§17. Bi-Directional Hydrogen Isotopes Permeation through the First Wall of a Magnetic Fusion DEMO Reactor

Zhou, H. (Dept. Fusion Sci., Grad. Univ. Advanced Studies),
Hirooka, Y., Ashikawa, N., Muroga, T., Sagara, A.

Reduced activation steel alloys such as F82H are currently considered to be the candidate materials for the first wall of magnetic fusion DEMO reactors. For the blankets employing self-cooled breeder, the first wall is exposed to the edge plasma, containing energetic D^+ and T^+ on the one side and on the other side it is exposed to T_2 gas bred in blankets. Under these conditions, it is highly possible that these hydrogen isotopes would penetrate the first wall by a phenomenon called "bi-directional permeation": [1] deuterium as well as tritium would transport into the blanket by plasma-driven permeation (PDP), which will hinder the recovery of tritium and will probably necessitate isotope separation; and [2] tritium would flow in the counter direction to the edge plasma by gas-driven permeation (GDP), which will affect edge plasma density as well as isotope mixture imbalance. Despite its critical importance, there have been neither experimental nor theoretical studies on bi-directional permeation of hydrogen isotopes through reduced activation alloys.

Hydrogen bi-directional permeation has been experimentally demonstrated for the first time in a steady state laboratory-scale plasma facility: VEHICLE-1.[1)] For the bi-directional hydrogen permeation experiments, the hydrogen partial pressure and H_α emission at the plasma side are detected by a partial pressure gauge and a visible spectrometer, respectively. The membrane is made by a ferritic steel alloy: F82H with a thickness of 0.5 mm. The membrane temperature is between 550 and 600 °C and the hydrogen gas pressure for GDP is set to be 700 Torr. At the plasma side, the electron temperature is raised up to ~10 eV for the improved sensitivity of H_α spectroscopy. As shown in Fig. 1, both of the hydrogen partial pressure and H_α intensity at the plasma side have been found to increase when GDP take place. This result indicates that GDP may take place in the opposite direction of PDP, which then affects the edge plasma density (i.e. recycling >100%).

A one-dimensional diffusion code: DIFFUSE [2)] has extensively been executed, employing multiple hydrogen isotopes (D/T) for bi-directional permeation. The input data for DIFFUSE are such that the thickness of a membrane made of α-Fe (used as a surrogate of F82H) is 5 mm at a temperature of 527 °C, the D/T inflows from the plasma-facing side are driven by PDP with D/T bombarding fluxes of 5×10^{15} D/cm^2/s and 5×10^{15} T/cm^2/s at a bombarding energy of 100 eV, and the T inflow from the gas-facing side is driven by GDP with a T_2 gas pressure of 1 Pa. Recombination release and Sieverts' law are employed as the boundary conditions for the plasma-facing surface and gas-facing surface, respectively. An intrinsic trap density of 1% and a trapping energy of 0.62 eV in the α-Fe bulk are assumed. Figure 2 show the time evolution of D/T-concentration profiles. The same isotopic species (T) has been found to interact with each other in the two counter flows. Deuterium flow appears to be independent of these tritium flows, driven by its own concentration gradient, i.e. "random walk" diffusion, suggesting that deuterium through the first wall will result in the mixture of D-T in the breeder/coolant, which necessitates an isotope separation process in the tritium-recovery loop.

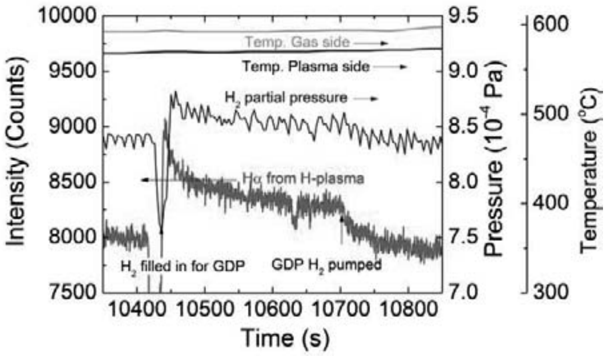

Fig. 1. GDP hydrogen P_{H2} pressure and H_α signals detected in the upstream hydrogen plasma in VEHICLE-1.[3)]

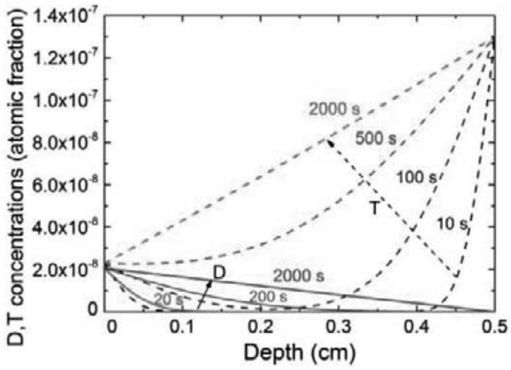

Fig. 2. Time evolution of D/T-concentration profiles calculated by the DIFFUSE-code for bi-directional PDP-D/T and GDP-T_2 from the upstream and downstream surfaces, respectively.

1) Hirooka, Y. et al.: Journal of Nuclear Material **337-339** (2005) 585.
2) Baskes, M.: "DIFFUSE83" Sandia Rep. SAND83-8231.
3) Hirooka, Y. et al.: "Laboratory experiments and modelling on bi-directional hydrogen isotopes permeation through the first wall of a magnetic fusion DEMO reactor", paper accepted by Fusion Science and Technology.