulse-height distributions (PH) from valid and penetrating particles detected by an MCP.

Table 1: PEP coincidence schemes

	JDC	JEI	JoEE	JENI	JNA	NIM
ToF coincidence	1x			2x	1x	1x
Anti-coincidence	1x	1x	1x			
Matching energy			1x			
Matching position				1x	1x	
Total coincidence	2	1	2	3	3	1
PH threshold	1x			1x	1x	