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Update in the nuclear responses of the European TBMs for ITER during operation and shutdown

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ABSTRACT

The depiction of the nuclear responses of the ITER European Test Blanket Modules (TBMs), Helium Cooled Lithium Lead (HCLL) and Helium Cooled Pebbles Bed (HCPB) is presented in this work. Following important components update, and important methodological advances, the nuclear heat and the tritium production have been revisited, giving new estimations 10% higher than the previous evaluation for nuclear heat in both TBMs and to 15% higher for HCPB T production. This has an impact on the thermo-mechanical design of the TBM and the tritium handling. In addition, the Shutdown Dose Rates in the respective port interspace have been characterized in local approach. It shows a performance that could imply compatibility with planned in-situ maintenance activities when analysed in global approach, an improvement with respect to previous evaluations.

1. Introduction

ITER is a Nuclear Facility INB-174. The Test Blanket Modules (TBM) of ITER are components hosted in the ITER equatorial ports to provide the first experimental data on the performance of the breeding blankets in the integrated fusion nuclear environment. They are $46.2 \times 68.5 \times 167\ cm^3$ components with lithium in different chemical forms, together with a neutron multiplier and the cooling circuits to remove the plasma neutrons energy recovered as nuclear heat. ITER will host six TBMs in three equatorial ports: #2, #16 and #18 [1,2]l.

The ITER equatorial port #16 will host the two European TBMs [3,4]: i) Helium Cooled Lithium-Lead (HCLL) and ii) Helium Cooled Pebble Bed (HCPB). The HCLL has the eutectic Pb-16%Li as neutron multiplier and tritium breeder. The HCPB has Be pebbles as neutron multiplier, and Li_4SiO_4 ceramic pebbles as tritium breeder. In both cases, the lithium is enriched at 90 at. % in ^{6}Li. The TBMs will be cooled with a helium circuit based on massive cooling channelling in the TBMs structure, made of EUROFER [5]. These are basic and fundamental technological concepts for the future European DEMO reactors to be tested in ITER. The European TBMs have already passed the Conceptual Design Review phase in ITER. The Preliminary Design Phase is envisaged for the coming years, and an update in the nuclear responses was needed.

The TBMs must meet certain design criteria for satisfactory operation. The mechanical integrity requires the depiction of the nuclear heat as load for the TBMs design. The tritium production is a relevant parameter with regards to two aspects. On the one hand, tritium production is one of the goals of the TBMs technologies to be checked in ITER, key for the tritium self-sustainability of the nuclear fusion. On the other hand, tritium presents safety related concerns, and the prediction of the tritium inventory generated by the TBMs must be accurate.

The last evaluation of the nuclear heat and T production in the HCLL and HCPB TBMs was made in 2011 [6]. Since then relevant components and methods have evolved. The TBMs external dimensions have varied, and the Port Plug Frame (PPF) shape has been shaved in its first wall, letting the TBMs be more exposed to the plasma. In addition, the geometry modeling capabilities have undergone a strong evolution, mostly thanks to the development of the SuperMC tool [7,8] (formerly MCAM) in a first instance, and Spaceclaim [9] in the second.

With regards to planned in-situ maintenance activities in the ITER equatorial port interspace 16, the TBMs, together with the TBM shields, play a major role. Hosted inside the Port Plug Frame, they must shield the neutron flux along the port plug enough to help to meet a Shutdown Dose Rate (SDDR) of 100 μSv/h at 10^6 s of cooling time after irradiation with the ITER conservative irradiation scenario of reference, called SA-2. In Table 1 the irradiation scenario is shown considering the different

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Table 1
SA-2 Irradiation scenario considering the different components exposures as factors.

Duration	Fusion power (MW)	Repetition	Load factors			
			Scenario #1 TBMs, Shields & Pipe Forest	Scenario #2 PP Frame	Scenario #3 Pb-16Li	Scenario #4 Bio-shield plug, TBS pipes and Port components
2 y	2,68	once	–	–	0.0024	0.0054
1 y	20,6	4 times	–	–	0.0183	0.0413
1 y	20,6	4 times	–	0.0413	0.0183	0.0413
1 y	20,6	twice	0.0413	0.0413	0.0183	0.0413
0,667 y	0	once	–	–	–	–
1325 y	41,5		0.0830	0.0830	0.0367	0.0830
3920 s	0	17 times	–	–	–	–
400 s	500		1.0000	1.0000	0.4425	1.0000
3920 s	0	3 times	–	–	–	–
400 s	700		1.4000	1.4000	0.6195	1.4000

exposures of the components. The latest evaluation of the SDDR in the ITER equatorial port 16 was made in 2014 and published in 2016 [10].

Since then, important changes have also happened. The gaps between the TBMs and the PPF, identified as a driver of the SDDR, have been reduced (as studied in [11] considering dummy TBMs). The Pipe Forest modelling has been improved with respect to previous work. In addition, a new and significantly improved MCNP model of the ITER Tokamak, called Cmodel v1 R2.1 [12] is now available. With respect to B-lite v3, considered in the last study, C-model now contains a heterogeneous and detailed modelling of the Blanket Shields Modules and the Vacuum Vessel, which were also identified as drivers of the SDDR in the previous study.

These aspects motivate a re-evaluation of the nuclear heat, the tritium production and the SDDR considering the updated designs and the latest modelling capabilities available to be considered in the TBMs Preliminary Design Phase of ITER. However, it should be noted that this work is still of a preliminary nature and will be consolidated in time.

2. Computational tools, MCNP model and setting

The original CAD models of the equatorial port #16 (Fig. 1) were refurbished using Spaceclaim 2016 to be translatable to MCNP5 [13] format using the tool SuperMC [7,8]. The resulting MCNP models were debugged until lost particle rate was $< 10^{-9}$ considering a homogeneous dispersed isotropic source in the model in void mode.

The EP#16 MCNP model, from plasma to bioshield, was then inserted in the latest ITER reference MCNP model, named C-model v1 R2.1 [12]. The resulting model is shown in Fig. 2.

To save computational resources and to allow a direct comparison with the previous work [10], the socalled local approach has been adopted. To this end, the neighbouring ports have been blocked in terms of neutron flux transmission, neglecting the cross-talks between ports. It has no impact on the quantities computed in the TBMs, but it represents an underestimation of the SDDR in the interspace [14]. To avoid confusions, a "Δ" sub-index will follow all the SDDR results to highlight its local nature. Thus, the SDDR results shown here cannot be used to demonstrate compliance of the SDDR limit, but simply the compatibility with the limit can be checked. If local SDDR is $< 100_{\Delta}$ μSv/h, a later global analysis will be recommended, considering the contributions of all the ports to check whether SDDR < 100 μSv/h in

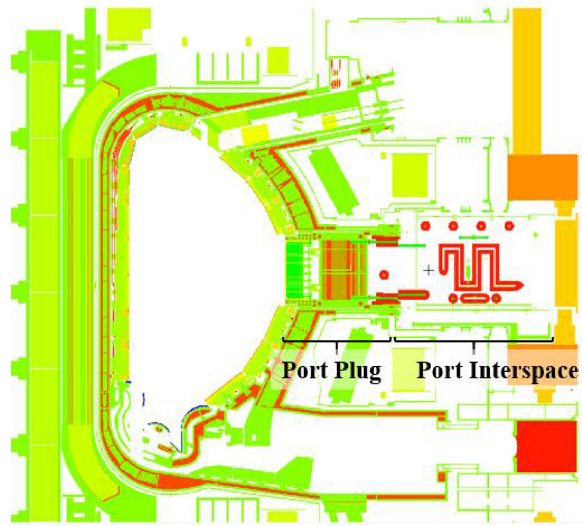

Fig. 2. ITER Equatorial port #16 inserted into C-model.

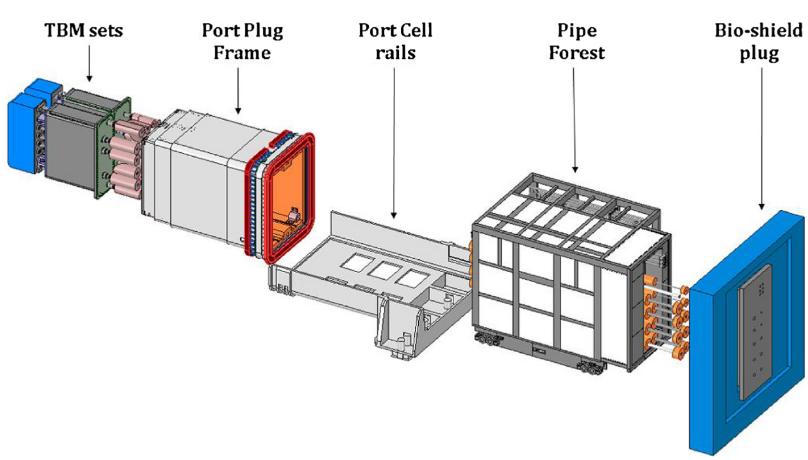

Fig. 1. ITER Equatorial port 16 components: Test Blanket Modules (TBMs), Port Plug Frame (PPF), Port Cell rails, (PC rails) and Pipe Forest (PF).