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Modeling of fuel retention in JT-60U

JT-60U炉内水素蓄積モデルの構築

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A model for fuel retention build-up in vacuum vessel of JT-60U was derived by using accumulated data for analyzes of erosion/re-deposition and fuel retention in carbon tiles used for the JT-60U. In the model, four different hydrogen retention mechanisms for re-deposited layers, highly and slightly eroded surfaces and bulk were applied depending on the location of the plasma facing tiles.

1. Introduction

More accurate fuel retention model is urgently required for ITER and next step fusion devices from viewpoints of tritium safety and economy [1]. After extensive studies on time dependence of erosion/re-deposition and fuel retention in carbon tiles used for JT-60U [2], we have summarized fuel retention mechanisms in the carbon tiles and derived a model for fuel retention build-up in JT-60U.

2. Analysis

Analyzed carbon tiles were retrieved from divertor region, baffle plate and first wall in JT-60U. The carbon tiles were exposed to DD plasma heated by D-NBI with different experimental campaign of 1992 to 2004. At end of each experimental campaign, HH discharge heated by H-NBI was performed to remove tritium (T) produced by DD reactions. Tile temperature changed from baking temperature of 573 K to 700 K - 1400 K during discharges. Erosion/re-deposition of the plasma facing surface of the tiles was observed by SEM, and H+D retentions (fuel retention) in not only plasma facing surface but also bulk of the tiles were measured by TDS.

Retention mechanisms were divided into four different regions (i.e., re-deposited layers, highly and slightly eroded surfaces and bulk).

3. Retention mechanisms in JT-60U

3.1 *Retentions in re-deposited layers*

In the re-deposited layers, fuel retention is caused by re-deposition on the tiles and increases linearly with increasing thickness of the layers. Growth rate of the layers depends on location of the tiles, and it changes from 1 to 4 × 10^{20} $C\cdot s^{-1}$. One can notes that hydrogen concentration (= (H+D)/C) in the layers is saturated. (H+D)/C in the re-deposited layer varies from 0.13 to 0.08 depending on tile temperature.

3.2 *Retentions in eroded surfaces*

The fuel retention in the eroded regions rapidly increased to ~2 × 10^{22} H+D atoms·m^{-2} in short discharge time. Afterwards, it increased very slowly to 3~4 × 10^{22} H+D atoms·m^{-2} different from that for the re-deposited layers. Since the plasma facing surface of the eroded surfaces was exposed to very high particle flux, hydrogen concentration of their surface must be immediately saturated to produce hydrogen saturated layers in earlier discharge time. At the same time, the hydrogen saturated layers were eroded by subsequently impinging particles. Accordingly, the fuel retention rate for the eroded tile was determined by a balance between growth and recession of the thickness of the saturated layers. Since the retention rates of the outer divertor and the first wall, which are eroded, both are quite different due to the different heat load or temperature rise. Therefore highly eroded surface (outer divertor) and slightly eroded surface (first wall) should be separately taken into accounts.

3.3 *Retention in bulk*

Retention in bulk is caused by penetration of neutral particles and/or gases through open pores of carbon tiles. The penetrating particles are retained only at the surfaces of graphite grains facing to the open pores and the retention rapidly saturates because of extremely small diffusion coefficient of hydrogen into graphite grains. Therefore, the hydrogen isotopes (H,D) were uniformly distributed in mm scale in the bulk of the tiles and the retention in the bulk saturates with early discharge time with a saturation concentration of 2~10 × 10^{-4}.

4. Model for fuel retention build-up in JT-60U

Fuel retention rates for four different regions are summarized in table I. Using these results, fuel retention build-up in the vacuum vessel of JT-60U is derived.

Figure 1 shows the total fuel retention build-up in JT-60U with separation of four different regimes. For a earlier discharge time, retention in the bulk caused by penetration of gases through open pores of carbon tiles could occupy a significant part of the total fuel retention. But it would saturate soon and hardly increase to become minor. With increasing the discharge time, retentions in the slightly eroded surface exceeds bulk retention but they also saturate a little later. Since the retention rates in the highly eroded surface are very small, the contribution stays very small, even though it continues to grow. For prolonged operation, retention in the re-deposited layers becomes dominant in the total fuel retention.

General tendency of increase of the total fuel retention in JT-60U is very similar to that for ITER's estimation by Roth et al. [1]. Higher temperature operation of JT-60U results in appreciably smaller retention compared with the Roth's estimation for ITER. This is a clear indication that higher tile temperature operation would significantly reduce the T retention in machines using carbon as PFM.

Table I. Retention rates for plasma facing surfaces

	Retention rate	Temp. (K)
Re-deposited layer	1.3× 10^{15} [/s]	800-1000
Highly eroded	$(10^{22}\times\text{time})^{0.13}$ (9 m^2) [/m^2/s]	1400
Slightly eroded	$(10^{18}\times\text{time})^{0.16}$ (200 m^2) [/m^2/s]	700
Bulk	2~10 × 10^{-4} [/s]	700-1400

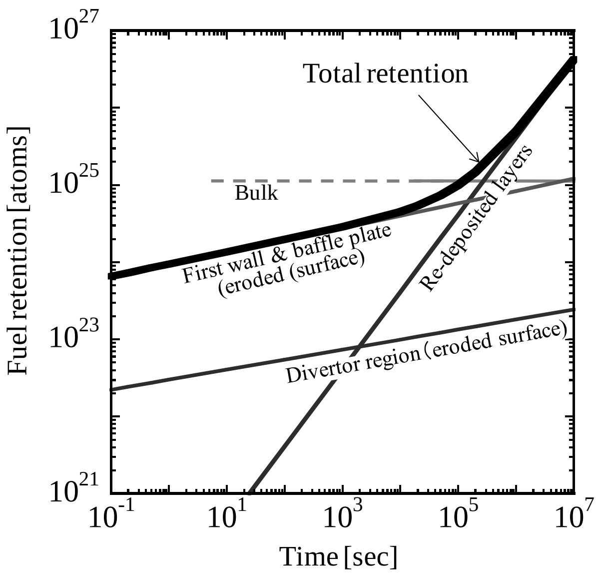

Fig.1. Fuel retention build-up in JT-60U according to the present modeling with four different mechanisms for retentions in re-deposited layers, two different eroded surfaces and bulk. Note that T inventory limit of ITER (700 g T) is 1.4 × 10^{26} atoms.

5. Summary and conclusion

A model for fuel retention build-up in JT-60U was derived in which four different fuel retention mechanisms for re-deposited layers, highly and slightly eroded surfaces and bulk were applied depending on the location of the plasma facing tiles. According to the model, although the tendency of increase of fuel retention is similar to the previous estimation in ITER, the fuel retention rates were appreciably smaller because of higher temperature operation in JT-60U. This suggests that the higher temperature operation would significantly reduce the T retention in machines using carbon as PFM.

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