Integrated modelling of multi-channel transport including Tungsten in JET

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Tungsten (W) was chosen as a Plasma Facing Component because of its high melting point, its low erosion rate and low hydrogen retention. But due to its large charge number, 74, W ions are not fully stripped even in the hot tokamak core, leading to a relatively high degree of line radiation. This means that accumulation of W in the plasma core can be highly deleterious. Above a certain threshold, this leads to the loss of confinement and eventually disruptions. To avoid central W accumulation, an accurate understanding of time evolution of W transport using integrated modeling is a key issue. W transport is both turbulent and neoclassical. In the central region of JET core, W transport has been shown to be mostly neoclassical, whereas in the outer part the turbulent transport dominates [1]. Neoclassical transport depends on main ion temperature and density gradients, as well as plasma rotation. Therefore, in order to understand the mechanisms of W transport, it is crucial to model accurately and self-consistently the temperature, density and rotation profiles, as well as heat sources and radiative losses.

To predict temperature, density and rotation profile evolution, one needs to model the interplay between heat, particle, angular momentum, sources and losses, transport (both neoclassical and turbulent), over multiple confinement times while self-consistently letting the current diffuse and reconstructing the magnetic equilibrium. On the first time step, the initial temperature, density and rotation profiles create turbulent and neoclassical transport, but also interplay with the heat sources, radiative losses and the current diffusion and the magnetic equilibrium, leading to new profiles. On the next step, the updated profiles interplay again with the different elements. The iteration goes on for several confinement times. The iteration between the various modules is schematically illustrated on figure 1.

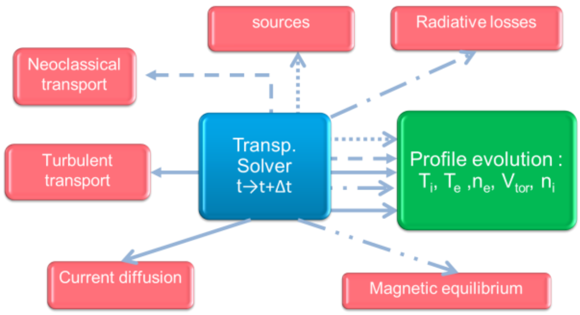

Figure 1 : Integrated modeling scheme

JETTO [2] is the chosen transport solver for our simulations. QuaLiKiz [3], a gyrokinetic quasi-linear code, models turbulent transport, including ITG, TEM and ETG, which transports particles, heat and momentum. QuaLiKiz is used from pedestal top inward. To model the pedestal, an "Edge Transport Barrier" is used with a turbulent diffusion and width allowing to reproduce the measured electron temperature and density. In our simulations ELMs and sawteeth are not modeled, nor is the scrape-off layer. NEO [4] is chosen to model neoclassical transport because it accounts for poloidal asymmetries. In presence of NBI momentum input, those asymmetries are shown to increase neoclassical W transport by an order of magnitude in JET [8,1]. Radiative losses are modeled by SANCO [5], PENCIL [6] simulates NBI source. Current diffusion is also predicted. The magnetic equilibrium is not self-consistent and is read from EFIT files. W and Berylium are present in the simulation. The W initial content is set to match initial radiation measurements, and then an incoming flux is added at the separatrix during the whole simulation. Be content is adjusted to match measured Zeff. To summarize, our simulations predicts, over multiple confinement times, the evolution of temperature, density and rotation profiles, heat and momentum transport, impurity transport including W with poloidal asymmetries taken into account, heat source, radiation losses and current diffusion. This level of integrated modeling is the first of its kind.

The first step on the way to understanding W behavior is to reproduce an existing experimental pulse, to validate the integrated modeling tools. The JET-ILW hybrid pulse 82722 (B= 2 T Ip= 1.7 MA) was chosen because it has been widely studied [1] and shows a W accumulation. The time window simulated is 5.5s to 7.1s, as illustrated on Figure 2. NBI is the only heat source with 16MW. In the time window the pulse presents no MHD apart sawteeth and ELMs.

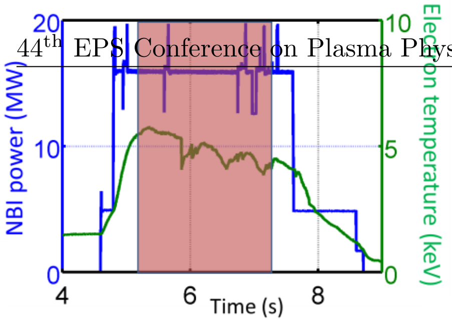

Figure 2 : NBI power (blue) and central electron temperature from ECE (green)

Figure 3 shows the comparison between JETTO-QuaLiKiz (magenta) and measurements for the electron density profiles, at three different times (6s, 6.5s, 7s). One can see that QuaLiKiz predictions lie onto experimental uncertainties over the studied time window.

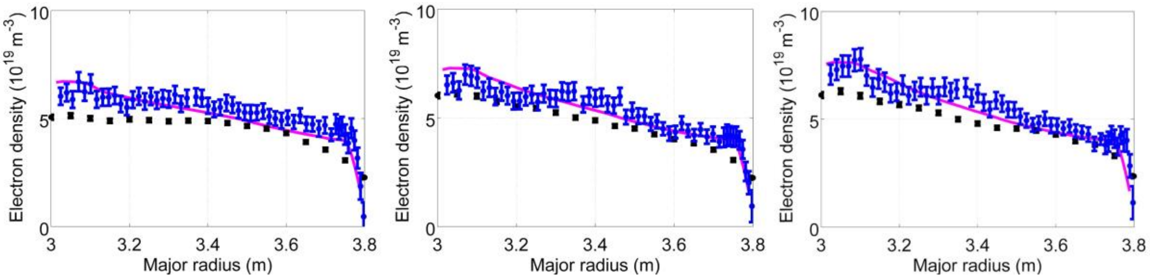

Figure 3 : Electron density profiles from JETTO-QuaLiKiz simulation (magenta) and HRTS (blue) and LIDAR (black) at 6s (left), 6.5s (middle) and 7s (right)

Ion temperature (figure 4 left), electron temperature (figure 4 middle) and toroidal rotation (figure 4 right) from JETTO-QuaLiKiz (magenta) are also compared with HRTS (blue) and charge exchange (black) measurements. Only one time t=7s (t_0 +1.5s) is shown. QuaLiKiz predictions lie within experimental uncertainties for the ion temperature. QuaLiKiz slightly over predicts toroidal rotation, and over predicts electron temperature in the center. To summarize, QuaLiKiz predictions lie within experimental uncertainties and are reliable enough to predict W transport.

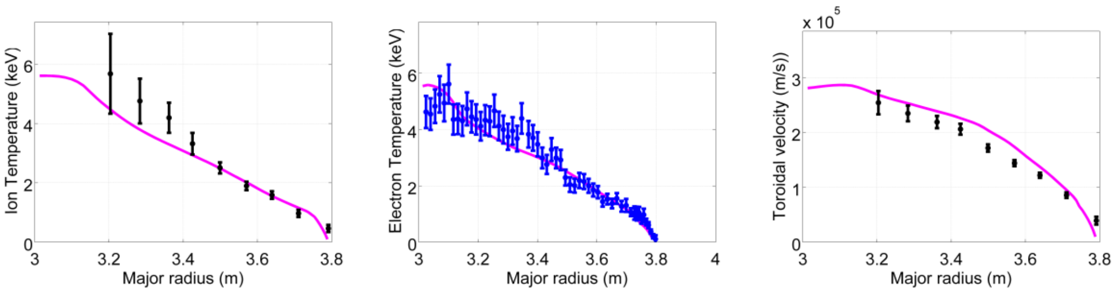

Figure 4 : Comparison between JETTO-QuaLiKiz (magenta) HRTS (blue) and Charge Exchange (black) for ion temperature (left), electron temperature (middle) and toroidal rotation (rotation), at t=7s (t_0 +1.5s)

Now we compare 2D W density prediction from JETTO-QuaLiKiz-NEO versus the W densities inferred from SXR and UV measurements [M. Sertoli]. Figure 5 shows JETTO-QuaLiKiz-NEO simulations (figures 5.a and 5.c), W density estimated from experiment (figures 5.b and 5.d), at two different times (t=6.2s and t=7.1s).

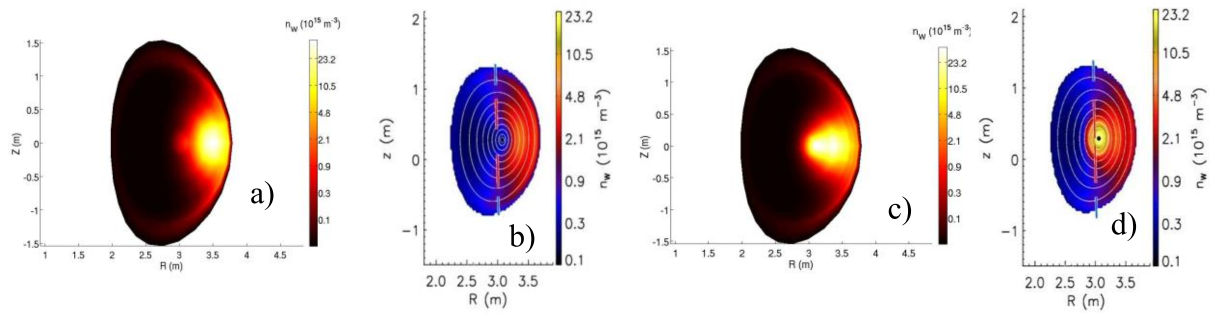

Figure 5 : 2D W density : comparison between JETTO-QuaLiKiz-NEO and estimated W density

At t=6.2s, after 0.7s, both 2D maps show similar poloidal asymmetries, but the simulated one shows some amount of W in the center, while there is none in the inferred profile from measurement. It comes from the initial flat W profile assumed in the simulation, and therefore there is already some W in the center at the beginning of the simulation. At t=7.1s, on the 2D profile inferred from measurements, most of the W went to the center of the plasma. On the 2D modelled W profile, this trend is weaker although the W content clearly moved inward. The simulation also shows that, despite the non-modeling of sawteeth, ELMs and pedestal, the W accumulation is fairly reproduced. That means that, for that specific shot, sawteeth and ELMs do not play a major role in the W transport mechanisms.

To summarize, a simulation over multiple confinement times, flux driven, multi-channel (temperature, density and rotation profiles), including Be and W, accounting for poloidal asymmetries was performed for the first time. The simulation successfully reproduces the time evolution over 1.5s (hence 5 confinement times) of the temperature, density and rotation profiles. Moreover, the W accumulation is correctly reproduced, even if the W does not fully go to the center. The simulations show highly non-linear interplays highlighting the importance of prediction and the need for fast and reliable modeling tools, such as neural networks [7].

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