

HYDROGEN GAS BALANCE IN ASDEX UPGRADE WITH DIV IIB

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Introduction :

The retention of hydrogen isotopes in plasma facing components of fusion devices represents a serious difficulty for the utilisation of future machines. Especially credible estimations of the tritium retention is highly needed, since the accumulation of tritium in the vessel wall materials of thermonuclear fusion devices can become a major operation problem. Hydrogen is retained in the plasma facing wall and e.g. in flakes behind in vessel structures. A large fraction is pumped out from the vessel during and shortly after the discharge. Another small fraction is retained permanently, leading to the accumulation of hydrogen on and in the vessel walls. Several mechanisms are responsible for hydrogen trapping: adsorption on internal porous surfaces, implantation of energetic hydrogen atoms or ions, diffusion of implanted atoms into the bulk wall material and codeposition with eroded atoms.

This contribution describes hydrogen gas balance investigations on a plasma pulse to pulse basis to determine the amount of hydrogen which is retained for long time scales in the torus. Similar investigations have been performed on JET [1], DIII-D [2,3,5], TdeV [2], AUG [2,3,4].

Machine Characteristics and Diagnostics :

ASDEX Upgrade is a midsize tokamak ($R = 1.65$ m, $a = 0.5$ m, $\kappa \sim 1.6$) which performs in standard operation lower single null plasmas in deuterium as working gas. Most of the plasma facing components are fabricated from carbon. In addition, the inner wall, the inner divertor baffle and the protection tiles of the upper inner passive stabilizing loop (PSL, see Fig. 1) are covered with a thin Tungsten layer ($\approx 1 \mu\text{m}$) amounting to 15 m^2 of plasma facing surface [9]. The volume of the vacuum vessel is relatively large (45 m^3) compared to the plasma volume (ca. 13 m^3). The low magnetic field side of the inner wall is characterized by many complex structures like diagnostics and limiters.

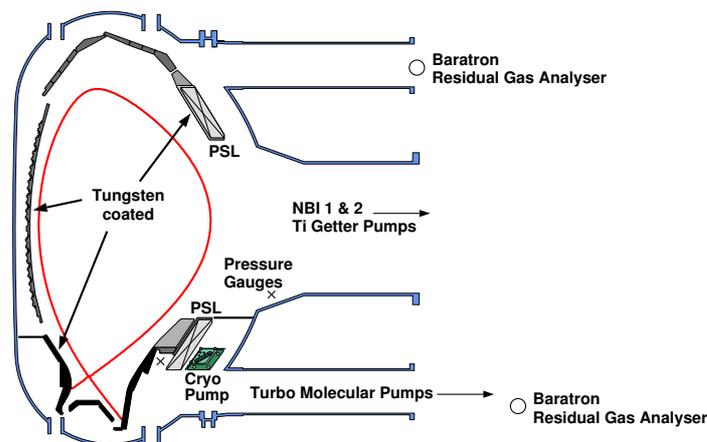


Figure 1: *AUG cross-section showing the positions of the pumps and indicating the pressure measurements and the W coated first wall sections.*

The gas pumping is provided by a toroidal cryopump ring (CP) and 14 turbo molecular pumps (TMP) attached to the divertor volume with pumping speeds of $S=105 \text{ m}^3/\text{s}$

and $11 \text{ m}^3/\text{s}$, respectively. In addition, two NBI beam lines located toroidally 180° apart can pump through midplane ports by means of Ti getter pumps (GP), $S_{eff} \approx 55 \text{ m}^3/\text{s}$ together in the pressure range of interest. This pumping capability has a small effect during a discharge since the main chamber pressure is typically one to two orders of magnitude lower than in the divertor volume.

Several calibrated feedback controlled piezo valves provide the gas inlet optionally from the midplane and/or into the divertor private flux region. The pressure is monitored by two barotrons, several ionization gauges (ASDEX gauges) in various toroidal and poloidal positions and two residual gas analysers in the TMP pump duct (see Fig. 1). One gas analyser covers the mass range of the most important hydrocarbons ($C_xH_yD_z$, masses 14-44) and the second one measures the light species H_2 , HD, He and D_2 . It is important to note that He and D_2 can be well separated.

Investigation Phases:

Generally, the D gas balance investigation is divided into three phases. The first covers a time window from 0 to 12 s after start of a discharge including the plasma phase and a few seconds pumping after it (see Fig. 2). It starts with a short deuterium gas

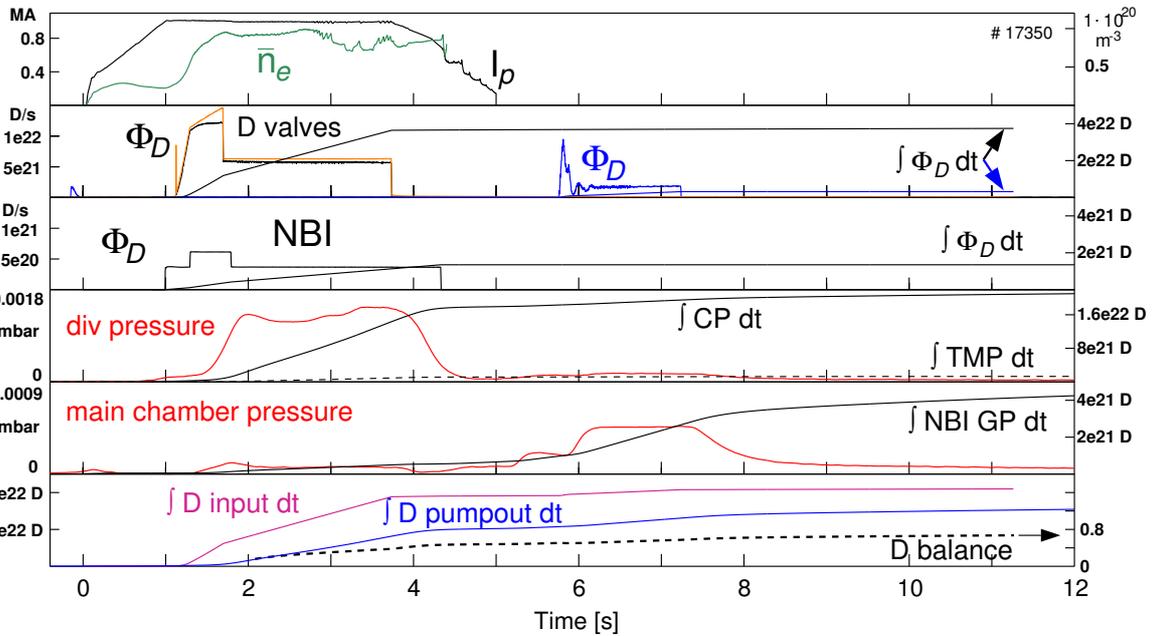


Figure 2: Typical time behaviour of injected and pumped deuterium particle inventories of a NBI heated discharge.

injection (prefill) to assure the required pressure in the vessel for successful plasma break down ($\approx 10^{-4} \text{ mbar}$). During the discharge piezo valves provide the plasma particle fuelling. The injection of NBI represents, if applied, an additional deuterium source which contributes in total about a few times 10^{21} deuterium particles corresponding normally to a few percent of the total particle fuelling. After I_p ramp down a ca. 1.5 s lasting deuterium pulse is appended (to $\approx 4 \cdot 10^{-4} \text{ mbar}$) for diagnostic purposes. The second phase covers a 5 min lasting glow discharge cleaning (GDC) in He which starts typically 2 min after each discharge. This leads to outgasing of the first wall and provides reproducible conditions for the breakdown of the next discharge. The He panel of the cryopump is warmed up during GDC and releases deuterium/hydrogen molecules and a mixture of light hydrocarbons collected during the preceding discharge. The CP

is not able to pump He. The LN₂ shield of the CP is continuously cooled during the whole operational week. The third phase covers the complete warm up of the cryopump during the weekend after every week of plasma operation, leading also to the release of the molecules trapped on the LN₂ shield.

The injected deuterium gas takes typically the following paths: a large part is pumped during and shortly after the discharge by the CP, the TMP and NBI GP. The deuterium trapped on the CP and released during He panel warm up is pumped finally by the TMP. Figure 3 sketches the paths of the injected deuterium molecules. Hydrocarbons sticking on the CP are partly released during the He panel warm up and

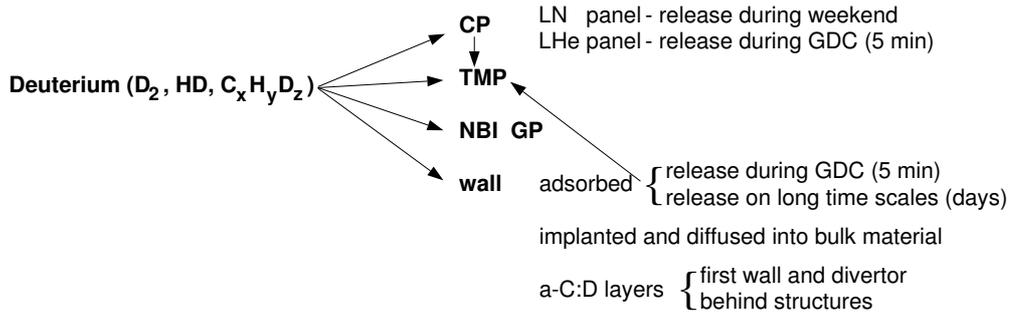


Figure 3: Sketch of the paths from deuterium molecule injection into different molecular species and storage locations.

pumped out.

The deuterium gas balance R_D in the first phase is described by the ratio

$$R_D = \int (\Phi_{CP} + \Phi_{TMP} + \Phi_{NBI GP})^{pumped} dt / \int (\sum \Phi_D^{valves} + \Phi_D^{NBI})^{input} dt$$

where Φ_{CP} is the deuterium flux pumped by the CP, Φ_{TMP} by the TMP, $\Phi_{NBI GP}$ by the NBI GP and Φ_D^{valves} are the deuterium particle fluxes injected by the different gas valves and Φ_D^{NBI} by the NBI. Figure 4a) shows the balance overview. At very low

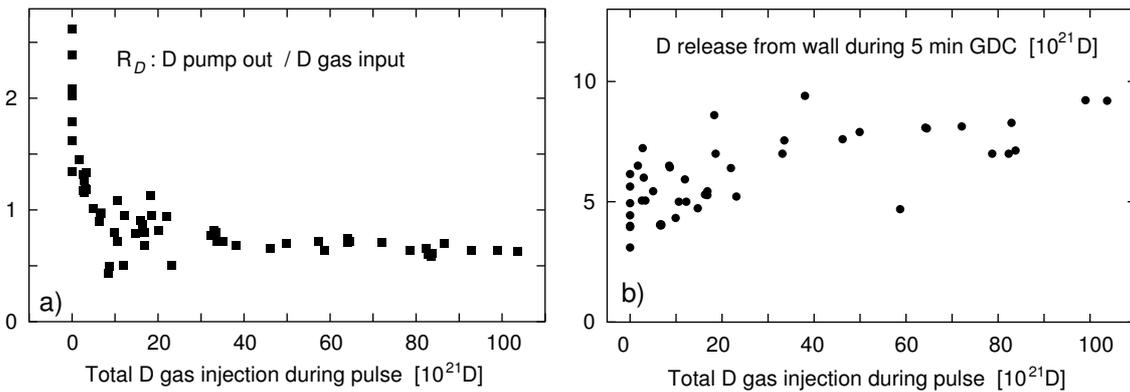


Figure 4: a) Deuterium gas balance as function of injected D gas during plasma phases. b) Deuterium released from the wall during 5 min GDC (see Fig. 5).

injection levels R_D exceeds clearly 100% which indicates that low density plasmas can reduce the long term wall inventory as e.g. He GDC does [5]. Already at a small amount of gas injection R_D reduces to values around 65%. The number of deuterium particles transported by the most important hydrocarbon molecules like methane, ethane and ethylene is estimated to be in the percentage range of the pumped total D flux. A fraction of $H/(H+D) = 5\%$ is here assumed which fits the measured mass spectra well.

In phase two the D release from the walls during GDC (see Fig. 4b)) is determined by fitting an e-function to the $D_2 + HD$ peak time traces of the residual gas analyser and integrated over 5 min (see Fig. 5). The fitted time constant is ≈ 300 s which means

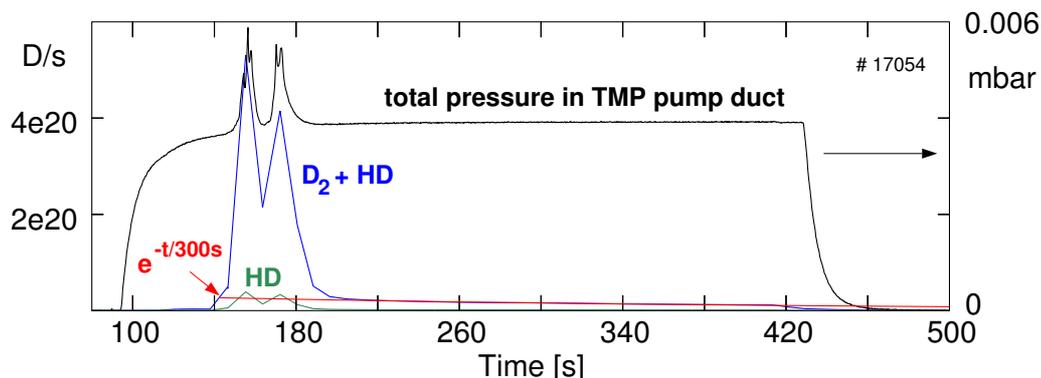


Figure 5: Total pressure in the TMP pump duct and deuterium release during GDC. The double peak corresponds to D released from the He panel, the D in the tail comes from the wall. The fitted e-function to calculate the release of adsorbed D is also shown.

that we remove about 60% of the deuterium adsorbed on the walls during GDC. The total amount is about $7 \cdot 10^{21}$ particles after every discharge (see Fig. 4b)) representing about 10% of the injected D. In parallel, the deuterium particles pumped in this phase which are bound to hydrocarbons lie below one percent. In phase three about 10^{21} to 10^{22} deuterium particles are pumped out during the weekend after complete CP warm up. The characteristic decay time of the D_2 partial pressure is one day.

Conclusion :

The investigation of the deuterium gas balance on a discharge to discharge basis shows a strong variation and a clear reduction of the ratio of pumped to injected D with increasing D gas input. At low levels of gas injection the D balance surpasses clearly 100% which means that the wall inventory is reduced performing such discharges. This is supported by the experimental observation that very low density plasmas can be attained after conditioning the vessel walls via several consecutive zero gas injection discharges. At higher gas injection rates the balance levels off at $\approx 65\%$. Only a small amount of deuterium is transported by gaseous hydrocarbons, implanted into the divertor tiles [6] and retained in a-C:D layers inside the vessel [7,8] (estimated to be a few percent, each). In addition, about 10% of the missing deuterium is released from the walls after every plasma during 5 min of GDC. Pumping over the weekend after a week of plasma operation brings $\leq 10\%$ D. Within the experimental errors one can conclude that about 10-20% of the deuterium which is injected into the torus is retained on longer times in the AUG vessel.

References :

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