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Recent advances in electrospun hydrogen-rich polymeric nanofiber composites for space radiation shielding

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As human space exploration extends beyond Low Earth Orbit toward sustained lunar and future Mars missions, lightweight and multifunctional radiation-shielding materials are increasingly required to mitigate the complex Galactic Cosmic Ray and Solar Particle Event (SPE) environment. Hydrogen-rich polymers offer advantages over conventional high-Z metallic shields because of their low density and reduced production of high-energy secondary radiation. This review critically evaluates recent advances (2020–2026) in electrospun hydrogen-rich polymeric nanofiber composites for space radiation shielding, with emphasis on the relationships among polymer chemistry, nanofiber architecture, functional fillers, and shielding performance. Particular attention is given to polyethylene-based systems, boron-containing fillers, hierarchical architectures, and the influence of processing and interfacial characteristics on radiation attenuation and multifunctional performance. Radiation-transport modelling, including Monte Carlo approaches, together with molecular-scale and computational materials-design strategies, is examined as a route toward predictive optimization; however, limitations associated with heterogeneous datasets, model validation, and the lack of standardized mission-relevant testing remain significant barriers. The review further identifies critical challenges in electrospinning scalability, environmental durability, long-duration radiation exposure, and translation from laboratory testing to aerospace implementation. Overall, the available evidence indicates that shielding performance cannot be attributed to nanofiber morphology alone and must instead be evaluated through the combined effects of hydrogen content, areal density, architecture, filler distribution, and radiation type. Future progress will require quantitatively validated structure-property-performance relationships, standardized testing protocols, scalable manufacturing, and integrated experimental-computational approaches to enable reliable qualification of lightweight shielding systems for long-duration space missions.

KEYWORDS

boron nitride nanotubes, electrospinning, Galactic cosmic rays, hydrogen-rich polymers, multiscale materials design, polymeric nanofiber composites, space radiation shielding