Study on Tritium Behavior in the WCCB Blanket Using LTZO Ceramic Pebbles

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論 文 名　：　Study on Tritium Behavior in the WCCB Blanket Using LTZO Ceramic Pebbles
(LTZO セラミック微小球を用いた WCCB ブランケットにおけるトリチウム挙動に関する研究)
Title

区　　分　：甲
Category

論　文　内　容　の　要　旨

Thesis Summary

DT fusion reactors, being expected as a next-generation energy source, rely on a significant quantity of tritium, a radioactive isotope of hydrogen, as its principal fuel. Since the natural abundance of tritium is only about 3 kg, it is imperative to establish a self-sufficient tritium fuel cycle. This cycle encompasses the processes of production, recovery, separation, purification, storage, and delivery of tritium to the reactor. In each component of the complex fuel cycle, tritium is present dynamically and statically, and its concentration and temperature vary widely by orders of magnitude. In addition, the target tritium throughput far exceeds the tritium throughput that humanity has experienced in the past. Hence, there is an urgent need for tritium engineering research and development efforts. Furthermore, it is imperative to thoroughly evaluate the safety of the tritium fuel cycle as substantial tritium chemical plants, given the increasing social attention and demands for safety associated with nuclear facilities handling radioactive materials.

This study primarily examines blanket and coolant systems among the various cycle components, assuming the newly developed $Li_{2+x}TiO_{3+y}$ + 20 wt% Li_2ZrO_3 (LTZO) ceramic pebbles are loaded into the blanket as an advanced tritium breeding material. This Ph.D. dissertation is devoted to JA-DEMO reactor and divided into three research topics: Li mass loss behavior, tritium release behavior, and tritium permeation behavior. The outline of each chapter is as follows:

Chapter 1 functions as an introductory section, providing a concise overview of the imperatives and technical complexities related to the tritium fuel cycle in DT fusion reactors. Subsequently, it delves into individual study topics, addressing their respective technical concerns and outlining their objectives.

Chapter 2 provides an overview of the essential principles of fusion tritium engineering, for instance, the mass transfer theory and models, intending to enhance comprehension of the subsequent chapters.

Chapter 3 presents the characterization of the LTZO pebbles as advanced tritium breeders from the

fusion engineering aspect. The crystal structure of the base material, Li_2TiO_3, and the fabrication process of the LTZO ceramic pebbles are introduced. The literature on Li_2TiO_3 with excess Li anticipates LTZO structure. In addition, the results of XPS, XRD, TDS, SEM-EDX, and specific surface area measurements delineate the LTZO characteristics and determine the stoichiometric ratio of the LTZO.

Chapter 4 discusses the Li mass loss behavior. Experiments quantify the Li mass loss rate and the maximum mass loss. The same fundamental analysis method as in Chapter 2 observes the macroscopic and microscopic structure. Finally, the Li mass loss rate simulates its effects on the tritium production compared with the Li burn-up rate in JA-DEMO.

Chapter 5 discusses the tritium release behavior. Firstly, the theoretical equation characterizes the LTZO pebble from the perspective of nuclear physics. Then, experiments evaluate the tritium release behavior from the as-received and long-term heated LTZO pebbles based on the tritium mass balance and elucidate the tritium release mechanisms.

Chapter 6 comprehensively analyzes the tritium permeation behavior between the high-temperature and high-pressurized water. Experimental results establish the water-to-water tritium permeation model. The experimentally obtained tritium mass transfer coefficients simulate the time variation of the tritium concentration in the primary and secondary cooling water systems. The required design of the tritium-containing water treatment system is obtained based on the tritium mass balance, varying the tritium concentration limits in the primary water coolant.

Chapter 7 concludes the whole dissertation, and then Chapter 8 presents the future outlook of the studies that this dissertation focuses on.

Appendix A and B are complementary additions to the discourse presented in Chapter 5. Appendix A conveys how to calibrate ionization chambers. Appendix B pursues the causes of the tritium recovery gap in theoretical and experimental values using a Monte Carlo simulation code and the heat conduction equation approach.