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OPTIMIZATION OF PASSIVE RADIATION SHIELDING FOR MANNED EXPLORATION BEYOND CISLUNAR SPACE USING HIGH-PERFORMANCE COMPUTING SERA ENVIRONMENT

Abstract

The space radiation environment, which includes high energy Galactic Cosmic Rays (GCR), Solar Particle Events (SPE), and trapped radiation belts, presents a significant challenge for deep space missions beyond Cislunar space. All of which pose a significant hazard to astronaut health and to sensitive electronics. Thus, there is a need to significantly reduce radiation dose enabling long duration space flights by development of improved shielding techniques. Traditional techniques use passive radiation shielding systems designed by manual iterative approaches, with the designer choosing shielding materials and thicknesses by hand, then using stochastic or deterministic methods to calculate the effectiveness. Presented here is a newly developed simulation methodology to optimize and design shielding, called SERA (Space Environment Radiation Analysis). The SERA optimizing simulation code is based on GEANT4 and DAKOTA. GEANT4 is a Monte Carlo code written in C++ used for simulating radiation transport in many different environments. SERA is built on this framework aimed at optimized and computationally efficient analysis of radiation transport through spacecraft and passive shielding materials. SERA simulates the energy deposition, dose, and equivalent dose within a volume of interest or detector within a spacecraft. SERA runs on multiple computer architectures and is optimized to run on high-performance computing (HPC) clusters with multithreading and message passing interface. This allows multiple HPC nodes to quickly analyze different passive shielding configurations. DAKOTA is an optimizing tool that provides iterative algorithms able of controlling simulation runs (such as by SERA) with the final output being complete optimization studies and analysis, including uncertainty quantification, deterministic and stochastic calibration, and parametric, sensitivity, and variance analysis. An interface between GEANT4 and DAKOTA allows iterative analysis of different passive shielding configurations altering the materials, thicknesses, and configurations, using parametric analysis, Monte Carlo sampling, or genetic algorithms. This allows DAKOTA to create an optimized passive shield design that results in the lowest dose and energy deposition based on design criteria such as shielding mass, structural properties, thermomechanical properties, and heat transfer properties. This paper presents the SERA methodology and SERA analysis of passive shielding configurations for two test scenarios: an inflatable space habitat and a rigid cylindrical spacecraft. For both scenarios, the effectiveness of different shielding configurations against GCR and a SPE was analyzed for a mission beyond Cislunar space, optimizing the shielding based on constraints of reducing mass and positive structural/thermomechanical properties.