A Deterministic Electrons/Photons, Protons/Trapped Heavy Ions (C-O-S) Transport Suite for the Study of the Jovian System

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A Langley Research Center (LaRC) developed deterministic suite of transport codes which describe the transport of electrons/photons, protons/heavy ions in condensed media is used to simulate the effects and exposures from spectral distributions typical of electrons, protons and carbon-oxygen-sulfur (C-O-S) trapped heavy ions in the Jovian radiation environment. The particle transport suite consists of a coupled electrons/photons deterministic transport algorithm (CEPTRN) and a light/heavy ion deterministic transport algorithm (HZETRN). The primary purpose for the development of the transport suite is to provide a means to the spacecraft design community to rapidly perform numerous repetitive calculations essential for electrons/protons/heavy ions radiation exposure assessments in complex space structures. Several favorable comparisons have been made with statistically oriented Monte Carlo (MC) calculations. ITS V.30 (integrated Tiger series) MC package was used for electrons/photons transport verfication in the Jovian environment [1]. FLUKA and HETC-HEDS were used for protons/heavy ion transport verification at low Earth orbit (LEO) [2] as Jovian heavy ion counter (HIC) spectra were not available to the authors. The proton/heavy ion models have been extensively validated in LEO by comparing to measurements aboard the International Space Station (ISS) and the Space Transportation System (STS) [3]. The transport suite verifications versus MC packages have indicated that for typical space environment spectra at LEO or at Galilean satellites, the particle transport accuracy has not been compromised at the expense of computational speed.

The radiation environment of the Galilean satellite Europa is used as a representative boundary condition to show the capabilities of the transport suite. While the CEPTRN/HZETRN suite can directly access the output electrons/protons spectra of the Jovian environment as generated by the Jet Propulsion Laboratory (JPL) Galileo interim radiation electron (GIRE) model of 2003 [4], for the sake of relevance to the upcoming Europa Jupiter system mission (EJSM4) workshop, the authors have opted to directly use the tabulated 105 days at Europa mission fluence energy spectra [5] to produce the corresponding depth-dose curve in silicon behind an aluminum shield. The transport suite can also accept ray-traced thickness files from a computer-aided design (CAD) package and calculate the total ionizing dose (TID) at a specific target point. The dependency on a CAD generated ray-traced file is inherent in the deterministic nature of the transport formalism. In that regard, using a low-fidelity CAD model of the Galileo probe generated by the authors, the transport suite was verified versus aluminum equivalent shell simulations for orbit G1–I32 of the Galileo extended mission (1996-2001) [6].

Beyond computing the traditional aluminum-silicon depth-dose curve as a standard shield-target combination, for a limited number of candidate shielding materials such as tantalum (Ta), copper (Cu) and tungsten (W), the transport suite is used to evaluate the particle flux and TID dose due to electrons, protons and C-O-S trapped heavy ions at Europa (Rj=9.4) as a function of latitude, longitude and altitude. Furthermore, the fast execution time of the transport suite allows a design engineer to swap shield materials to perform Z-grade optimization on multi-layered shields.

The Jovian radiation environment will be presented first. An explanation of the particle transport formalism as implemented in the transport suite will follow. Validation results versus Galileo probe measurements will also be shown followed by an explanatory description on how shield designers can go about performing Z-graded studies or final shield optimization.

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