

Predictive integrated modeling of core impurity transport in the Volumetric Neutron Source (VNS) Tokamak

E. Bray¹, C. Angioni², M. Siccino^{2,3}, C. Bourdelle⁴, D. Fajardo², T. Luda², G. Tardini²,
E. Fable², G. F. Nallo¹, C. Marchetto¹, F. Subba¹

¹NEMO Group, Dipartimento Energia, Politecnico di Torino, 018
Corso Duca degli Abruzzi 24, Torino, 10129, Italy.

²Max-Planck-Institut für Plasmaphysik, Boltzmannstrasse 2, D-85748 Garching, Germany

³EUROfusion Consortium, Boltzmannstr.2, Garching 85748, Germany

⁴CEA, IRFM, F-13108 Saint-Paul-lez-Durance, France

Significant efforts within the EUROfusion program have focused on developing the Volumetric Neutron Source (VNS), aimed at testing in-vessel components under high neutron fluxes representative of future fusion reactors. The concept involves injecting a deuterium neutral beam into a tritium plasma to maximize the fusion yield, as in JET's record fusion pulse [1]. To achieve a high Neutron Wall Load (NWL) of ~ 0.5 MW/m² while minimizing tritium consumption, the VNS is designed as a compact, high-aspect-ratio tokamak ($R \approx 2.5$ m), with beam-driven current and strong plasma rotation due to the absence of a central solenoid. Tungsten plasma-facing components are required to sustain high damage rates (dpa) in steady-state operation.

A first design point has been identified [2] and is currently being refined. To this aim, this work presents integrated core plasma transport modelling, focusing on micro-instability-driven turbulence and tungsten transport. Predictive simulations are carried out using ASTRA, coupled with FACIT [3] and TGLF-SAT2 for neoclassical and turbulent transport, respectively. RABBIT and TORBEAM are used for NBI and ECRH power deposition, while the NEUT subroutine accounts for recycling effects, mainly affecting tritium. Pedestal transport is treated using the scaling law by J. Puchmayr [4].

Due to the high tritium throughput - nearly an order of magnitude higher than deuterium pellets - the two species are simulated separately to avoid unphysical positive tritium density gradients. Additionally, the strong rotation driven by NBI generates large parallel velocity gradients, potentially triggering Kelvin-Helmholtz-like instabilities. Assuming $Pr = 1$ and an edge momentum diffusivity of ~ 1 m²/s ensures simulation stability, without entering loops, by which the parallel velocity gradient instability eventually leads to the collapse of the temperatures. Tungsten transport is analyzed by performing a scan of the source coming from the wall and the ECRH power to study core impurity accumulation.

The results identify preliminary operational limits for VNS, primarily related to the strong NBI-driven rotation, which could be mitigated, for instance, using static coils.

References

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