*34th EPS Conference on Plasma Phys. Warsaw, 2 - 6 July 2007 ECA Vol.**31F**, P-2.030 (2007)*

GAS BALANCE IN HIGH DENSITY DISCHARGES AT ASDEX UPGRADE

V.Rohde[1], V. Mertens[1], T.Loarer[2] and ASDEX Upgrade Team

[1]*Max Planck Institut für Plasmaphysik, EURATOM Association, Garching, Germany*
[2]*Association EURATOM-CEA, DSM-DRFC,CEA Cadarache, St. Paul lez Durance, France*

Introduction

A critical issue of the present ITER design is the use of carbon as first wall material. The expected high erosion rate causes the formation of a:C-H layers, which will contain a significant amount of Tritium (T) and could lead to unacceptable T vessel inventory. In ASDEX Upgrade (AUG) extensive studies of the deposited layers and their D inventory have been performed during the last years [1,2]. Gas balance is an alternative and complementary approach, which allows a discharge resolved determination of the amount of gas retained in the vessel. Comprehensive investigations in Tore Supra (TS) using gas balance reveal, that during long discharge operations (>6min), at low plasma density, up to 50 % of the puffed gas can be retained in the vessel [3].

AUG is following a stepwise transition towards a full tungsten device [4]. Before moving towards full metallic plasma facing components (PFCs), experiments have been carried out on the retention observed with carbon as main plasma facing component. Estimation of the ITER gas balance requires knowledge of long / high density pulses in actual fusion devices for extrapolation. Whereas the pulse length is matched at TS, the ion flux is lower by orders of magnitude. High density pulses in ASDEX Upgrade reach relevant ion fluxes foreseen in ITER, although they are restricted to some seconds.

Experiments

In present devices wall recycling is sensitive on wall conditioning. After a major vent outgasing of the PFCs can significantly contribute/modify the gas balance compared to regular plasma operation. Here we discuss data of the campaign 2005 from pulse 19990 to 20580, in total 277 successful plasma discharges. After a major vent 4 boronisations and 1710 s of divertor operation, equal to a deuterium throughput of 4.6e24 atoms had been performed

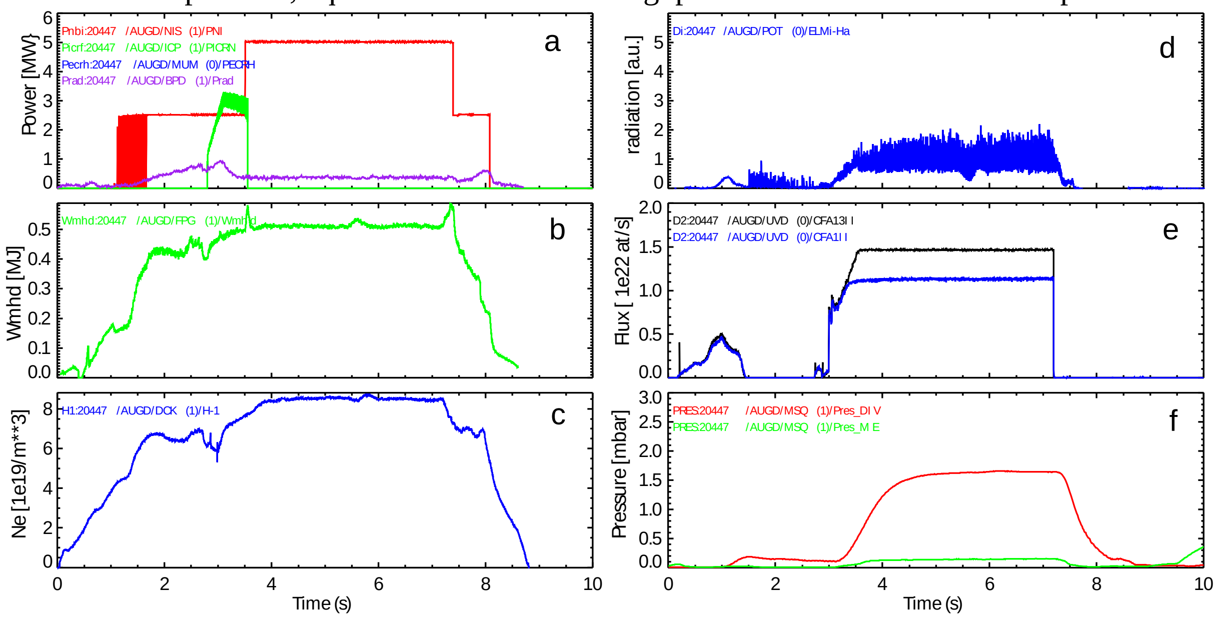

Fig.1: Main parameters of the plasma discharge 20447, showing time traces of the heating and radiation powers (a), energy content (b), line-averaged density (c), ELM behaviour (d), gas puffing rates (e) and divertor pressure (f)

before shot 19990. The behaviour of a typical high density H-mode (#20447) discharge is shown in Fig.1. After the plasma build up, modulated NBI is used to measure the LH transition threshold. During the flat top (H-mode) phase two heating power steps (2.5 and 5 MW NBI) are done, a moderate heating for AUG. A plasma density of 7.1e19m^{-3}, or 0.7 times the Greenwald density is reached. For fuelling, a continuous gas puff of 2.6e22 at D/s is applied. For gas balances, the gas inlet valves and the pumping speed of the torus pumping system have been calibrated. The accuracy of gas balances is 10 %, limited by the installed in vessel cryo pump. The amount of gas pumped is derived from the pressure (Baratron gauge type), located in between the cyro- and turbo pumps. To extend the measuring sensitivity, an ionisation gauge at the same location is also used particularly for the low pressure range. This instrument is adjusted to the readings of the baratron during the high dense phases. After the shot, a calibrated gas puff, is applied for calibration of the Li beam diagnostic, and is also used to validate the measurements. The plasma content is approximated by $N_{plasma} = n_e * V$, where n_e is the line averaged plasma density and V the plasma volume. The pumped gas is calculated using: $\Gamma_{pump} = S_{TPS} * P_{div} + S_{cryo} * P_{div} * C + S_{NBI} * P_{ME}$, with S the pumping speeds of the Torus Pumping System (TPS), Cryo Pump (Cryo) and NBI boxes, P the pressure at the divertor(div) and main chamber (ME), and C a factor taking the pressure drop at the pumping duct into account. The gas input, plasma content and pumped gas for the shot 20477 is shown in Fig 2.

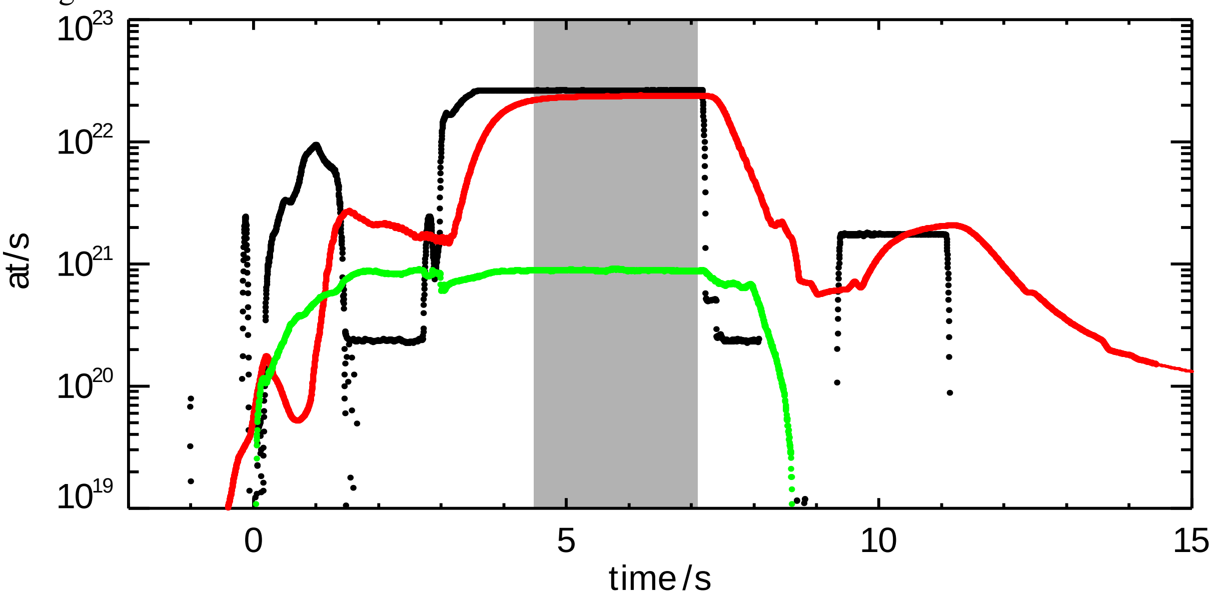

Fig.2: Time resolved gas rates for shot 20447. The rate of puffed gas is indicated in black, the pump rate in red and the plasma inventory in green. The "puff=pump" phase is indicated in grey.

The plasma is build up as a limiter discharge (0.0-0.7 s), for building up the plasma density a gas puff is needed (0.7-1.7 s). The behaviour during these phases depends strongly on the wall pumping, i.e. the wall conditioning. The tungsten used at the main chamber stores He, which originates from He glow discharge cleaning performed between pulses and releases it during this phase. A fresh boronisation reduces the He recycling [1]. After plasma build up, a low density phase is followed. This phase depletes the wall: much more gas is pumped than puffed. The gas balance after this phase is still positive, so the wall inventory prevails from the plasma start up. The high dense phase starts at 3s applying a strong gas puff. At the same time the heating power is switched to 5 MW. During this phase, a rise of the divertor pressure is observed, resulting in a higher amount of pumped gas. It is worth to mention that the core plasma conditions are changed on a much faster time scale. After one second an equilibrium is reached, which we call the “puff=pump” phase (4.7-7.1 s). The amount of puffed gas is pumped out, so no additional inventory builds up at the wall. The amount of gas needed to reach this equilibrium is calculated by averaging over 24 discharges: about 1.7e22 at D have to be retained in the vessel to reach the “puff=pump” phase. The balances for the different phases are summarised in table 1. The balance is calculated by

$$N_{balance} = (N_{puffed} - N_{pumped} - N_{plasma}) / N_{puffed}$$

Phase	N_{puffed}	N_{pumped}	N_{plasma}	$N_{balance}$
	*1e20 at	*1e20 at	*1e20 at	
Limiter	15.0	0.9	3.7	30 %
Ramp-up	47.0	5.1	6.9	20 %
Low	460.0	290.0	8.9	65 %
Puff=pump	610.0	590.0	7.6	96 %
Divertor phase	1130.0	981.0	2.1	87 %
Shot	1150.0	984.0		86 %
Calibration puls	30	29		98 %

Tab.1: Gas balance for the different phases of shot 20447.

The time resolved balance for this discharge is shown in Fig 3. During the plasma build up gas is stored in the wall and plasma. For the medium density phase the inventory is slightly reduced. With strong puffing, first the wall is additionally loaded, leading to the “puf=pump” phase (indicated in grey). At the end of the discharge, the outgasing of the wall starts. In total 1.6e22 at D or 14 % of the puffed gas are not pumped during this shot. Due to subsequent discharges only an average outgasing could be estimated. On the average over the different discharges types, about 20 % of the puffed gas is pumped away on a 10 h time scale [5]. From deposition at the divertor and remote structures about 4 % of the puffed D is found [2]. Keeping the accuracy of the gas balance of about 10 % in mind, good agreement is found.

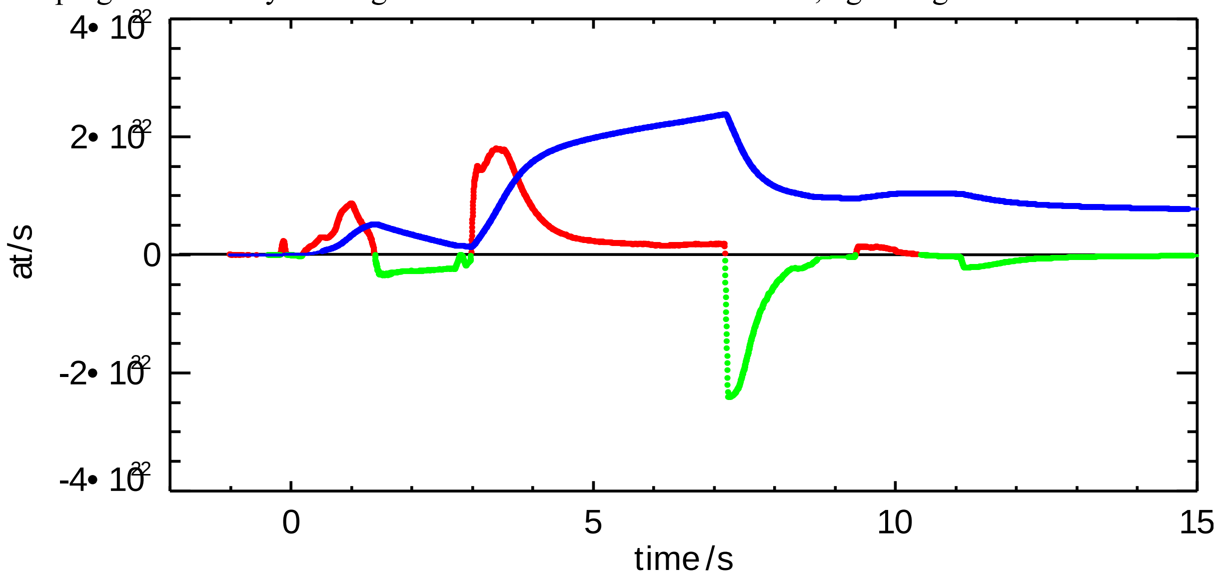

Fig.3: Total gas balance for shot 20447. Phases of gas deposited in the vessel are indicated in red, phases of vessel depletion in green. The integral is shown in blue.

Discussion

The behaviour of wall saturation was investigated taking shots of the 2005 campaign starting with 19990 into account. In Fig 4. the total amount of puffed gas during the divertor phase is plotted versus the amount of gas retained in the vessel during the shot. Again the outgasing after the shot is not taken into account. For low gas amounts $\int \Gamma_{puffed} < 1e22at$, the balance could be negative or positive. A medium puff $\int \Gamma_{puffed} < 4e22at$ shows a linear behaviour with a short term retention of 40 %. For higher fluxes a clear saturation is observed. A maximal retention of 5e22 at had been observed.

.

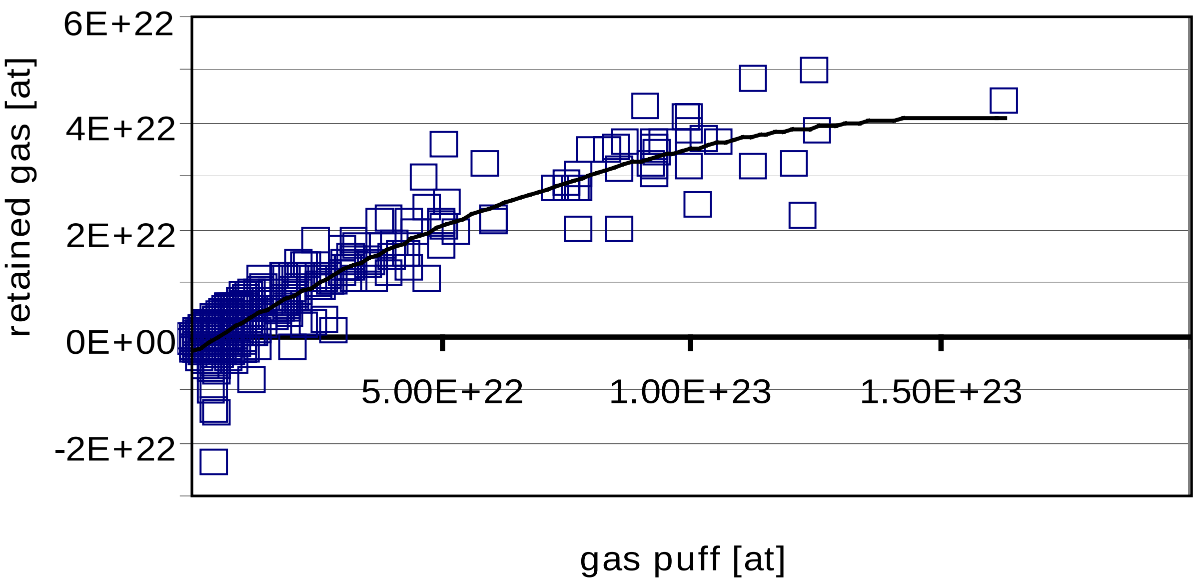

Fig.4: Retained amount of gas versus gas puffed during the divertor phase for the discharges 19990-20580.

Summary and Conclusions:

Time resolved gas balances in AUG show different phases. At the start of the discharge, the wall pumping is strong and dominates the balance, only 25 % of the puffed gas is pumped by the pumping systems. After the plasma density build-up, typically 50 -65 % of the gas is retained in the vessel walls. However, strong gas puff will lead to wall saturation, during which equilibrium between the particle injection and pumping is reached. In ASDEX Upgrade typically 1.7e22 at of gas are needed to reach this “puff=pump” phase. Most of the gas retained during the shot is pumped on a longer time scale after the shot or during glow discharge cleaning. For high density shots the wall inventory will be independent on the shot duration. Taking only the surface area into account for an extrapolation a puff of 2e23 at is expected for ITER to reach wall saturation. Of course, redeposition and implantation have to be taken into account.

References

[1] V. Rohde et al., J. Nucl. Mat., 363-365 (2007), 1369
[2] M. Mayer et al., submitted to Nucl. Fusion
[3] E. Tsitrone et al., J. Nucl. Mat., 363-365 (2007), 12
[4] R. Neu et al., this conference
[5] V. Mertens et al., ECA, 27A, P-1.128 (2003)