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Feasibility Study of Diffusion Bonding of Zirconium to Tungsten Using Vanadium Interlayer and Its Implication on Decay Heat Driven Power Limit of a Water-Cooled Tungsten Target

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In developing a high-power water-cooled tungsten target for spallation neutron production, one of the important factors that limits the beam power on the target is decay heat driven temperature rise in tungsten in loss of coolant accidents. When tungsten is exposed to water vapor, tungsten oxides formed in steam is known to become volatile at above 800 oC causing radiological hazards with a risk of significantly elevated inhalation dose. A significant fraction of decay heat in the spallation volume is deposited in the cladding volume that protects tungsten from aggressive corrosion and erosion by coolant water in radiation environments. Tantalum has proven operational records as tungsten cladding material at world's leading spallation sources, the TS1 and TS2 targets at ISIS, the LANSCE target at LANL and the CSNS target. However, its high specific decay heat deposition per volume in spallation environment is a limiting factor in further increasing the beam power on the target. To study the feasibility of replacing tantalum with a low decay heat cladding material, we studied the feasibility of diffusion bonding of zirconium to tungsten. Zirconium alloys have extensive operational records in hadron radiation environments, and post irradiation material properties data are available in nuclear and spallation communities. It was used as cladding material for early generation uranium spallation targets at KENS, IPNS and ISIS and has been used as canning material for the MW class lead target at PSI. For this study, a vanadium interlayer was used between W and Zr to avoid the known formation of a brittle ZrW2 intermetallic layer along the W-Zr bond line during high pressure and high temperature diffusion bonding processes. Single step vacuum hot pressing was performed with W, V and Zr plates. The W-V and V-Zr bonding layer did not show a trace of ZrV2 intermetallic subdomain formation, showing the feasibility of using zircalloy alloys for tungsten cladding material. To demonstrate the full feasibility of three-dimensional diffusion bonding, a single step hot isostatic pressing of V and Zr plates on a tungsten brick was performed. Particle transport and thermal simulations showed that a zirconium clad spallation target has a higher decay heat driven beam power limit of 800~kW compared to the 400~kW power limit calculated for a tantalum clad tungsten target.

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