Remote Handling Strategy of Volumetric Neutron Source Blanket

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Abstract

A feasibility study of a new testing facility, i.e. the volumetric neutron source, VNS, in a tokamak configuration was initiated in 2023 and it is now under way with the purpose of addressing potential showstoppers. Key outcomes of the engineering activities are presented in [1]. The main goal of the VNS is to provide a realistic environment to test the in-vessel components of a fusion reactors, in particular the tritium breeding blanket. The lessons learned during previous years of DEMO development point to the need for a thorough nuclear design integration already at level of the basic machine design, hence the issues related to the maintenance of the in-vessel components have been addressed at a basic level. The work presented here describes the remote maintenance strategy for VNS blankets, which is an adaptation of the concept proposed for DEMO in previous years [1]. The work discuss the basic approach for development of an integrated remote blanket strategy of the VNs blanket. Consistent with the initial requirements of the machine [2], the remote replacement sequence of the blankets, the potential list of the required tools and transporter and the conceptual design of some of the main tools are presented and discussed in this article.

Keywords: Remote Maintenance VNS, Volumetric Neutron Source, Breeding blanket testing, DEMO, tokamak,

Introduction

The Volumetric Neutron Source (VNS) is a beam-driven tokamak that has been developed for the purpose of testing in-vessel components of fusion reactors [1]. The VNS design draws upon lessons learned from previous development projects, such as ITER and DEMO [1]. The VNS incorporates innovative approaches to reduce construction risks by adopting ITER-like concepts while introducing customized solutions tailored to its unique requirements. The work focuses on development of an integrated remote maintenance strategy for the VNS blanket, starting from previous studies carried out for DEMO [1], **Error! Reference source not found.**. The study is based on the definition of a preliminary remote replacement sequence of the Blanket with the associated potential list of required tools and transporters. The vertical transporter of the VNS blanket segments is under development, results about the extraction sequence and the accessibility to the blanket segments are here discussed. The kinematic model of the transporter has been created and tested in a virtual environment to validate the assumed extraction sequence.

Maintenance strategy overview

A tritium Shielding Blanket (SB) is installed inside the vacuum vessel (VV) of VNS, covering most of the plasma-facing surface to absorb neutrons and attenuate secondary gamma radiation resulting from neutron interactions [1]. Due to neutron irradiation over time, the SB materials degrade, necessitating periodic replacement during the VNS operational lifetime. The associated in-vessel maintenance operations must be conducted using remotely operated tools and in a manner that could later be adopted in commercial fusion power plants, ensuring reasonably short downtimes [1]. Segments are extracted from the VV through the upper ports using a vertical transporter, and once removed, are transported to the Active Maintenance Facility (AMF) within casks in a double sealed environment to prevent the spillover of the radioactive dust once the upper port is opened and to prevent the outgassing of the tritium and to reduce the radiation propagation in the tokamak building**Error! Reference source not found.** (Figure 1). This design uses ITER-like concepts for remote handling, while incorporating innovative solutions to improve reliability and efficiency [1]. Consequently, the VNS reactor design aims to demonstrate rapid and reliable remote maintenance techniques, ensuring availability levels compatible with the economic requirements of FPPs. The present phase of the VNS remote maintenance project is centred on the development of a robust maintenance strategy taking into account the aspect related to the integration of the RH tools with the machine components. The basic idea of the strategy is to develop methods, tools and procedures that can be applied to all commercial FFPs, ensuring the required machine availability and the economic sustainability of fusion energy. The approach is based on the assumption that the development of the RH scheme of the machine evolves in parallel with the design of the plant. The remote maintenance strategy for Shielding Blanket segments in the VNS must meet several critical requirements to ensure efficiency, safety, and compatibility with high plant availability goals. These requirements include [1]:

1. **Contamination Protection:** The RH tools must operate within a sealed cask located in a sealed room,
2. **Availability**: The swift replacement of SB segments is of crucial importance in order to maintain VNS availability.
3. **Manipulation**: The RH system must enable complex kinematics to lift, to extract and to tilt the SB segments by a few degrees, in order to disengage

them from their supports during the process of extraction from the VV. *This operation must ensure compatibility with the blanket support scheme and facilitate efficient handling.*

4. **Design Criteria**: The BB cask and transporter must conform to EN 13001-3 standards. According to the current configuration of the machines a payload of up to **12 tons** is assumed for the dimensioning of the SB transporter structures**.**
5. **Decontamination**: The design of the system is predicated on decontamination by minimizing surface complexity, incorporating removable panels to isolate complex components, and using materials with low tritium absorption [[1]].
6. **Compatibility with High Radiation Fields**: Remote maintenance tools must be radiation-tolerant, ensuring reliable operation in high-radiation environments.
7. **Standardization**: In order to optimize operations and to reduce the cost related, wherever possible, the maintenance tools must be designed with standardized components, thus facilitating repair, replacement, and re-commissioning.

This strategy has been shown to improve plant availability and provides a robust basis for similar systems in future fusion power plants.

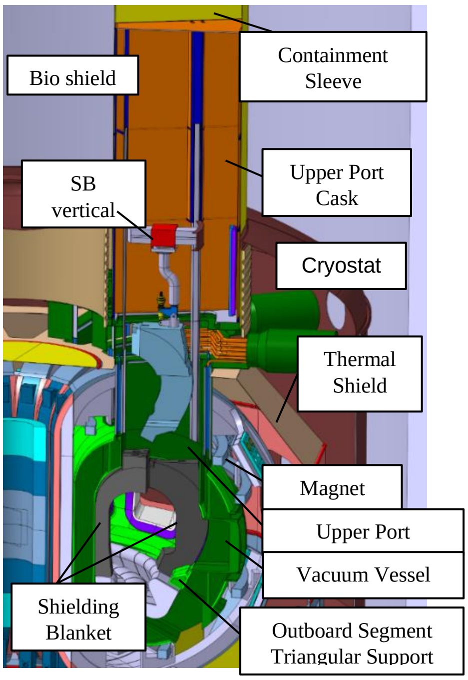

Figure 1 Overview of Main components of VNS Tokamak during remote maintenance

Kinematic simulation of the removal sequences, even if in at level of feasibility study, proved the possibility of the remote extraction and manipulation of the VNS blanket segments. In the following figures the critical step of the removal sequence are illustrated.

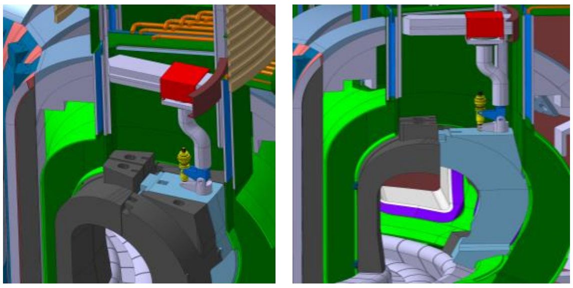

Figure 2 Left: Blanket Segment Gripping; Right: Triangular Support Unlock

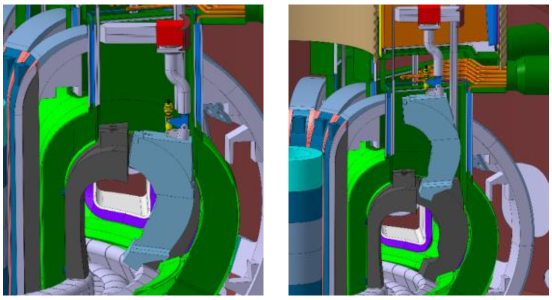

Figure 3 Left: Blanket Segment Tilting and Extraction; Right: Blanket Segment Lifting

Conclusion

Preliminary indications from CAD kinematic simulations in virtual environment performed on the central outboard segment and the inboard segments suggest the feasibility of segment replacement, according to the configuration of the current layout of the VNS Blanket supports. The article further delineates the requisite steps for the removal of the VNS SB, taking into account all components present in the upper port. It is further suggested that a considerable degree of effort is still required to implement the proposed maintenance strategy, including the design of the conceptual equipment and the testing of mock-ups Error! Reference source not found.. These steps are essential to drive the development process forward and achieve the expected results more efficiently.

References

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