NFRP FINAL PROJECT

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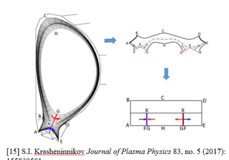
Introduction

In this report we are going to analyze data from numerical simulations run on SOLPS-ITER, the objective of this report is to compute and comment on different plasma parameters, in order to understand what is the divertor regime. All data and graphs shown in this report were produced on MatLab.

Mesh

SOLPS-ITER uses two kinds of meshes, one for the plasma with quadrilateral elements and one for the neutrals with triangular elements. The typical TOKAMAK shape is cut in the bottom section and unfolded to create a rectangular domain, whose size is usually [98,38], where the following notation has been used (poloidal direction,radial direction). in this setup our domain contains two guard cells in each direction.



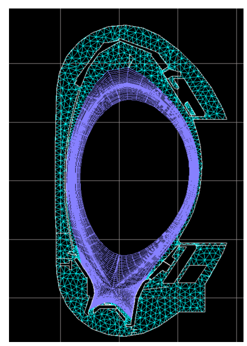


Figure 1: SOLPS-ITER mesh

Ion Fluxes

The aim of this section is to compute the fluxes of Deuterium (D) and Neon (Ne) ions in different regions of the machine. There is obviously only one possible ion for deuterium, while neon can be ionized up to 10 times. Please note that the Ne+ flux is the result of the sum of the fluxes of all possible Neon ions.

	D+ FLUX [s^-1]	Ne+ FLUX[s^-1]
IT	(-) 2,0751e23	(-) 4,6097e21
OT	2,6057e23	4,9462e21
IDE	(-) 4,5116e21	(-) 5,2544e20
ODE	7,9514e21	(-) 3,3355e20
CB	1,3008e21	2,5654e19
SEP	2,7393e21	6,1140e19

Table 1: Ion Fluxes [ions/s]

It is worth noticing that the fluxes at the targets are considerably higher than the ones at their respective entrances. This is due to recombination in the colder zones outside the main plasma. At this point it would be premature to make any assumptions on the regime of the machine, even tough recombination is one of the main physical processes to look for when trying to reach detachment.

Charged Particles Thermal Fluxes

The following section deals with the fluxes deposited respectively by ions and electrons in different regions of the TOKAMAK. Fluxes at the targets are considerably lower than in the entrance regions.

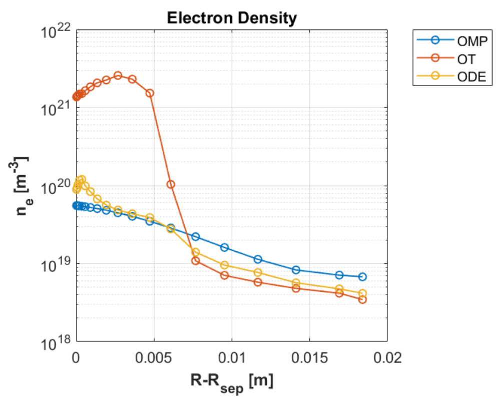
	Electron Flux [W]	Ion Flux [W]
IT	(-) 2,8713e5	(-) 1,4264e5
OT	6,5933e5	4,5408e5
IDE	(-) 9,1302e6	(-) 1,0441e6
ODE	1,3565e7	1,7787e6
CB	1,8036e7	1,2068e7
SEP	1,8804e7	8,3835e6

Table 2: Fluxes [W]

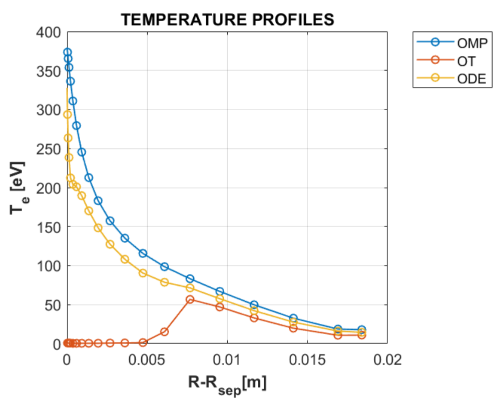
Considering the results of the previous section, it seems reasonable to think that this is due to radiative recombination. Radiation emitted by this process is emitted isotropically, hence spreading the power in different regions of the machine, rather then it being focused only on the targets.

1D Profiles

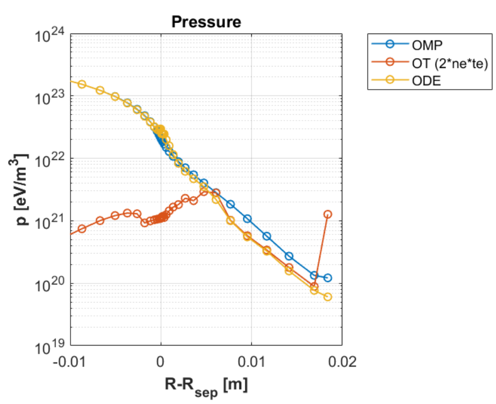
Even tough the problem is inherently 3D due to the geometry and the different physical phenomena acting on different scales and directions, (just think about turbulence and plasma instabilities) it can be a good idea to use simplified 1D models to get a grasp of what is happening inside the machine, to later dig deep with the more complex analysis. In the following section, a collection of 1D profiles is shown.



(a) Density Profiles



(b) Electron Temperature



(c) Electron Pressure

From the two point model we have $n_u t_u = 2 n_t t_t$. Even tough we know that the assumptions made to derive the two point model fall in certain operation scenarios. Taking a closer look at the electron pressure 2c, we can see how the two point model miserably fails at predicting the actual behavior of the machine. This discrepancy between the pressure at the target, together with a huge reduction in target density and high recombination would seem to point in the direction of a detached regime.

Power Density

Minimizing heat fluxes to the targets is one of the main obstacles to overcome in order to obtain fusion as an energy production source. There is an engineering limit to the power that can be dissipated with modern technology which is $\approx 10MW/m^2$. It is clear from the bottom graphs that there is a

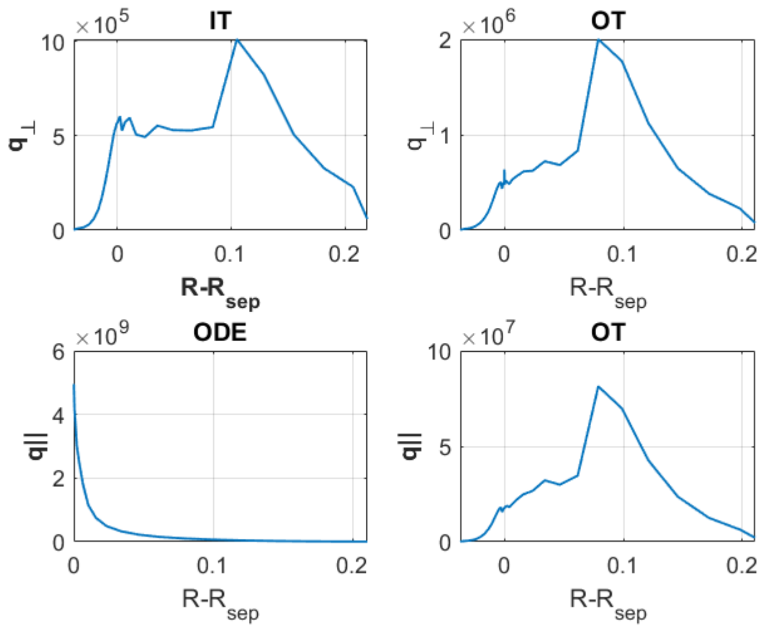


Figure 3: 1D Power Distribution

huge reduction in power flux going from the Divertor Entrance region to the target itself, although it seems like it is not enough, in fact the parallel power density at the outer target is still tenfold the engineering limit. This could be a potential "machine killer" if not taken into account.

2D plots

Figures 5a to 5c show the source terms for different ions. These terms are non-zero only in the colder regions of the machine where and ionization processes are present. A positive value for the source term is indicative of ionization, on the other hand a negative sign refers to recombination. As expected recombination only occurs really close to the targets, where the temperature is the lowest, hence the recombination cross section σ_{recomb} is larger. Another key physical phenomenon to take in

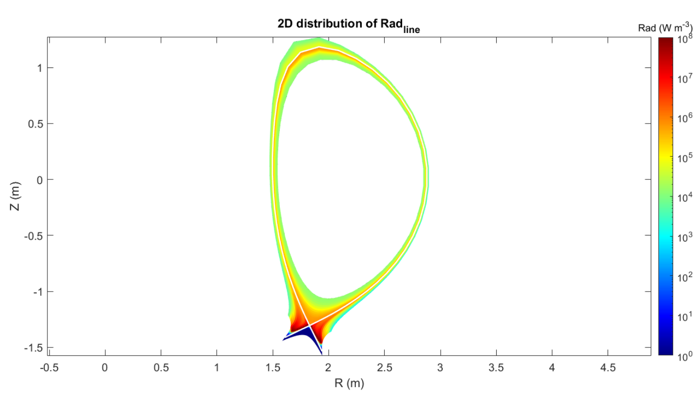
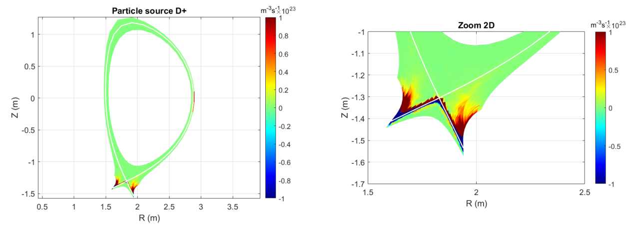
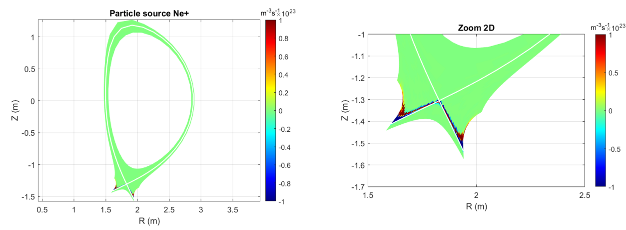


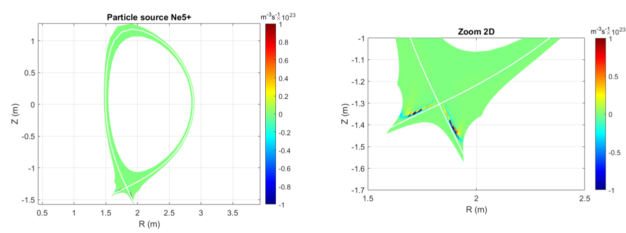
Figure 4: Line Radiation



(a) Production Rate of D+



(b) Production Rate of D+



(c) Production Rate of D+

Figure 5: Production Rates of different species

consideration is line radiation, coming mainly from impurities and radiative recombination. In Fig 4 is shown the distribution of line radiation density troughout the whole machine. It is higher near the targets, where most of the phenomena leading to radiative processes occur. Obviously the density of neutrals is higher in the colder zones of the machine as shown in Fig 6.

Outer Divertor Regime

From the previous analysis it seems like the outer divertor is operating in detached regime. This conclusion can be drawn by looking at a few crucial factors:

- Density drop at the target [see Fig 2a]
- Temperature drop at the target [see Fig 2b]
- Pressure losses in a flux tube [see Fig 2c]

It can be interesting to see how these parameters evolve along a given flux tube (see fig 7). "Partially detached is defined as a significant reduction of heat flux and pressure along field lines between midplane and divertor target for the first few (2) power decay lengths in the scrape-off layer (SOL)". Looking at figures 3 and 2c it is easy to see the huge reduction in parallel heat flux going from the midplane to the target (almost 2 orders of magnitude), as well as a significant reduction of pressure between the midplane and the target, suggesting therefore a pronounced detachment divertor.

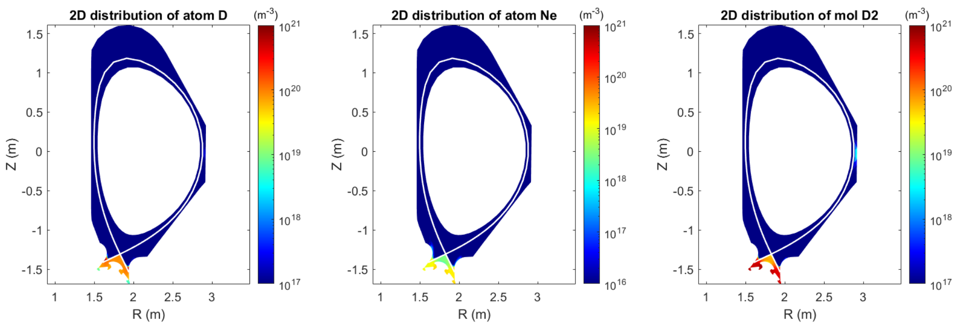
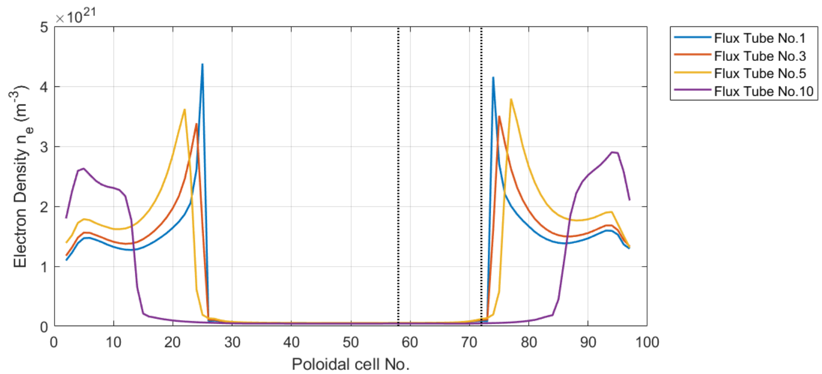
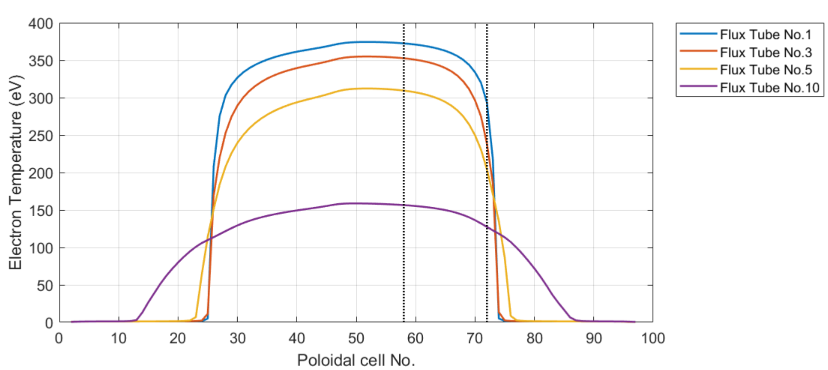


Figure 6: Neutral Density



(a) Electron Density in a flux tube



(b) Electron Temperature in a flux tube

Figure 7: Evolution of physical quantities along a flux tube