34th EPS Conference on Plasma Phys. Warsaw, 2 - 6 July 2007 ECA Vol.**31F**, P-1.061 (2007)

# OPTIMISATION OF THE SHAPE OF THE ITER DIVERTOR DOME

A.S. Kukushkin[1], H.D. Pacher[2], V. Kotov[3], D. Reiter[3],

D. Coster[4], G.W. Pacher[5], H.-P. Zehrfeld[4]

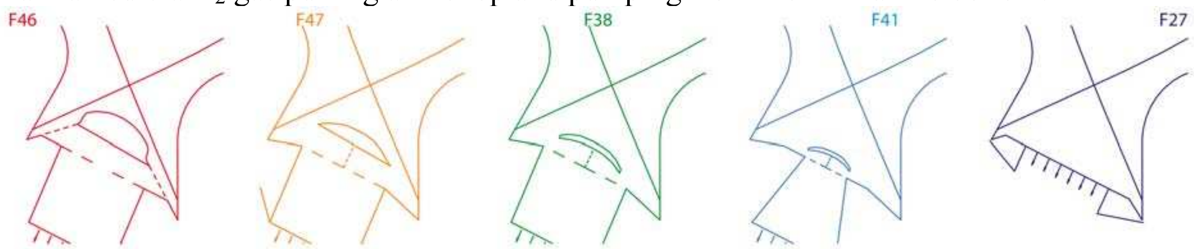
*[1] ITER Organisation, Cadarache, France;*

*[2] INRS-EMT, Varennes, Québec, Canada; [3] FZ Jülich, Jülich, Germany;*

*[4] Max-Planck IPP, Garching, Germany; [5] Hydro-Québec, Varennes, Québec, Canada*

The divertor dome introduced to compress the neutrals in the private-flux region (PFR) of ITER reduces the flexibility of the magnetic configuration and adds to the cost of the machine, and so there is a strong incentive to either reduce its size or even remove it completely. In our previous papers [1, 2] we have shown that the complete removal of the dome would increase the pumping speed necessary to keep the helium density in the plasma low well beyond the practical limits, whereas an increase of the dome length would increase the power loading of the targets. In the present paper we analyze the effect that a reduction of the dome would make on the divertor performance in ITER.

The B2-Eirene code, version solps4.2 [3], is used in our modelling. The most essential feature of this version is the non-linear Monte-Carlo model for the neutral particle transport, which takes into account neutral-neutral and molecule-ion collisions with up-to-date molecular kinetics [4]. Thereby the global properties of the neutral gas are modelled more accurately than with a linear model, and this allows a meaningful analysis of the pumping parameters and correlation with the externally imposed constraints on throughput and pumping speed. The modelling assumptions are the same as in [1−3]; in particular, the plasma consists of D (representing both D and T), He, and C ions, D, He, and C atoms and $D_2$ molecules, and all the surfaces are covered with carbon in this study. The particle balance is maintained via $D_2$ gas puffing at the top and pumping from the PFR at the bottom.



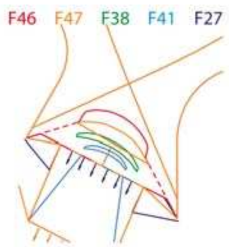




*Fig. 1. The dome shapes used in the present study. F46 is our standard modelling configuration with the plenum added, F27 the configuration without the dome. Partly transparent surfaces representing the grill at the duct entrance and the dome supporting structures are shown with dashed lines. The superposition of all the domes considered is also shown (right).*

For this study, we selected 3 variations of the divertor dome arrangement, in addition to the standard dome and the configuration without dome, Fig. 1. A new element in the model geometry is the plenum at the bottom where the absorbing surface representing pumping is now located. This was done in order to demonstrate that uniform particle absorption at the divertor floor does not lead to an artefact. Simulations (not shown here) were carried out with and without this plenum, with re-positioning of the supporting structures from the dome corners to the centre, as in F47 and F46, and with reduction of the plenum opening, as in F41 and F38. All exhibited very small differences.

Following the approach developed in [5, 6], we scan the throughput for every selected geometry, scale the gas pressure in the PFR, $p_{DT}$, by a factor $f_{dome}$, to have the incipient detachment of the inner divertor at the same scaled pressure, and use this scaled pressure as the x co-ordinate in the comparison. $f_{dome}^{-1}$ is the increase of pumping speed that would be required to provide the same throughput as for the standard dome. We therefore compare operational windows for physically similar operation. Fig. 2 shows such a comparison for the D neutral influx to the core across the separatrix, the peak power loading of the outer target $q_{pk}$, and the separatrix density of He ions.

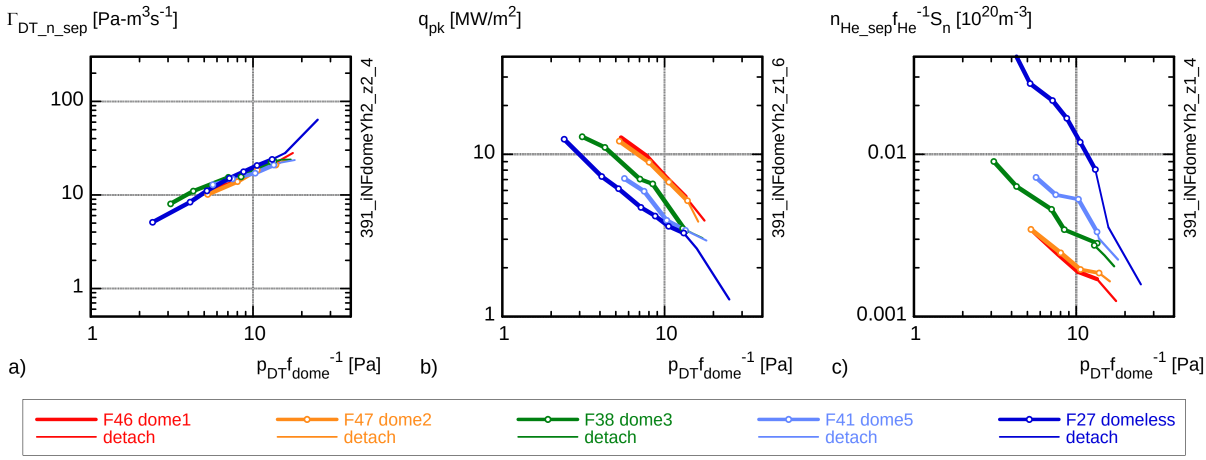



*Fig. 2. Neutral DT influx to the core (a), peak power loading of the target (b), and helium density at the separatrix (c) vs. the normalised neutral pressure in the PFR for different dome configurations. The helium density is scaled with the fusion power and pumping speed, see [6, 3] for details. $f_{dome}$ is 1 (F46), 0.84 (F47), 0.74 (F38), 0.68 (F41) and 0.69 (F27).*

With this normalisation, the neutral influx to the core, which can affect the core confinement, is matched well for all the geometries in the comparison, Fig. 2a. F47 has higher neutral pressure below the X-point and higher $n_{DT}$ (not shown) at the separatrix but is otherwise similar to F46 where the dome is closer to the X-point. Subsequently there is a clear trend: the peak power loading becomes progressively lower, Fig. 2b, and the helium density at the separatrix progressively higher, Fig. 2c, as the dome is reduced in size and eventually removed. The latter is consistent with our previous finding [2] that the dome is essential for pumping by cooling the neutrals down. There is therefore a trade-off between the power handling and helium removal efficiency; for example the smallest dome, F41, gives 30% reduction of the power load for a factor 3 increase of the helium concentration at the separatrix, and complete removal of the dome would have twice this effect. Evaluation of the consequences of this trade-off requires dedicated studies with the core model: the helium density in the core is the sum of three components [6] of which one, related to the helium transport in the core, is not directly affected by the edge conditions, and therefore the resulting helium density in the core is likely to increase by less than a factor 2. Engineering considerations (neutron shielding, diagnostic access, etc.) are also important. Furthermore, let us now examine to what extent the operational flexibility would be improved by reducing the dome.

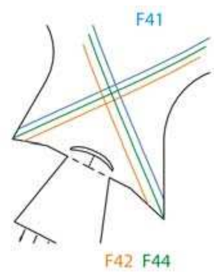



*Fig. 3. Variation of the strike-point position. Downwards: F41, F44, F42*

If the divertor floor were re-designed to ensure the same heat removal capability as for the target, reduction of the dome would in principle allow a wide excursion of the separatrix strike-points over the divertor floor. In order to examine the operational conditions for such horizontal targets, we did two series of runs for configurations with the divertor shape of F41 but with the strike-points either in the corners between the vertical target and the divertor floor (F44), or definitely on the floor (F42), Fig. 3. Instead of changing the magnetic configuration, in this study we moved the divertor with respect to the rest of the machine, thus excluding any side effects of different magnetic configurations. The initial results of this study are shown in Fig. 4 where the same parameters as in Fig. 2 are plotted for the various positions of the strike-points. One can see that shifting the strike-points to the divertor corners (F44) results in no qualitative change in the performance, although the peak power is somewhat lower and the helium density somewhat higher, as for the case of the dome size variation. However, when the strike-points are on the divertor floor (F42), the divertor operation is completely different. First, full plasma detachment with maximum temperature well below 1 eV occurs in the inner divertor at all pressures studied, and in the outer divertor for the higher pressures. The neutral influx to the core is a factor 2 to 5 higher than for the strike-point on the vertical target or at the corners.

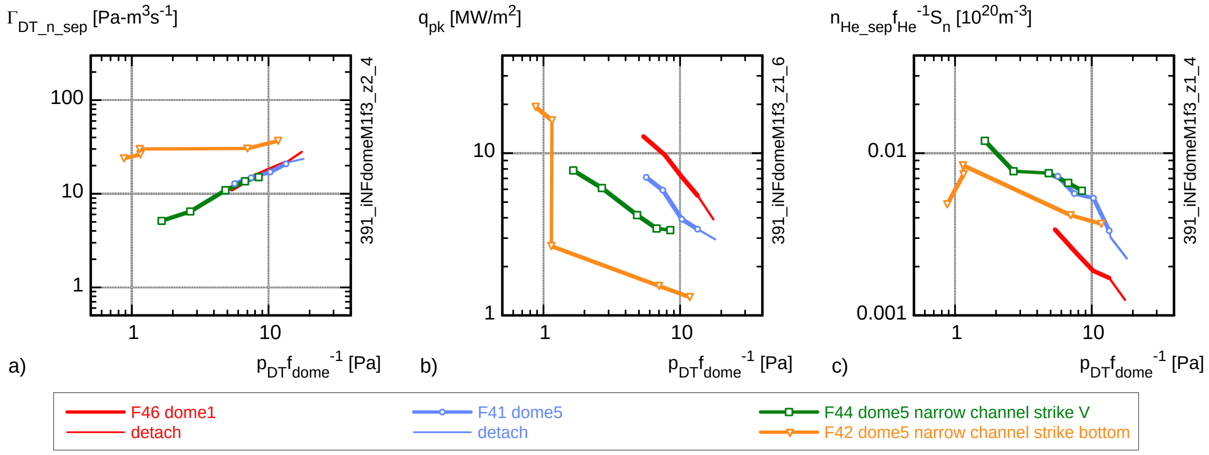



*Fig. 4. Neutral DT influx to the core (a), peak power loading of the target (b), and helium density at the separatrix (c) vs. the normalised pressure in the PFR for the different locations of the separatrix strike-points. The data for the standard configuration are also shown for comparison. $f_{dome}$ is 1 (F46), 0.68 (F41) and 0.75 (F42, F44). F42 is not in the same detachment state as the others. See also the caption for Fig. 2 for more detail.*

This means that the divertor operation in ITER with strike-points on the divertor floor has no window with partially attached plasma combining acceptable power loads with high efficiency of neutral plugging in the divertor. At lower neutral pressures, the $q_{pk}$ in the outer divertor is beyond the design limits, whereas the plasma is still fully detached in the inner divertor. Moreover, at the lower $p_{DT}$ the pumping speed would have to be increased by more than an order of magnitude to maintain the density pedestal in the main plasma.

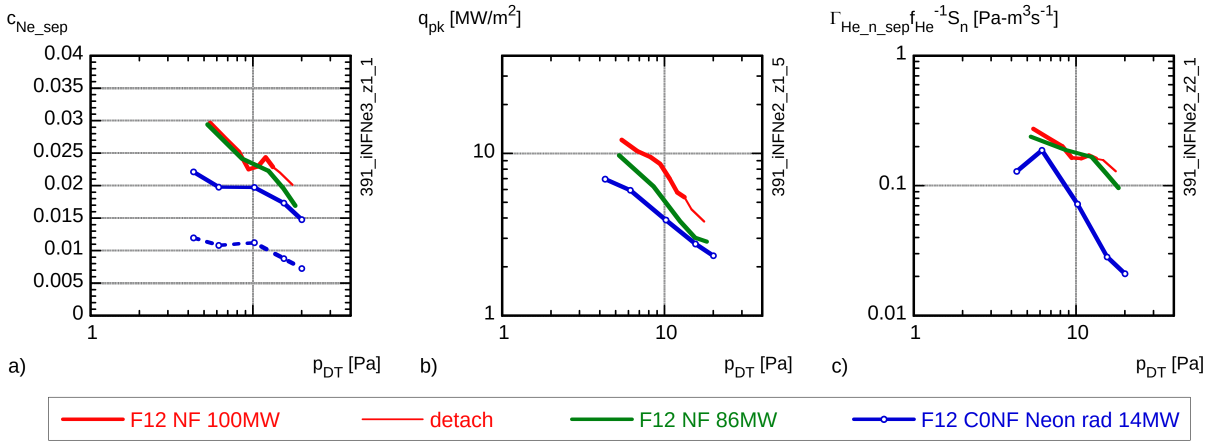



*Fig. 5. Impurity concentration (solid: C, dashed: Ne) (a), peak power loading of the target (b), and helium atom flux across the separatrix (c) vs. the neutral pressure in the PFR without neon at 100 and 86 MW, and with 14 MW neon radiation at 100 MW input power to the SOL.*

As a further flexibility study, and to prepare a study of ITER carbon-less operation at a later stage, seed impurities (neon) were added to the edge plasma. The core modelling studies [8] indicate that core plasma seeding with impurities can be beneficial for ITER. Even with carbon-covered walls, these seeded impurities can affect the divertor performance. Neon is assumed to be puffed as atoms from the top and pumped from the PFR, like the fuel components. A first series of runs with the SOL input power $P_{SOL}$ of 100 MW and the Ne puffing rate adjusted to keep the total radiation from Ne at 14 MW (concentration from 0.7 to

1.3%) is presented in Fig. 5, where one can see that the presence of neon reduces the carbon concentration by a similar amount, 0.5 to 1%. This leads to a reduction of carbon radiation by 5 MW, i.e. an increase of the total radiation including neon by 9 MW. The seeded neon radiates more effectively than carbon, and the radiation peaks further from the divertor plate, so that the peak power load on the divertor plates is reduced (Fig.5) even compared to a neon-free case having 14 MW less input power. The helium density is hardly affected by the seeded neon, but the helium neutral flux across the separatrix is significantly reduced.

In addition to these results with carbon-covered walls, initial simulations with full neon seeding and carbon-free machine have been started. The results are not yet complete but judging from the trends to date it is likely that ITER operation with carbon targets and carbon-covered walls will be similar to ITER carbon-free operation with neon seeding at an edge concentration between 1 and 2%.

## Conclusions

We have presented the study of a reduction of the dome size intended to enhance the configuration flexibility of the ITER divertor by increasing the distance to the X-point, decreasing the dome thickness and reducing its size up to the point of complete removal. The results show a gradual progression towards improved (lower) $q_{pk}$ and degraded helium pumping (higher concentrations, or higher pumping speed requirements), and detailed studies with core modelling are necessary to weigh one against another. Whereas the complete removal of the dome would require up to an order of magnitude higher pumping speed to keep the helium low, a strongly reduced dome would offset a 30% improvement in $q_{pk}$ against a factor 2 to 3 degradation in helium pumping plus engineering issues such as reduced neutron shielding and diagnostic access. These factors are closer to 1 for intermediate cases with smaller reduction of the dome height.

However, the increase of the operational flexibility of the divertor at burn would be limited. The simulations indicate that operation with the separatrix strike-points on the divertor floor would imply full detachment of both divertors for achievable pumping speeds. No operational window is found for the operation at partial detachment that allows acceptable conditions for the targets with efficient neutral plugging in the divertor. Since full detachment with the related strong neutral influx to the core is unlikely to be an acceptable operation mode, as follows from present experimental results, the operation should be restricted to keep the strike-points on the vertical targets, and thus larger domes are equally good for this. Start-up flexibility may, however, benefit from a reduced dome height.

Initial results of ITER divertor modelling taking into account the presence of seeded neon with carbon-covered walls indicate a significant improvement of peak power load and helium pumping. Extrapolation from preliminary results with a carbon-free machine indicates that ITER operation with carbon targets and carbon-covered walls will be similar to ITER carbon-free operation with neon seeding at an edge concentration between 1 and 2%. Further simulations are under way.

This report was prepared as an account of work by or for the ITER Organisation. The Members of the Organisation are the People's Republic of China, the European Atomic Energy Community, the Republic of India, Japan, the Republic of Korea, the Russian Federation, and the United States of America. The views and opinions expressed herein do not necessarily reflect those of the Members or any agency thereof. Dissemination of the information in this paper is governed by the applicable terms of the ITER Joint Implementation Agreement.

[1] A.S. Kukushkin, H.D. Pacher, V. Kotov, et al., Proc. 32nd Eur. Conf. on Contr. Fusion and Plasma Phys., Tarragona, 2005, paper P1.025.
[2] A.S. Kukushkin, H.D. Pacher, V. Kotov, et al., *J. Nucl. Mater.* 363–365 (2007) 308.
[3] A.S. Kukushkin, H.D. Pacher, V. Kotov, et al., *Nucl. Fusion* 45 (2005) 608.
[4] D. Reiter, V. Kotov, P. Börner, et al., *J. Nucl. Mater.* 363–365 (2007) 649
[5] H.D. Pacher, A.S. Kukushkin, G. W. Pacher, et al. *J. Nucl. Mater.* 313–316 (2003) 657.
[6] A.S. Kukushkin, H.D. Pacher, G.W. Pacher, et al., *Nucl. Fusion* 43 (2003) 716.
[7] A.S. Kukushkin, H.D. Pacher, D.P. Coster, et al., *J. Nucl. Mater.* 337-339 (2005) 50.
[8] G.W. Pacher, H.D. Pacher, G. Janeschitz, et al., *Nucl. Fusion* 45 (2005) 581.