Implementation of a tightly baffled long-legged divertor in TCV EX-D

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The TCV tokamak contributes to the development of nuclear fusion energy through proof-of-principle experiments and by performing experimental tests of theoretical models that are used to extrapolate existing solutions to a reactor [1]. As part of the Swiss Roadmap for Research Infrastructures the SPC will augment TCV to test a tightly baffled, long-legged divertor (TBLLD), a divertor concept [2] that promises to increase the power exhaust capability of a divertor with no or only minor deviations of the magnetic configuration from a conventional single-null divertor.

Edge plasma simulations using the SOLPS-ITER code predict that a TBLLD in TCV can increase the divertor's power exhaust capability by up to an order of magnitude compared with an unbaffled TCV configuration [3]. Tight baffling along the divertor leg sustains a high poloidal gradient in the neutral density, promoting higher neutral densities in front of the target. As a result, a high fraction of the exhaust power is passed from the plasma to the neutrals before the plasma interacts with the divertor target.

The simulations guided the development of the specifications for a proof-of-principle TBLLD for the outer TCV divertor leg. The gas baffles that form the TBLLD are designed to be compatible with high power auxiliary heated TCV plasmas. The considered core scenarios include high power L- and H-modes, the latter with edge localised modes (ELMs) or quasi-continuous exhaust (QCE). While electron cyclotron resonance heating (ECRH) of L-modes does not unduly constrain the plasma positioning, neutral beam injection (NBI) heating, highly desirable for H-mode access, requires a magnetic axis close to TCV's midplane, thereby, limiting the vertical extent of the TBLLD. Adopting a straight, vertical TBLLD facilitates the engineering design and allows the continued use of TCV's reciprocating divertor probe array (RDPA) to diagnose the plasma along the outer divertor leg. These constraints and consequent choices result in a 0.335 m deep divertor, Figure 1. The simulations predict that a distance between the inner and outer baffle that corresponds to 10 heat flux fall-off lengths, λ_q, already significantly affects the power exhaust [3]. Measured heat flux fall-off lengths of the targeted core scenarios, mapped to the outboard midplane, $\lambda_{q,u}$,vary from 1.6 mm to 3.5 mm. Poloidal flux expansion, f_x, broadens the scrape-off layer (SOL) in the divertor. In TCV, f_x can be varied from approximately 2 to 7, whilst maintaining the flux surfaces parallel along the divertor leg, and to higher values, if some flaring towards the target is accepted. Flux expansion can, therefore, be used to control the plasma plugging in the

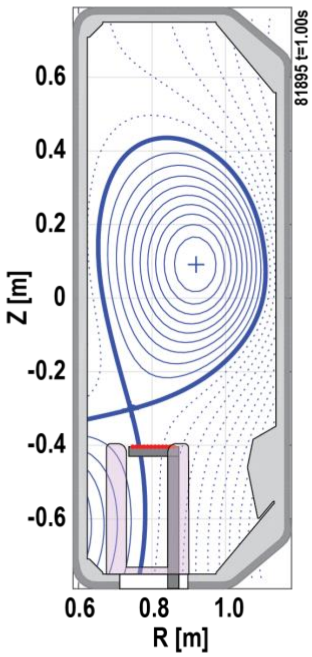

Figure 1. *Poloidal cross section of an NBI heated H-mode with the planned TBLLD contour (mauve) designed around TCV's RDPA (grey & red).*

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TBLLD. A baffle distance of 0.113 m is chosen to allow all core scenarios to be tested with a baffle distance of not more than 10 λ_q, Figure 1.

The engineering design of the TBLLD is based on 64 inner and 64 outer baffle tiles, each, made from the same high purity, polycrystalline graphite used for the TCV wall protection tiles. Each tile has a single attachment to the vessel. Ceramic inserts between baffle tiles at four toroidal locations avoid the induction of toroidal currents. The design is also resilient to halo currents that can arise from vertical displacement events, similarly to the design criteria used for the first-generation TCV baffles [4].

A proof-of-principle of the TBLLD concept requires establishing a high neutral density in the divertor. Neutral gas losses through gaps in the baffles must remain small compared to the transport of neutrals from the target to the baffle throat. The gas tightness was analysed using kinetic modelling of the neutral gas, which resulted in tolerances that limit gaps between tiles to 0.2 mm. With higher gas tightness required compared to the first-generation baffles [4], no through openings for diagnostics are foreseen.

This divertor geometry without lateral baffle openings challenges diagnostic access to the divertor. Essential measurements will include target plasma particle and heat loads and the neutral particle distribution along the divertor leg. The former measurements will be provided by target Langmuir probes and surface eroding thermocouples and the latter by a poloidal set of ASDEX-type pressure gauges. Further, desirable, measurements to characterise the divertor plasma along the divertor leg will be obtained by the RDPA together with horizontal lines-of-sight of the divertor spectrometer system and photodiodes. Additionally, several vertical interferometer chords will provide line-integrated information about the divertor electron density. While further plasma characterisation would be desirable, this foreseen set should suffice to test the plasma-edge models used to extrapolate the TBLLD performance to a reactor.

The procurement of essential items has commenced and it is planned to the test the TBLLD in a dedicated experimental campaign in 2026. Following a successful validation of the TBLLD concept, a second phase of the research infrastructure upgrade would aim at the exploration of an optimised baffle geometry, that also includes a solution for the inner divertor, and is compatible with an attractive core scenario, such as negative triangularity plasma shapes [5].

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