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一种基于多层涂硼圆筒的 γ 补偿中子探测器的仿真研究

摘要

硼涂层电离室因其强大的辐射耐受性、长寿命、耐高温高湿度以及可靠的性能，被广泛应用于反应堆外部核仪表系统中的中子探测。这些电离室在核能、辐射防护和放射医学中有着广泛的应用。硼涂层电离室中的电信号主要由伽马射线和中子产生，通过补偿技术可以显著降低伽马噪声。然而，由于可能存在补偿误差，伽马噪声仍可能影响中子信号。在低中子通量和高伽马噪声条件下，传统的硼涂层电离室信噪比较低，导致中子信号被伽马噪声掩盖，难以准确测量中子通量。为了提高硼涂层电离室的中子探测效率和灵敏度，本研究提出了一种基于平行板伽马补偿电离室的多层硼涂层圆柱体结构的新设计。这种新结构显著增加了单位体积内的有效硼涂层体积，取代了传统仅在电极表面涂覆硼化合物的方法，从而提高了中子探测效率。通过结合 Geant4、Garfield++ 和 SRIM 的联合模拟，优化了电离室的结构参数，并计算了改进前后的中子探测效率。模拟结果表明，改进后的硼涂层电离室中子探测效率显著提高，为实际中子探测应用提供了一种有前景且可靠的解决方案。

关键词

关键词：硼涂电离室；中子探测器；伽马补偿；蒙特卡洛仿真

Abstract

The boron-coated ionization chamber is widely used in neutron detection for reactor external nuclear instrumentation systems due to its strong radiation resistance, long service life, high-temperature and humidity tolerance, and reliable performance. These ionization chambers find extensive applications in nuclear energy, radiation protection, and radiological medicine. The electrical signals in boron-coated ionization chambers are primarily generated by gamma rays and neutrons, with gamma noise significantly reduced through compensation techniques. However, due to potential compensation errors, gamma noise may still affect the neutron signal. Under low neutron flux and high gamma noise conditions, traditional boron-coated ionization chambers exhibit a low signal-to-noise ratio, leading to neutron signals being obscured by gamma noise, making accurate neutron flux measurements difficult. To enhance the neutron detection efficiency and sensitivity of boron-coated ionization chambers, this study proposes a novel design that incorporates a multilayer boron-coated cylindrical structure based on a parallel-plate gamma compensation ionization chamber. The new structure significantly increases the effective boron-coated volume per unit volume, replacing the traditional method of coating boron compounds only on electrode surfaces, thereby improving neutron detection efficiency. Using combined simulations with Geant4, Garfield++, and SRIM, the structural parameters of the ionization chamber were optimized, and the neutron detection efficiency before and after improvement was calculated. Simulation results demonstrate a significant enhancement in neutron detection efficiency with the improved boron-coated ionization chamber, providing a promising and reliable solution for practical neutron detection applications.

Keywords

Key words: boron coated ionization chamber; Neutron detector; Gamma compensation; Monte Carlo simulation

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