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Classical–Quantum Simulations for Optimized Shielding Against Solar Particle Events in Space Applications

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Space radiation poses a significant challenge for long-duration human space missions, with primary sources including Galactic Cosmic Rays (GCRs), Solar Particle Events (SPEs), and trapped particles within the Van Allen belts. These high-energy radiations induce severe biological effects on astronauts and degrade spacecraft systems, making effective shielding a critical requirement. Traditionally, passive shielding materials such as aluminum have been employed; however, their limitations, particularly the production of secondary radiation, necessitate the exploration of better alternatives.

In this study, the performance of shielding materials including lithium hydride, polyethylene, lithium borohydride, beryllium borohydride, and ammonia borane is evaluated in GCR and SPE environments using OLTARIS, a NASA-developed simulation tool. The October 1989 SPE is selected to analyze particle flux and dose distributions. Shielding effectiveness is found to vary depending on the radiation environment: beryllium borohydride demonstrates superior performance against SPEs, whereas lithium hydride provides the lowest dose under GCR exposure. In the SPE environment, shielding performance is strongly correlated with hydrogen content. The effect of solar modulation on GCR dose is also examined, revealing that higher modulation reduces both GCR intensity and radiation dose.

The complex nature of high-energy space radiation, combined with material interactions, introduces significant computational challenges. To address this, the material selection problem is formulated as a Quadratic Unconstrained Binary Optimization (QUBO) and solved using the Variational Quantum Eigensolver (VQE) and Quantum Approximate Optimization Algorithm (QAOA). By mapping OLTARIS simulation data onto the Ising model and applying these hybrid quantum-classical approaches, optimized shielding configurations that minimize radiation dose are identified. The results demonstrate strong agreement between OLTARIS simulations and quantum optimization outcomes across both GCR and SPE environments.

Auteurs: LALWANI, Kavita (MNIT Jaipur, INDIA); Mlle V V, Sreedevi V V (MNIT Jaipur, INDIA)

Orateur: Mlle V V, Sreedevi V V (MNIT Jaipur, INDIA)

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