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In situ tritium recovery behavior from Li_2TiO_3 pebble bed under neutron pulse operation

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Abstract

A binary pebble bed of lithium titanate (Li_2TiO_3) was irradiated in the Japan Materials Testing Reactor (JMTR), and its tritium recovery characteristics bed was studied under pulsed neutron operations. The temperature at the outside edge of the pebble bed increased from 300 to 350 °C immediately after the window of hafnium (Hf) neutron absorber was turned toward the reactor core, while the tritium recovery rate increased gradually. The ratio of tritium recovery rate to generation rate at the high-power, $(R/G)_{high}$, approached the saturated value of unity at about 20 h of operation. Overall tritium recovery behavior under the pulsed operation was similar to that under the steady state power operation. An estimated time constant of about 3 h for the tritium recovery was much longer than the thermal time constant of about 100 s.

1. Introduction

Engineering data on behavior of tritium breeders under neutron irradiation are indispensable for the design of a fusion blanket. It is necessary to know the tritium production rates and the heat generation profiles in the tritium breeder regions to design a fusion blanket. The major advantage of in situ irradiation experiments is its capability to provide such information with respect to neutron flux over a large volume prior to availability of a fusion reactor. Up to now, in situ irradiation tests such as CRITIC-III (Canada) [1], BEATRIX-II (US/Japan/Canada) [2–4], EXOTIC (Netherlands/EU) [5–7] and others were conducted.

Lithium titanate (Li_2TiO_3) pebbles [8,9] are a candidate breeder material for a tritium breeding blanket in a fusion reactor. In the present study, Li_2TiO_3 pebbles of 0.3 and 2 mm in diameter were fabricated, and a binary pebble bed of Li_2TiO_3 was irradiated in the Japan Materials Testing Reactor (JMTR) [10,11]. And behavior of tritium recovery from the Li_2TiO_3 pebble bed was studied under neutron pulse operation.

2. Experimental

A schematic diagram of a pulse-operation simulating mockup containing the binary pebble bed of Li_2TiO_3

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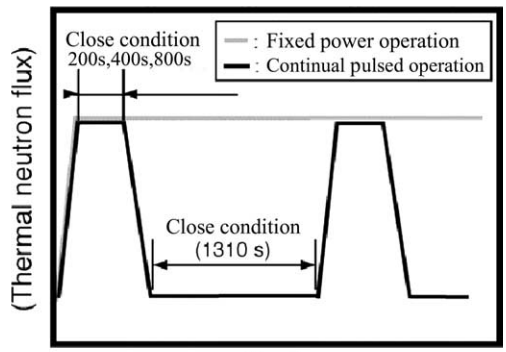

Fig. 1. Operation patterns in the first experiment and second experiment.

was reported in previous papers [10,11]. The mockup was irradiated in the largest irradiation hole, M-2, of JMTR. The outer diameter of the in-pile mockup was 65 mm. This mockup consists of a hafnium (Hf) neutron absorber to shield thermal neutrons. The Hf neutron absorber with a window was rotated by using stepping motor that was installed in this mockup to simulate pulsed operations of a fusion reactor environment. The dimension of the Li_2TiO_3 pebble bed was 20 mm in diameter and 260 mm in length.

The 0.3 and 2 mm diameter pebbles were packed to produce a Li_2TiO_3 pebble bed; see Table 3 of Ref. [10] for details. The packing fraction is 81.3%, and the loaded weights of the smaller and larger pebbles were 43 and 129 g, respectively. Multi-paired thermocouples and self-powered neutron detectors (SPND) for the measurement of the temperatures and the thermal neutron flux distribution, were installed in the Li_2TiO_3 pebble bed.

Two kinds of experiments were conducted in order to evaluate the tritium recovery from the Li_2TiO_3 pebble bed. The operation patterns and operating conditions of these experiments are shown in Fig. 1 and Table 1, respectively. The first experiment was conducted under operating conditions in which the window of the Hf neutron absorber was set at the open and closed positions, which corresponded to fixed values of high and low-powers, respectively. The other experiments were conducted under continual pulsed operation. In these experiments, the sweep gas flow rate and the hydrogen content of the sweep gas were fixed at 200 cm^3/min and 1000 $ppmH_2$, respectively. The moisture concentration was kept at less than 0.1 ppm. Further details of the in situ tritium release measurements were described in the previous paper [11].

3. Results and discussion

The ratio, (R/G), of tritium recovery rate (i.e. recovered amount per unit time) to generation rate (i.e. generated amount per unit time), was derived from the measured recovery rate (R) of tritium and the calculated generation rate (G), using a Monte Carlo code, MCNP4B [10].

The result of tritium recovery from the Li_2TiO_3 pebble bed in the first experiment (Run 1) is shown in Fig. 2. The temperature at the outside edge of the Li_2TiO_3 pebble bed increased from 300 to 350 °C immediately after the window of the Hf neutron absorber turned toward the reactor core. The tritium recovery rate gradually increased with elapsed time, and $(R/G)_{open}$ approached unity asymptotically. By assuming that the increasing behavior of $(R/G)_{open}$ could be approximated by a linear function with respect to a step function of the input power; the time constant for tritium release is estimated to be about 3 h. Where the time constant is defined as time becoming 63.2% of the value under the steady state.

The result of the tritium recovery from the Li_2TiO_3 pebble bed in the second experiment is shown in Fig. 3. The duration of the open condition was 400 s, which corresponds to the ITER pulsed operation [12]. In this experiment, the temperature at the outside edge of the Li_2TiO_3 pebble bed changed immediately from about 300 to 350 °C. On the other hand, the tritium release rate increased cycle by cycle gradually. As shown, the R/G_{av} was saturated after about 20 h, where G_{av} is the average of the tritium generation rate under the pulsed operating

Table 1
Operation conditions in the first experiment and second experiment

	First experiment (fixed power operation)	Second experiment (continual pulsed operation)		
Run number	Run 1	Run 2	Run 3	Run 4
Durations of high-power condition (Hf window: open)	20 h[a]	200 s	400 s	800 s
Duration of low-power condition (Hf window: closed)	–	1310 s	1310 s	1310 s
Number of pulse operation cycles	–	100	100	100

[a] Sufficiently long to observe the ultimate behavior.

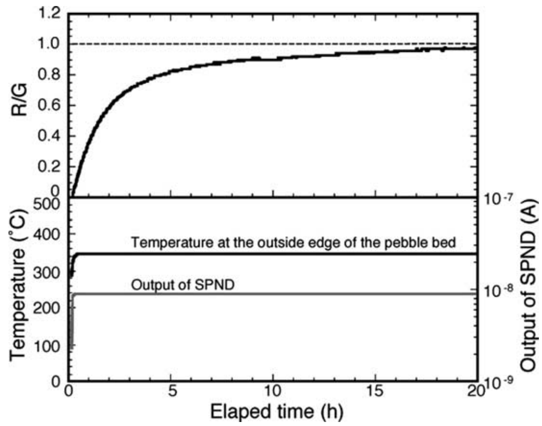

Fig. 2. Result of tritium recovery from Li_2TiO_3 pebble bed for step-functional power change in the first experiment.

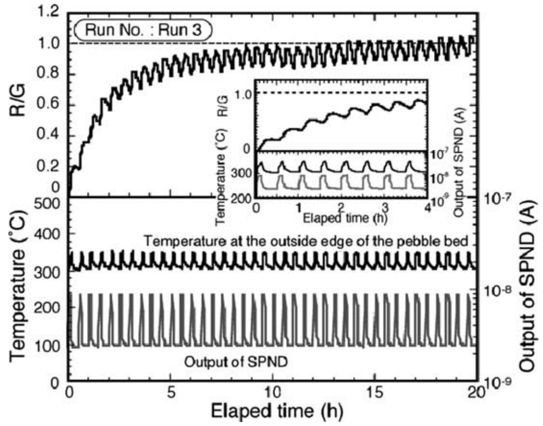

Fig. 3. Result of tritium recovery from Li_2TiO_3 pebble bed under pulsed operation in the second experiment.

conditions. The tritium release curve had a characteristic peak at the initial stage of the burn cycle due to the combined effects of the start of tritium generation and the temperature rising.

Tritium recovery characteristics from the first and the second experiments were compared in Fig. 4. Tritium release under the pulse operation increased cycle by cycle, and the ratio (R/G_{av}) was saturated to unity. Overall (i.e. smoothed) tritium recovery behavior under a long pulsed operation (open duration: 400 and 800 s) was almost the same as that under the fixed power operation in the first experiment. The time constant estimated for these pulsed operations is about 3 h, which is the same as that estimated from the first experiment.

On the other hand, the tritium recovery behavior for the burn duration of 200 s was different from that in the fixed power condition; namely, a longer time was needed

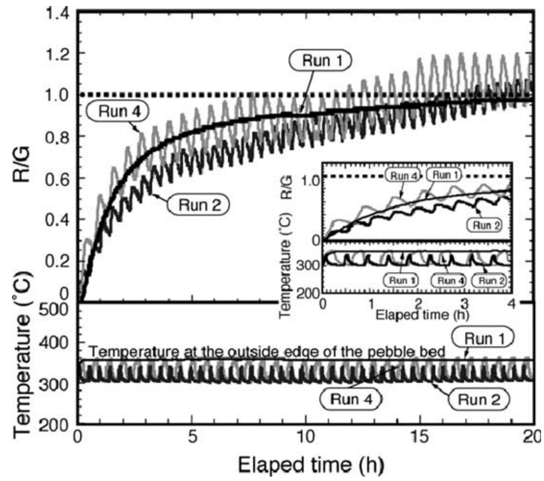

Fig. 4. Comparison of tritium recovery from Li_2TiO_3 pebble bed in the first experiment and the second experiment.

to reach the saturated state with a time constant estimated at 4 h.

An attribution to this long time constant for tritium release is that the burn cycle of 200 s is not long enough to achieve thermal equilibrium conditions in the pebble bed. This presumption is supported by the observed fact that the maximum temperature at the outside edge of the Li_2TiO_3 pebble bed was about 340 °C; this value is significantly lower than the corresponding value of 350 °C for the high-power duration of 400 and 800 s. As a future plan, advanced modeling analysis will be carried out on the tritium release from the Li_2TiO_3 pebble bed.

4. Conclusion

The effects of the pulsed neutron operation on the tritium release behavior of the Li_2TiO_3 pebble bed were evaluated. It is shown that the ratio of the tritium recovery rate to generation rate at the high-power, $(R/G)_{high}$, approached the saturated value of unity at about 20 h of operations. The overall (i.e. smoothed) tritium recovery behavior under the pulsed operation in the second experiment was almost the same as the behavior under the fixed power operation in the first experiment.

The estimated time constant for the tritium recovery was about 3 h for the long-pulsed durations of >400 s. However, a prolonged saturation behavior with a longer time constant of about 4 h was observed for the pulsed operation with a shorter burn pulse of 200 s. This is due to that the burn time of 200 s is not long enough as compared to the thermal time constant of 100 s. Nevertheless, the tritium release time constant (~3 h) is much longer than the thermal time constant.

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