EXHAUST OPERATIONAL SPACE ASSESSMENT FOR THE EUROPEAN VOLUMETRIC NEUTRON SOURCE (EU-VNS)

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The current strategy for EU-DEMO tritium breeding blanket R&D requires input from ITER Test-Blanket Modules. With the delays seen in the ITER research plan, de-risking actions are required for the process of nuclear qualification for the EU-DEMO blanket. One option is to devise a volumetric neutron source (VNS) and a European feasibility study for a tokamak-based VNS is currently undertaken [1,2]. In this study it is proposed that a testing facility of medium-size ($R \approx 2.5$m with large-aspect ratio $A = R/a \approx 4.6$), metal wall and D-T beam-target driven fusion power. Key requirement is a high machine availability with bulk tritium plasma producing fusion neutrons predominantly by beam target reactions from D neutral beam injection (NBI). For EU-VNS the expected $P_{edge}/R \approx 20$, requires an optimized divertor shape and the possibility of regular replacement of the metallic divertor components during downtimes of the device. In order to manage the heat load at the strike lines, a significant fraction of power entering the edge must be redistributed on the entire vessel surface by line-radiation of seeded impurities. To stabilize the plasma and to achieve large neutron wall loads however, the core impurity concentration must not exceed an upper limit of $Z_{eff} < 2 - 3$. At the required fusion power $P_{fus} \approx 30$MW about $2.5 \cdot 10^{19}$ Helium particles per second will be produced which must be removed in the divertor by active pumping in order to avoid additional dilution.

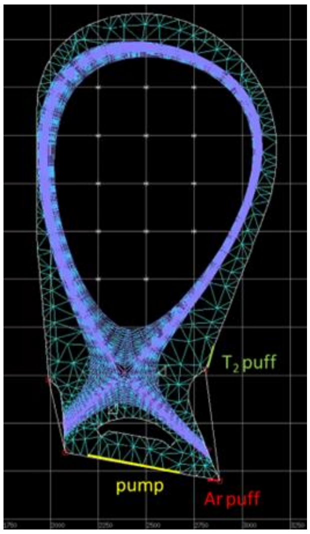


Figure 1 SOLPS-ITER simulation grid (84x36 quadrilateral cells) and EIRENE neutral triangular mesh, and depicted locations of T2-gas puff, Ar (Kr) -puff and pumping

In this contribution the results of a conceptional assessment of the operational space for power and particle exhaust in a possible EU-VNS are demonstrated. SOLPS-ITER [3,4] was setup for T+He+Ar plasma species simulations for the EU-VNS divertor conceptual study (fig. 1). In a second step, Ar is replaced by Kr to test sensitivity of the exhaust operational space on seeding species. For the model conditions at the core-side (i.e. pedestal top) the power entering the edge $P_{edge} = 50$MW is assumed to be equally shared between electrons and ions. The He-particle influx from the fusion product is resulting in $\Gamma_{He2+,core} = 2.5 \cdot 10^{19}\ s^{-1}$. The pump in the divertor private flux region (PFZ) is adjusted to a pumping speed ($S_{pump} \approx 20m^3/s$) to ensure sufficient He pumping and to keep the He concentration at about 1% at the core boundary. The radial anomalous diffusion is assumed to be flat everywhere with constant coefficients for radial particle diffusion and heat conductivities resulting into a radial heat decay length at the outer mid-plane of about $\lambda_q \approx 3$mm in the near-SOL close to the separatrix. To map out the exhaust operational space, the particle throughputs for the T-content (in terms of pellet-like content core fuelling rates and molecular

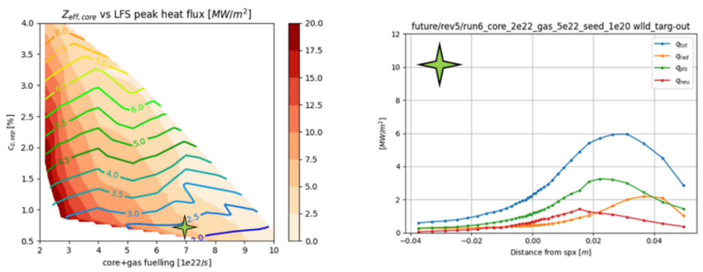
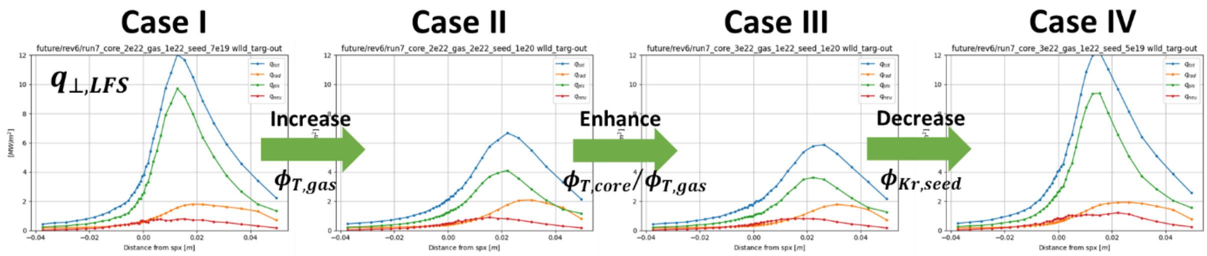


Figure 2 Left: operational space for T+He+Ar EU-VNS case: impurity concentration averaged at sepearatrix $c_{Z,sep}$ vs total T-particle throughput. Contour-plot color: LFS peak-heat flux $q_{pk,LFS}$, solid color lines Z^{eff} at core boundary. Right: LFS heat-flux density for a selected case (green star): blue total, orange: radiation, green: plasma, red:

gas fuelling) and Ar/Kr content (purely seeded from the divertor region) are scanned.

It is demonstrated by the SOLPS-ITER modelling that a finite operational window is found for the EU-VNS divertor configuration proposed with argon seeding in order to reduce the peak heat-load density at target plates to values safely below 10MW/m^2 (steady) despite the compact geometry of the VNS divertor (c.f. fig. 2). The compression of argon in the divertor is enough avoiding large amounts of core radiation. Similarly to ITER, also for EU-VNS with a narrow and hot near-SOL region being very opaque fuelling through the SOL is not very efficient. In the model, fuelling by pellets in the T+He+Ar case is more efficient compared to gas puffing as thus more efficiently reduces Z_{eff} to acceptable levels < 2-3. Consequently, the tritium density is high but within the Greenwald limit ($<n_T> \approx 1.1 \cdot 10^{20} m^{-3} < n_{GW} \approx 1.8 \cdot 10^{20} m^{-3}$) and hence there is room to optimize the overall scenario further. As a result, the required total T-throughput is very high ($\Phi_{T,gas} + \Phi_{T,core} \sim 1.1 \cdot 10^{22s} s^{-1}$) and is thus of the order of ITER values. Integrated modelling (core & edge) is required to resolve uncertainties in the assumed transport model and to self-consistently achieve ASTRA predicted top-pedestal conditions in combination with a working exhaust concept and expected total particle throughput requirements.

Kr can be more efficient compared to Ar to reduce upstream pressure through line radiation, and another set of T+He+Kr simulation cases were set up with all other numerical parameters kept the same, then repeating the scan of particle throughputs. This results in a wider operational space (c.f. fig.3) that allows to keep Z_{eff} < 2 and at the same time to keep the target heat-flux below or around the critical limit in steady-state. In addition, the required total T-particle throughput is about a factor 2 lower compared to the T+He+Ar case.



Case No.	$\phi_{T,core}$ [1/s]	$\phi_{T,gas}$ [1/s]	$\phi_{Kr,seed}$ [1/s]	Z_{eff}	$\langle c_z, sep \rangle$ [%]	$\langle p_{p,div} \rangle$ [Pa]	$q_{pk,LFS}$ [MW/m²]	$q_{pk,HFS}$ [MW/m²]
I	2e22	1e22	7e19	2.5	0.31	5.9	12.02	7.31
II	2e22	2e22	1e20	3.0	0.52	6.5	6.67	5.78
III	3e22	1e22	1e20	2.7	0.49	6.5	5.89	5.55
IV	3e22	1e22	5e19	1.76	0.15	7.3	12.17	8.35

Figure 3 Comparison of the T+He+Kr cases, optimized towards lowering Z_{eff} even further but staying ewithing the target heat-flux requirements. Pellet fuelling is more efficient to keep Z_{eff} down also for the T+He+Kr case, but the achievable low levels of Z_{eff} < 2 are more compatible with core plasma performance requirements

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