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The Performance Evaluation of Tritium Breeding Materials Under Service Conditions

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In D-T fusion reactors, tritium self-sufficiency is one of the key factors for maintaining steady-state operation. The key factors of tritium breeding materials are effective tritium breeding and stability of performance under long-term service. In terms of tritium breeding, a high lithium atom density is essential to produce substantial amounts of tritium, and good tritium release properties are required for efficient tritium recovery. However, the tritium release process is highly complex, influenced by various factors such as grain size, porosity, radiation defects, purge gas, and surface condition. Regarding stability over long-term service, it is crucial to ensure the stability of mechanical properties, thermal conductivity, and compatibility of tritium breeding materials under harsh operating conditions, namely high temperatures and high-flux neutron irradiation. These properties are crucial for the engineering design, normal operation, and safety of tritium breeding blankets. These issues require comprehensive research and analysis. The China Fusion Engineering Test Reactor (CFETR) prefers solid breeder blankets, primarily comprising two blanket design schemes: a water-cooled ceramic blanket using Li2TiO3 as the tritium breeding material and a helium-cooled ceramic blanket using Li4SiO4. Based on the main issues faced by tritium breeding materials under service conditions, this work comprehensively analyzes the tritium release behavior and the stable performance of tritium breeding materials under service environments.

Tritium release performance was evaluated, and the influence of various factors on tritium release was investigated. Experimental results indicate that tritium retention diminishes with escalating temperatures, while microstructure attributes such as grain size, porosity exert an influence on tritium release. Long-term service at high temperatures with He + 0.1%H2 flowing gas, showed that the average crushing load of Li2TiO3 pebbles remained stable, whereas the average crushing load of Li4SiO4 pebbles decreased. Significant microstructural changes, including grain size, porosity, and lithium loss, were observed for Li4SiO4 pebbles. The failure behavior of tritium breeding materials under prolonged annealing conditions was studied using the Weibull distribution analysis method, providing failure probabilities at different stresses. Long-term exposure to high temperatures affects the thermal conductivity of the breeding materials, with Li2TiO3 remaining relatively stable while the thermal conductivity of Li4SiO4 decreases. High-temperature lithium evaporation and irradiation accelerate the corrosion of tritium breeding materials on structural materials.

This work comprehensively analyzes the tritium release behavior, thermal stability and compatibility of tritium breeding materials under service conditions, providing data support for the blanket design of CFETR.

Speaker's title

Mr

Speaker's email address

qiqiang@ipp.ac.cn

Country/Int. organization

China

Affiliation/Organization

Institute of Plasma Physics, Chinese Academy of Sciences

Authors: QI, Qiang (Institute of Plasma Physics, Chinese Academy of Sciences); Dr GU, Shouxi (Institute of Plasma Physics, Chinese Academy of Sciences); ZHOU, Haishan (Institute of Plasma Physics, Chinese Academy of Sciences); LIU, Songlin (Institute of Plasma Physics, Chinese Academy of Sciences (ASIPP)); LUO, GUANG-NAN (Institute Of Plasma Physics, Chinese Academy Of Sciences)

Co-author: OYA, Yasuhisa (Shizuoka University)

Presenter: QI, Qiang (Institute of Plasma Physics, Chinese Academy of Sciences)

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