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Analysis of Neutron Attenuation and Activation Source Terms in Tokamak Vacuum Chamber Components

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During deuterium-tritium (D-T) fusion reactions, the reactor core predominantly generates high-energy fusion neutrons. These neutrons diffuse outward, exposing in-vessel components of the Tokamak vacuum chamber—such as the first wall, blanket, and divertor—to an intense neutron field characterized by high flux and energy deposition. Interactions between neutrons and structural materials within the vacuum chamber induce secondary activation products, which constitute the primary radiation source during reactor shutdown maintenance and serve as critical inputs for radioactive waste classification.
This study employs a Monte Carlo method to investigate the attenuation of neutrons across varying energy levels within the vacuum chamber components, based on a representative Gaussian fusion neutron spectrum derived from D-T reactions. The evolution of the neutron energy spectrum at different radial positions is analyzed, revealing distinct spectral characteristics post-attenuation and corresponding variations in activation source terms across radial distances. Notably, the relationship between activation-induced radioactive source terms and neutron fluence levels is not strictly linear. In fusion environments, where neutron flux and energy are significantly higher, activation source terms at varying depths cannot be derived through simple linear scaling factors.
By selecting representative material compositions of vacuum chamber components, this work utilizes an activation analysis program based on generalized TTA (Transmutation Trajectory analysis) method and the EAF (European Activation File) nuclear database to quantify activation sources under different neutron fluence conditions. Furthermore, the decay dynamics of activated nuclides post-shutdown are systematically investigated.
The results provide critical insights for optimizing material selection for vacuum chamber components, designing radiation shielding strategies during equipment handling, and establishing robust protocols for radioactive waste source-term analysis and classification in fusion reactors.

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