

Neutral particle fluxes on the divertor during overload mimic scenarios in Wendelstein 7-X

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The Wendelstein 7-X stellarator aims to achieve quasi-steady state operation of 30 minute plasma discharges with up to 10 MW of ECRH heating. The majority of the power exhaust during operation lands on the ten island divertors placed symmetrically around the machine. In the planned future experimental phase OP2, these divertors will be updated with active water cooling to allow for these long, high-power pulses.

During some operational scenarios planned for OP2, a toroidal current known as the “bootstrap current” is predicted to form, growing from 0 to 43kA over about 110 s, after which it should hold constant for the remainder of the pulse. However, during the evolution of the current, when it reaches 22kA, the strike lines will be shifted inwards towards the pumping gap and are predicted to put up to 14 MW/m² on areas which are only rated for 5 MW/m² [1].

One proposed solution is to implement “scraper elements” to intersect the magnetic field lines during the 22 kA case and prevent some heat flux from reaching the divertor edges. Ideally, the scraper elements would have minimal impact on the plasma once I_{BS} reaches its steady-state value. However, predictions show that this may not be possible^[2]. This may be problematic because when the scraper element removes heat flux from the divertor it also intersects particle flux, preventing neutral particles from reaching the pumping gap.

The predicted reduction in pumping efficiency of 49-59% for the overload case (22kA), as seen below in Figure 1, may not have too much impact, as the current only has this value for a few seconds. However, the scraper element is predicted to reduce neutral pumping efficiency by 22-27% during the steady-state case, which, for a long pulse like those planned for OP2, will last the majority of the discharge. This could have a strong negative impact on neutral pumping and density control.

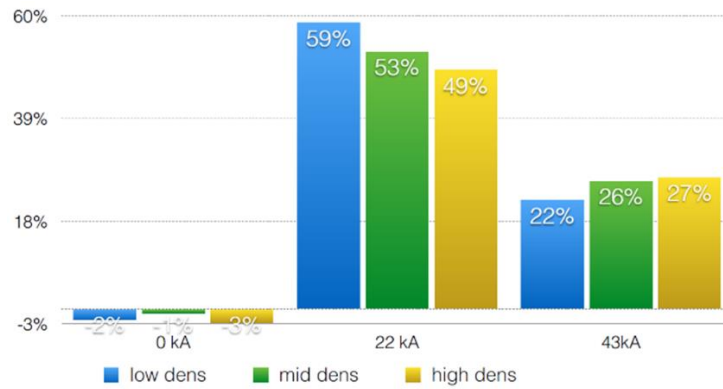


Figure 1: Predicted reductions in pumping efficiency for three different values of I_{BS} at three different densities.

As the high-power, long-pulse scenerios are not yet accessible, it is necessary to mimic the effects of the bootstrap current in order to confirm the predicted heat fluxes to the divertor and to test the effectiveness of the scraper element. During the previous campaign, OP1.2a, experiments were run with magnetic configurations mimicking different values of I_{BS} (0kA, 11kA, 22kA, 32kA, and 43kA, specifically) so that predictions of divertor fluxes could be confirmed. For the upcoming phase OP1.2b, two test divertor unit scraper elements (TDU SE) have been installed so that the scraper mimic experiments can be repeated and results can be compared with the scraper elements in place.

One step in measuring the impact of the scraper element on pumping efficiency is to calculate neutral particle fluxes on the divertor. This can be done with the H- α camera diagnostics which are spread throughout the vessel, viewing all of the divertors. These cameras capture light emitted as neutral hydrogen particles near the divertor are ionized by the plasma.

Camera data begins as video frames with an intensity level ranging from 0 to 4095. By identifying and removing bad pixels, subtracting a background level, correcting vignetting effects, and dividing by the exposure time, frames are adjusted to an absolute digital signal per second. Camera sensitivity to light is determined by taking calibration images with an integrating sphere of known spectral radiance and taking the ratio of photon flux arriving at the camera per unit area and solid angle to the absolute digital level seen by the camera. Multiplying this sensitivity value by the camera frames results in a measurement of photon flux to the camera per unit area per solid angle. After dividing by the filter transmittance and multiplying by the percent of light passing through the filter which comes from H- α emission, the result is photon flux per unit area per from a given solid angle. To get the total photon flux emitted per unit area, the camera frames are multiplied by the total solid angle 4π .

In order to convert from absolute photon flux to neutral particle flux, the frames are multiplied by the S/XB value for H- α . The measurements of density and temperature used to

estimate the S/XB coefficients are given by the divertor Langmuir probes, which are only present in one module and do not cover the entire divertor surface. In order to estimate an S/XB coefficient for all divertors, the coefficient must not depend strongly on density or temperature. This is only true for ionizing plasmas with edge $T_e > 10\text{eV}$ and $n_e < 10^{19}\text{ m}^{-3}$ [3].

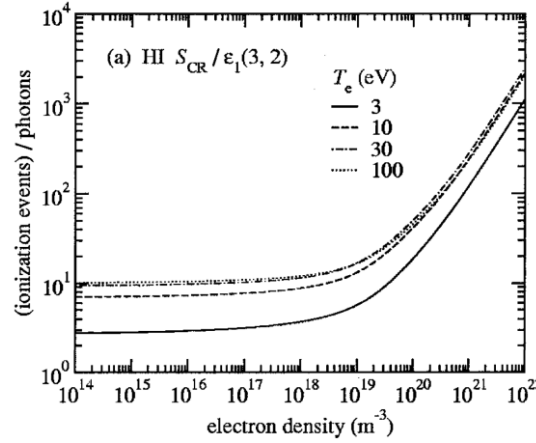


Figure 2: S/XB values plotted against n_e for four different values of T_e [3].

However, with our current operating parameters, the majority of the H- α emission comes from the release of hydrogen molecules, rather than single atoms, which then dissociate and ionize. While the exact efficiency has not been measured, it is estimated that, on average, for each hydrogen molecule released, one of the two atoms is able to emit Balmer radiation[4]. Therefore, the S/XB factor must be multiplied by roughly a factor of 2.

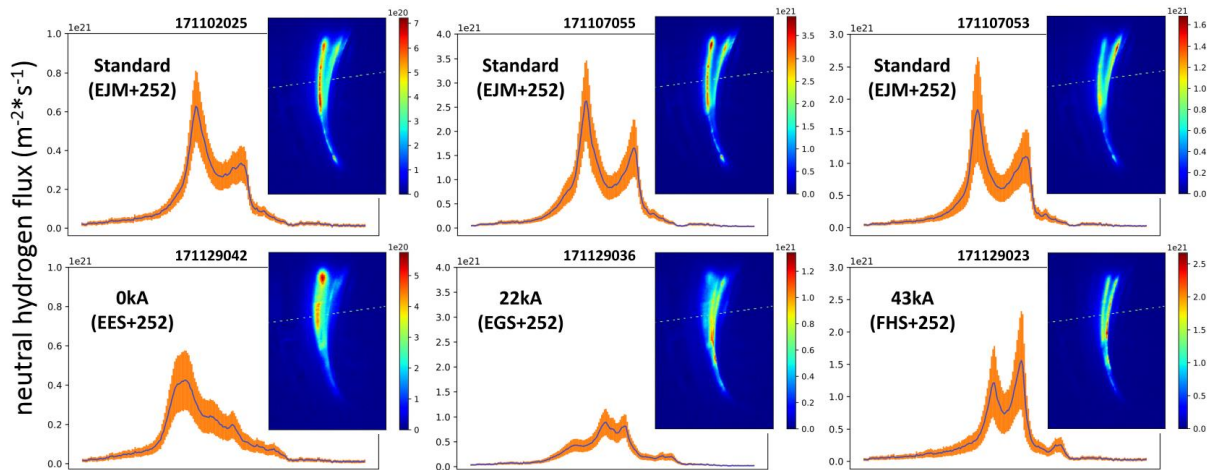


Figure 3: Comparison of neutral hydrogen flux seen by camera AEF51A for mimic configurations (bottom) compared to standard configuration shots (top) of similar density and input power. Plots show the average flux in a time interval along a profile line which follows the divertor Langmuir probes, with the orange lines being the uncertainty. The x axis is camera pixels. Images show flux on the whole divertor at one time.

Figure 3 shows images of the neutral hydrogen flux on the divertor targets, which appears as two bright strike-lines. As shown, all three mimic configurations had a decreased neutral flux along the selected profile lines, though the 43 kA case came the closest to matching

the flux of standard configuration. In the 0 kA scenario, the flux is spread more broadly over the divertor surface, concentrated mostly on the horizontal target, and has a maximum at the low iota end. With the overload value, 22 kA, the particle flux is much lower along the profile line and is highest right along the pumping gap, with a maximum near the middle of the divertor. In the steady-state scenario, 43 kA, the profile line is again more sharply peaked, like the standard case, but the peaks are shifted inwards and the flux on the vertical target is higher.

I_{BS}	0 kA	22 kA	43 kA
n_e (m^{-2})	$1 - 1.5 * 10^{19}$	$2 - 2.5 * 10^{19}$	$2 - 2.5 * 10^{19}$
T_e (MW)	1.2 - 1.5	4 - 4.5	3
Standard pulse #	171102025 (3-4 s)	171107055 (2-3 s)	171107053 (1-2 s)
Mimic pulse #	171129042 (3-4 s)	171129036 (3-4 s)	171129036 (2-3 s)
Maximum flux in standard pulse ($m^{-2} * s^{-1}$)	$0.96 (\pm 0.17) * 10^{21}$	$3.93 (\pm 0.70) * 10^{21}$	$2.93 (\pm 0.59) * 10^{21}$
Maximum flux in mimic pulse ($m^{-2} * s^{-1}$)	$0.67 (\pm 0.16) * 10^{21}$	$1.56 (\pm 0.35) * 10^{21}$	$3.60 (\pm 0.67) * 10^{21}$

Figure 4: Table listing the shots chosen, the time intervals examined, the plasma parameters during these intervals, and the maximum neutral flux for each interval.

As shown in Figure 4, looking at the entire divertor rather than a single profile line, the maximum value for neutral flux is lower for the 0 kA and 22 kA cases, but the steady-state 43 kA case is on par with the standard configuration.

The next step is to repeat these experiments with the two TDU scraper elements in place during OP1.2b and compare the neutral flux values to the above results in order to quantify the effect of the scraper element on neutral flux at the divertor for different values of I_{BS} . Along with data from the neutral gas manometers, the impact on pumping efficiency can be measured, which will be one step in determining whether the scraper elements are a viable solution to the problem of heat flux overload caused by bootstrap current evolution during OP2.

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