Progress in the concept development of the VNS - a beam-driven tokamak for component testing

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1. Mission and basic concept

VNS is proposed to complement the fusion development strategy, which includes today several major experiments including ITER [1], which aims at demonstrating burning plasma physics, Wendelstein7-X [2], which aims at developing fusion-relevant stellarator plasma scenarios, DONES [3], which aims at qualifying neutron radiation resistant structural materials, and others not mentioned here. The main purpose of VNS is the testing and qualification of fusion nuclear components [4]. VNS was proposed already in 1995 to complement ITER [5], [6] but was not implemented in the fusion program also because the ITER test blanket module (TBM) program was foreseen to enable relevant testing of the breeding blanket (BB) [7].

Achieving D-T fusion generating a high neutron wall load (NWL) is less challenging in VNS because a high plasma temperature is not required. A feasibility study has been concluded recently with the basic design of a tokamak machine integrated with the main plant systems including provisions for maintenance and able to meet safety & licensing requirements [8].

Informed by the results from the feasibility study, the main machine parameters were adjusted to address key issues of the VNS, see in Table 1: (i) the increase of the plasma size and current allowed a reduction of the aspect ratio and an increase of the elongation enabling the plasma to generate a fraction of its power through thermal fusion. This improves the ratio between external heat and fusion power, Q. (ii) The larger plasma current allows reducing the number of fast particles losses from the plasma that cause the erosion of the tungsten armour. This also increases the robustness w.r.t. known plasma disruptive boundaries, like the β limit. (iii) The larger plasma minor radius reduces the relative distance between plasma and control coils, thus improving the magnetic equilibrium and controllability.

VNS aims at reaching an irradiation damage level in the first wall of 30-50 dpa. Due to the relatively low fusion power, VNS will consume no more than approximately 1 kg of tritium, an amount that could be acquired from Canadian and South Korean CANDU reactors [9], [10], which supply approximately 2 - 3 kg/year, sold at ≈30 M$/kg [11]).

Table 1 VNS main tokamak parameters

Major / minor radius, R / a	2.67 m / 0.64 m
Aspect ratio, A	4.25
Magnetic field (@ 2.67 m radius), B_0	5.6 T
β_N [Tm/MA]	2.76%
Plasma current, I_p	2.5 MA
Fusion power, P_{fus}	38 MW
NWL peak	0.5 MW/m²
Heating & current drive (H&CD)	
- Neutral beam (NB) power - Electron cyclotron (EC) power	42 MW 8 MW
Tritium consumption / fpy	2.1 kg
Target irradiation damage level in the first wall	30-50 dpa

2 VNS design

2.1 Magnet system

The VNS magnet system consists of 12 toroidal field (TF), 6 poloidal field (PF) coils, the central solenoid (CS, see Figure 1. For thermal insulation of the superconducting coils a cryostat provides vaccum condition and the warm VV and cryostat surfaces are covered by thermal shields.

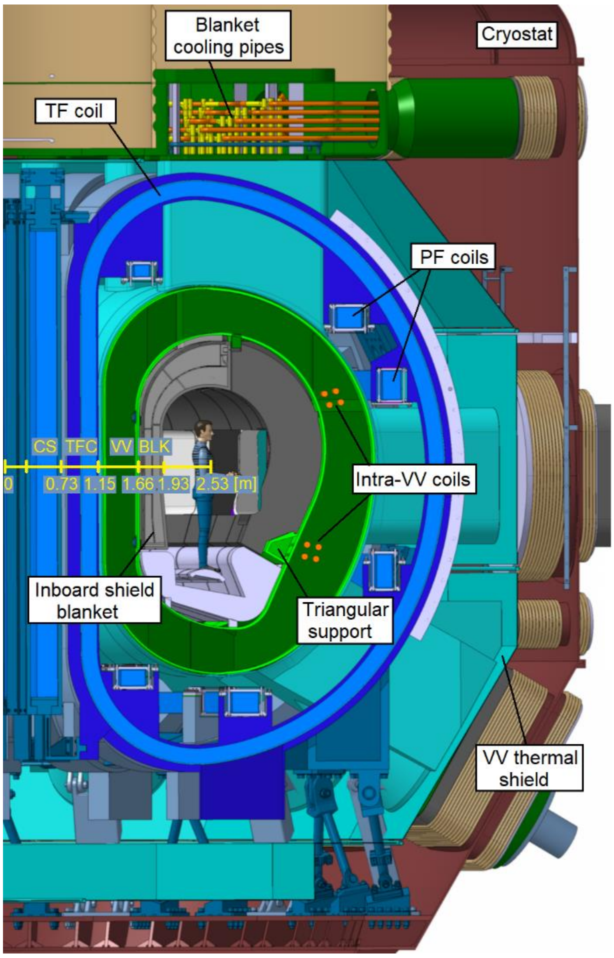

Figure 1 Section view of the VNS tokamak before the modification of main machine parameters incl. machine radial build. Abbreviations: TF coil (TFC), blanket (BLK)

2.2 Vacuum vessel and in-vessel components

The VV is a double wall structure with two shells, poloidal ribs and ports providing access into the main chamber. In-wall shielding plates of tungsten, B4C and SS304 are bolted in the interspace between the shells. The VV coolant flows from the bottom to the top filling the remaining volume inside the double-wall structure making the VV an effective n-shielding structure. The other main functions of the VV are to provide a high vacuum for the plasma and first confinement to the radioactive source terms inside the VV.

The in-vessel components (IVCs) are mounted to the VV inner shell. With the exception of the TBMs the IVCs are made of 316 Ti stainless steel in order to withstand the foreseen end of life neutron fluence without need for replacement [14]. The segmentation of the VNS IVCs follows the same principles as foreseen for DEMO [15], [16] i.e., in each sector the divertor is divided into 3 cassettes and the blanket into 5 segments allowing access to their service pipes and enabling their remote replacement [17].

2.3 Neutral beams

The dependency of VNS on the reliability of its NB injectors (NBIs) led to the choice of positive ion beams operated with 120 keV, a technology with decades of operational experience with low downtime from ASDEX-Upgrade (AUG) [18] [19]. Although at constant beam power a higher beam energy would decrease the number of injected D-particles into the T-plasma, positively affecting the fusion yield in VNS by reducing the D dilution of the T plasma, the technical issues and reliability risks associated with negative ion sources were considered unacceptable. Each of VNS's NBIs has been designed with four sources and can inject a power of 13.5 MW into the VNS plasma [20]. During plasma operation, three NBIs are in operation, while the fourth is in regeneration mode. In this mode, the torus valve is closed, the large cryopanels are heated to release the accumulated gas, which is then pumped out from the NBI box [21].

Acknowledgements

This work has been carried out within the framework of the EUROfusion Consortium, funded by the European Union via the Euratom Research and Training Programme (Grant Agreement No 101052200 — EUROfusion). Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Commission. Neither the European Union nor the European Commission can be held responsible for them.

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