Fusion Engineering and Design 130 (2018) 32–41

Contents lists available at ScienceDirect

Fusion Engineering and Design

journal homepage: www.elsevier.com/locate/fusengdes

Divertor options impact on DEMO nuclear performances

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ARTICLE INFO

Keywords:
Divertor
DEMO
Neutronics
TBR
SDR

ABSTRACT

The present paper addresses the impact of the divertor option on the nuclear performances of the Demonstration fusion reactor (DEMO). As the effect of the number and size of the divertor has been already evaluated, in this work the focus has been posed on the composition in terms of amount of cooling inside the divertor cassette. Transport responses, as the Tritium breeding ratio (TBR), neutron and gamma fluxes and spectra inside the plasma chamber, as well as activation responses such as shutdown dose rate, decay gamma fluxes and heating have been evaluated for two different blanket concepts of the future European DEMO reactor: DCLL and WCLL. Three different divertor compositions have been tested demonstrating the importance of this component not only locally but in the global radiation field. The transport analysis has been performed with the Monte Carlo code MCNP5 and the JEFF3.1.1 and JEFF3.2 data libraries. The activation responses calculated using Advanced D1S method have been recently assessed and summarized in the present paper.

1. Introduction

Tritium self-sufficiency is a prior requirement in a fusion demonstrative (DEMO) power plant.

Many efforts have been done in the past years [1–3] for the improvement in the prediction of the Tritium Breeding Ratio (TBR), which is the measure for the self-sufficiency.

With the course of time, the more sophisticated analyses, tools and data libraries have allowed to consider less margin of uncertainties in the TBR target value. Currently, for the fusion power demonstration reactor DEMO developed in the framework of the EU fusion roadmap "Horizon 2020", the requirement for the overall TBR is 1.1 [4] that is the target to be achieved for the sustainability and reliability of the plant. Indeed, due to the various uncertainties and plant-internal losses occurring during DEMO operation, a margin of 10% (for a final net TBR ≥ 1.0) is required.

All the margins of uncertainties that could occurs have been exhaustively characterized but the uncertainties due to specific engineering design assumptions are extremely difficult to quantify and predict since they usually change with the design progress. Generally, the TBR performance degrades as the design becomes more detailed. To account for this, it would be safe to include an uncertainty margin of 2–3% [3]. This is, however, not mandatory and might be neglected if one can be sure the design is technically mature.

In the prediction of the TBR some aspects of the design have not been sufficiently considered so far, as the case of the influence of the divertor as addressed in the present paper. The impact on the TBR due to the loss of blanket coverage related to the space occupied by the divertor have been recently published [5,6]. Three options: no divertor, 1 divertor (Single Null) and 2 divertors (Double Null) have been considered in these studies, evidencing a strong relation among the loss of blanket coverage area with the loss of TBR.

However, the impact on TBR and relevant nuclear responses is not only due to the geometrical loss of blanket materials but, considering the same dimensions, the divertor compositions could impact the radiation field inside the plasma chambers. The present paper deals with such problem and it is focused on the relevance of the material composition of the Divertor cassette on TBR performances and on the radiation environment. The divertor composition impacts also on activation of in-vessel components and this effect, recently introduced in [7], is detailed in this paper.

The methodology (DEMO designs, divertor designs, codes, libraries, irradiation scenario, etc.) applied for the execution of the activity is described in Section 2. The results of the impact of divertor composition on transport and activation responses are analyzed in Section 3.

2. Methodology, assumptions and input data

2.1. The DEMO design

A lot of efforts have been done in the recent years for the development of a DEMO conceptual design with special attention: 1) to the

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https://doi.org/10.1016/j.fusengdes.2018.03.020
Received 24 April 2017; Received in revised form 7 March 2018; Accepted 8 March 2018
Available online 15 March 2018
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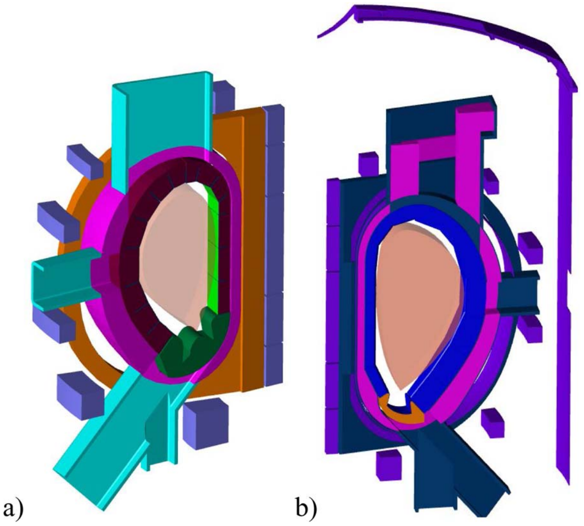

Fig. 1. DEMO generic designs: a) Baseline 2014, b) Baseline 2015.

Tritium Breeding Ratio target fulfilment for a sustainable operation of the plant and 2) to the use of low activation materials to demonstrate that the tangible part of this energy source is really committed to the environment.

2.1.1. DCLL and WCLL BB designs

As part of the first objective a special R&D Work Package in the framework of the EUROfusion Consortium Power Plant Physics and Technology (PPPT) programme, called Work Package Breeding Blanket (WPBB), was launched in 2014. This pack of activities focuses on the development of the Breeding Blanket (BB) modules which are the structures involved in the generation of the tritium fuel essential for the operation of the plant.

In this programme [8] 4 BB options are being conceived and improved. In particular, in the present paper, two blanket concepts have been studied: the Dual-Coolant Lithium Lead (DCLL) and the Water Coolant Lithium Lead (WCLL).

The development of a DCLL BB to be integrated inside the common DEMO generic reactor is currently lead by CIEMAT [9,10]. The DCLL concept is basically characterized by the use of self-cooled breeding zones with the liquid metal LiPb serving as tritium breeder, neutron multiplier and coolant and the ferritic–martensitic steel Eurofer-97 as structural material. The WCLL concept developed currently by ENEA [12] also uses PbLi as breeder but is characterized by the use of water for cooling the Eurofer structures. More details on WCLL design are in [12,13].

From the start of the programme up to now two generic DEMO design have been conceived and analyzed being known as DEMO baseline 2014 [14] and DEMO baseline 2015 [15] (shown in Fig. 1a and b respectively). The former DEMO design had 16 sectors of 22.5° and a plasma power of 1572 MW corresponding to a 5.581 × 10^{20} n/s source. The present DEMO design consist of 18 sectors each one of 20°. The reactor fusion power is 2037 MW corresponding to 7.323 × 10^{20} n/s source. The plasma parameters (radius, elongation, triangularity, radial shift, source peaking factor) are reported in [16] for previous DEMO design and in [17] for the present one. For the neutronic studies and in the present applications, 11.5° MCNP [18] model was used for DEMO

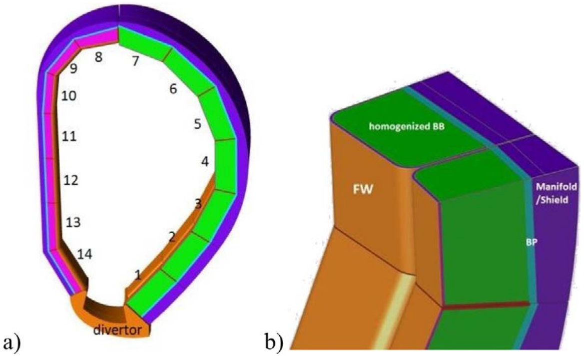

Fig. 3. a) WCLL neutronic design DEMO2015 with b) its detailed OB equatorial module.

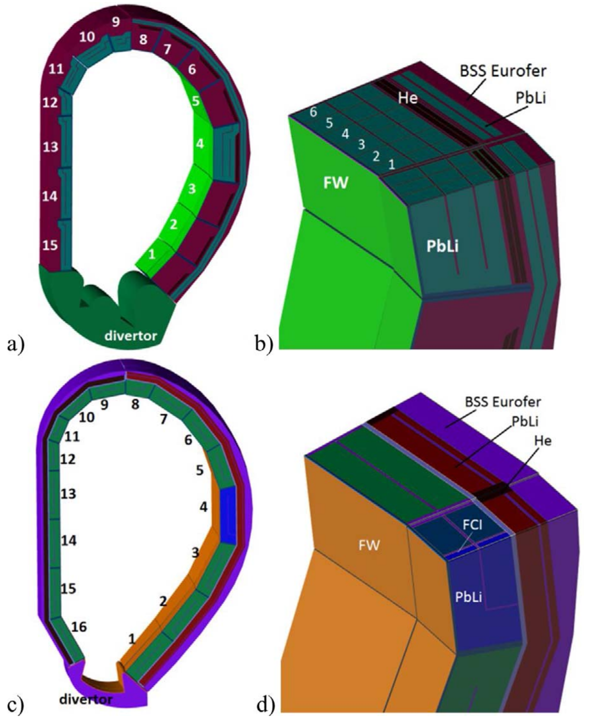

Fig. 2. DCLL: a) DEMO2014 design and b) its detailed OB equatorial module; c) DEMO2015 design with d) its detailed OB equatorial module.

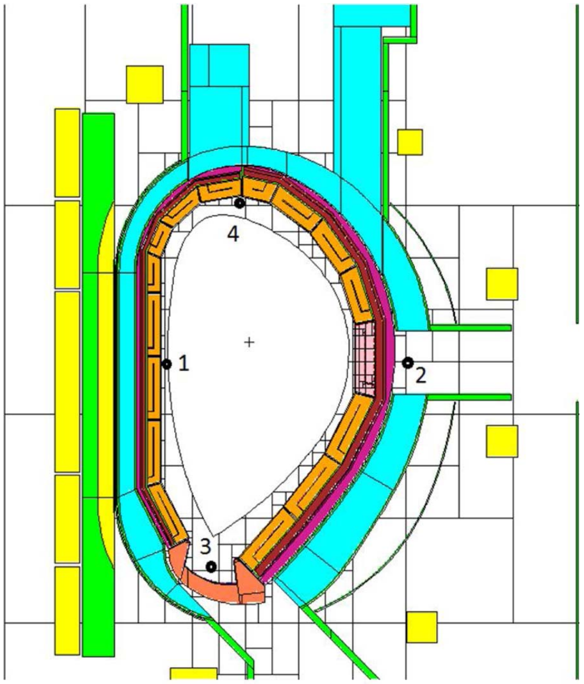

Fig. 4. MNCP DCLL DEMO model with the 4 detector in which the responses have been calculated as local values.

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