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Utilization of B4C-W shielding to minimize neutron and gamma dose and flux attenuation

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Nuclear fusion is pursued with distinct methodologies, including magnetic confinement fusion, inertial confinement fusion, and inertial electrostatic confinement fusion (IECF) [1]. The neutron and alpha particle emissions characteristic of D-T fusion exhibit dependency on fuel selection, with compositional modifications directly influencing resultant reaction outputs [2, 3]. As documented in the IEC book, the neutron flux generation rate of IEC device is 10^6 to 10^{12} s^{-1} [4]. Consequently, radiation shielding optimization for this neutron-emitting apparatus must incorporate spectral considerations of fusion-generated neutrons and secondary particle emissions to ensure operational safety. Prior studies have established frameworks for shielding design and radiological hazard mitigation in such fusion systems [5, 6]. Among the investigated shielding materials for IECF devices, prior research has employed structures comprising paraffin, boric acid (H3BO3), wood, and stainless steel to achieve effective radiation attenuation [5]. Our previous research [7,8] successfully implemented shield design simulations for this system, demonstrating effective radiation mitigation capabilities.

But in this work, by simulating with the MCNPX code, the attenuation performance of B_4C and W layers was analyzed for D-T fusion neutron shielding. Boron carbide (B_4C) is a well-established thermal neutron absorber due to its high neutron capture cross-section [9], while tungsten (W) exhibits superior gamma-ray attenuation properties owing to its high atomic density [10]. This work evaluates the substitution of B_4C for boric acid (H_3BO_3) and W for lead (Pb) in multilayer shielding configurations to optimize neutron and gamma radiation attenuation for a 14.1 MeV deuterium-tritium (D-T) fusion neutron source. We simulated an IECF device with a neutron source strength of 10^9 s^{-1} and isotropic angular emission with the MCNPX code. The distribution of energy is assumed as a Gaussian energy, defined by the 14.1 MeV neutron spectrum. Computational rigor was ensured by tracking 2×10^6 particle histories (nps), resulting in statistical uncertainties below 1%. Neutron and gamma fluxes were quantified using F2 surface tallies, with dose calculations employing the DFn card (IU=2 configuration), standardizing dose units to $\mathrm{Sv} \cdot \mathrm{h}^{-1}\mathrm{source}^{-1}$. Comparative analysis of shielding materials revealed that B4C-W configuration achieved gamma dose reduction (1.23 μSv), whereas H3BO3-W configuration demonstrated enhanced neutron attenuation (15.40 μSv). Gamma dosimetry results (1.23 μSv) were minimized using the W layer, while using H_3BO_3 with the W layer proved optimal for reducing neutron dose and flux (15.40 μSv). Material composition and material effects composition at fixed geometries reveal critical trade-offs in optimization and multifunctional radiation materials design. These results show a good improvement in reducing neutron and gamma doses compared to the results of previous studies, whose articles have also been published.

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