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高通量反应堆中锎-252 辐照生产特性初步研究

摘要

锎-252（^{252}Cf）是一种强大的自发裂变中子源，具有体积小、强度高、连续释放裂变中子及低热释放的特点。作为重要的放射性同位素，^{252}Cf 广泛应用于反应堆启动中子源及瞬发 γ-中子探测中。^{252}Cf 的制备途径包括反应堆辐照、加速器法以及地下热核爆炸，其中高通量反应堆辐照是实现大规模生产最重要且最有效的方法。本研究采用详细的燃耗分析程序与蒙特卡罗模拟相结合的方法，对 ^{252}Cf 的生产过程进行评估，分析在不同中子通量水平和能谱条件下典型靶核材料的产量和效率差异，探讨了不同靶核素的转化特性，并提出适用于高通量反应堆的 ^{252}Cf 优化辐照方案。研究进一步分析了反应堆中 ^{252}Cf 生产的主要损耗链及关键中间核素。结果表明，辐照通道中的中子能谱对 ^{252}Cf 的产量有显著影响，其中（n, γ）反应是限制生产效率的主要因素。通过优化能谱以增强瓶颈核素的（n, γ）反应截面，有望显著提升 ^{252}Cf 的生产能力。本研究也为高通量反应堆中 ^{252}Cf 生产过程中的辐照方案、靶结构设计及靶材布置优化提供了理论基础。

关键词

高通量堆；锎-252；辐照生产；转换特性

Abstract

252Cf is a powerful spontaneous fission neutron source, characterized by its compact size, high intensity, continuous neutron fission, and low heat emission. It is an important radioisotope, used as a neutron source for the reactor startup and prompt γ-neutron detection. Possible pathways for preparation of 252Cf include reactor irradiation, accelerators, or underground thermonuclear explosions, with high flux reactor irradiation being the most important and effective approach for large-scale production. This paper employs a detailed burnup analysis program coupled with Monte Carlo simulations to evaluate the 252Cf production process, analyzing differences in production yield and efficiency under various neutron flux levels and energy spectra for typical target nuclei. The conversion characteristics of different target nuclei are discussed, and optimized irradiation schemes for 252Cf production in high flux reactors are proposed. This study examines the primary depletion chain in the reactor-based production of 252Cf and analyzes main intermediate nuclides. The findings reveal that the neutron spectrum in the irradiation channel significantly influences 252Cf yield, with the (n, γ) reaction being the primary factor affecting production efficiency. Enhancing the (n, γ) reaction cross-section of bottleneck nuclides through energy spectrum optimization can significantly improve productivity. This research also lays the foundation for optimizing irradiation schemes, target structures, and target arrangements in high flux reactors for 252Cf production.

Keywords

252Cf, High flux reactor, Irradiation production, Conversion characteristics.

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