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RADIATION ENVIRONMENT AND EFFECT ANALYSIS OF THE ZODIAC PIONEER MISSION

Abstract

A priority in ESA's Space Safety Program for Planetary Defense is developing fast rendezvous satellites to study potentially hazardous asteroids. The ongoing study, led by Tyvak International, aims to design a small satellite with high delta-V capability for the Zodiac Pioneer asteroid scout mission. This initiative focuses on NEAs with potential rendezvous in the next 8 year, with Politecnico di Torino handling radiation assessment in various mission scenarios. First use case is the Earth's close encounter with the 99942 Apophis asteroid, expected by April 13, 2029. Throughout the mission, the radiation environment will be highly mutable due to variations in solar activity and changes in the spacecraft's distance to both the Sun and Earth during Apophis' flyby. These variations translate into different radiation sources affecting the spacecraft's onboard electronics. A comprehensive analysis requires characterizing each mission phase with the related radiation environment.

However, conventional tools fail to do such an accurate analysis due to the unavailability of defining multi-segment interplanetary missions and adopting a minimum mission length of 6 months. This results in an unfeasible evaluation of an effective trajectory-based radiation environment when the trajectory is characterized by fluctuations in Sun distances occurring in brief intervals. Hence, we proposed and developed a new comprehensive framework to estimate the total ionizing dose (TID), covering the trajectory-induced variation in the daily dose contribution. The framework is built upon a dose database constructed using ESA's SPENVIS tool, considering different interplanetary missions with variable durations, Sun distances, and solar activity. The developed framework receives the trajectory, time spent at each distance, and solar conditions at each point as input.

Considering the different interplanetary trajectories to reach different targets, the developed software method accurately estimates the dose contribution considering the trajectory characteristic. Indeed, the so far analyzed trajectories differ in cruise duration, Sun distances, and time spent in solar maximum, leading to highly variable protons flux affecting the cruises. The platform evaluates these parameters to provide TID estimation tailored to the current trajectory under study, avoiding generalities. Adopting effective trajectory-based dose estimations introduces radiation sensitivity as a further metric in the final trajectory decision. This approach underlines the key differences between the trajectories, masked in conventional tools when adopting worst-case scenarios (or average values), which are mission design constraints affecting

all the trajectories. Most importantly, it avoids TID overestimation since the boundary conditions are maintained for a negligible duration compared to the entire mission length.