DEMO Port Plug Design and Integration Studies

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Abstract. The EUROfusion Consortium established in 2014 and composed by European Fusion Laboratories, and in particular the Power Plant Physics and Technology department aims to develop a conceptual design for the Fusion DEMOnstration Power Plant, DEMO. With respect to present experimental machines and ITER, the main goals of DEMO are to produce electricity continuously for a period of about 2 hours, with a net electrical power output of a few hundreds of MW, and to allow Tritium self-sufficient breeding with an adequately high margin in order to guarantee its planned operational schedule, including all planned maintenance intervals. This will eliminate the need to import tritium fuel from external sources during operations. In order to achieve these goals, extensive engineering efforts as well as physics studies are required to develop a design that can ensure a high level of plant reliability and availability. In particular, interfaces between systems must be addressed at a very early phase of the project, in order to proceed consistently. In this paper we present a preliminary design and integration study, based on physics assessments for the EU DEMO1 Baseline 2015 with an Aspect Ratio of 3.1 and 18 Toroidal Field Coils, for the DEMO port plugs. These aim to host systems like Electron Cyclotron Heating launchers currently developed within the Work Package Heating and Current Drive that need an external radial access to the plasma and through in-vessel systems like the breeder blanket. A similar approach shown here could be in principle followed by other systems, e.g. other heating and current drive systems or diagnostics. The work addresses the interfaces between the port plug and the blanket considering the Helium-Cooled Pebble Bed and the Water Cooled Lithium Lead which are two of four breeding blanket concepts under investigation in Europe within the Power Plant Physics and Technology Programme: the required openings will be evaluated in terms of their impact onto the blanket segments thermo-mechanical and nuclear design considering mechanical integration aspects but also their impact on Tritium Breeding Ratio. Since DEMO is still in a pre-conceptual phase, the same methodology is applicable to the other two blanket concepts, as well.

1. Introduction

In 2014, 29 Research Units and Universities from 26 European countries plus Switzerland, signed the EUROfusion consortium agreement for the *Development of Fusion Energy* [1] on behalf of Euratom. Within this framework, the Power Plant Physics and Technology department (PPPT) focuses its effort for the development of a pre-conceptual design for the DEMOnstration Fusion Power Plant, DEMO [2], [3]. Due to the high complexity of the system, extensive engineering efforts as well as physics studies are required for developing a consistent design that can guarantee high level of reliability and availability [4], mitigating the risks associated to moving targets and many interfaces.

Following what reported in [5], in this paper we present a preliminary design and integration study for port plugs dedicated to systems that require an external radial access to the plasma, i.e. Electron Cyclotron (EC) launchers developed by the PPPT Work Package Heating and Current Drive (WPHCD) [6] and devoted to provide localized heating and current drive [7], other heating and current drive systems or diagnostics, all interfacing with in-vessel systems like the breeder blanket. The work is based on physics assessments for the EU DEMO1 baseline 2015 [8], a tokamak with an Aspect Ratio (AR) of 3.1 and 18 Toroidal Field (TF) Coils (see figure 1 for the main parameters and a cut out of the machine).

Parameter		**Value**
Geometry	R_0	9.072 m
	a	2.927 m
	AR	3.1
	No. of TF Coils	18
Physics	I_p	19.6 MA
	B_T at R_0	5.667 T
	$\langle T_e \rangle$ (T_0)	13.07 (27.4) keV
	$\langle n_e \rangle$ (n_0)	7.983e+19 (1.01e+20) m^{-3}
Power flow	Thermal power	2389.1 MW
	Fusion power	2037 MW
	Net electrical power	500 MW

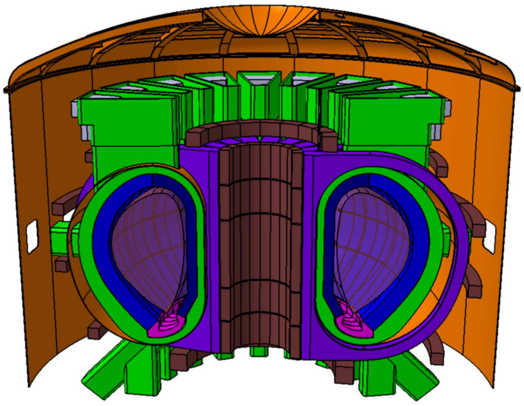

Fig. 1: Main parameters (left) & Tokamak complex cut out (right) for the EU DEMO1 baseline 2015 with AR = 3.1 and 18 TF Coils. The value for thermal power refers to a study performed for HCPB blanket.

2. System Interface and Requirements

As the DEMO project is in the pre-conceptual phase, its development is dominated by uncertainties on system requirements. These uncertainties are due to the huge number of outstanding technology and physics issues, e.g. safety, neutronics, performance and reliability, that need to be resolved consistently. As a consequence, interfaces between systems play a key role. In this frame, the requirement capture has been initiated aiming to define general guidelines for port plug design, but it is far from being completed.

In order to cope with a floating environment that provides a limited number of reference point for a design assessment, we applied the following simplified methodology: firstly, a reduced number of interfaces have been considered: the interface with the Tokamak System (in particular with the Breeding Blanket and the Vacuum Vessel systems) and the interface with the Maintenance system; secondly, we captured top level requirements essential to initiate the design, supported by assumptions that provide their justifications.

More specifically, we have preliminary identified three kind of requirements namely, safety requirements, structural/mechanical requirements and interface requirements. Being DEMO a nuclear facility, safety aspects are by far the most relevant. Therefore, safety requirements need to be carefully captured in order to meet stakeholder needs and safety regulations. In particular, port plugs shall provide the safety function of tritium and dust confinement barrier. It is important to stress that the validation of this requirement will be undertaken as the design will reach a sufficient level of maturity in order to allow safety assessments to be integrated into the design process for preparing the safety documentation for regulatory approval.

Structural/Mechanical requirements need to be captured to cope with loading conditions and to ensure system reliability. At the moment when this paper is being written the loads are still under definition. This fact imposes to make assumptions in order to preliminary define a design for port plugs. In this frame, we have generally assumed that the system shall be designed in a ways such that it shall retain its vacuum and structural integrity after off-normal events, e.g. during plasma disruptions. From the mechanical point of view, this means that the port plug system shall be capable of being supported from the port plug flange in a cantilever position to avoid electrical contact with neighbouring components.

The interface requirements are the most complex to assess as they *sit* between interfacing systems, affecting the design of both. As previously mentioned, for simplicity we have considered only a few interfaces of port plugs with breeding blanket, vacuum vessel and maintenance. Independently on which system will be hosted into port plugs, they are all expected to require radial access to the plasma. This fact has an impact on both the structural integrity of the Out-Board Multi-Module Segments (OB-MMSs), and in particular on the maintenance scheme, and on the Tritium Breeding Ratio (TBR) [9, 10] as the presence of opening will reduce the amount of breeding material included into the blanket system. The latter is particularly important since one of the essential features of DEMO is to allow Tritium self-sufficient breeding.

Therefore, for being compliant with this requirement the number and size of the openings need to be such that the total Tritium design targets which are depending on the blanket concepts is met.

This approach is more qualitative than quantitative, and it does not give the *exact* solution to the problem resolving all the issues related to moving targets, but aims to provide a first approximation that will be refine during the progress of the design development.

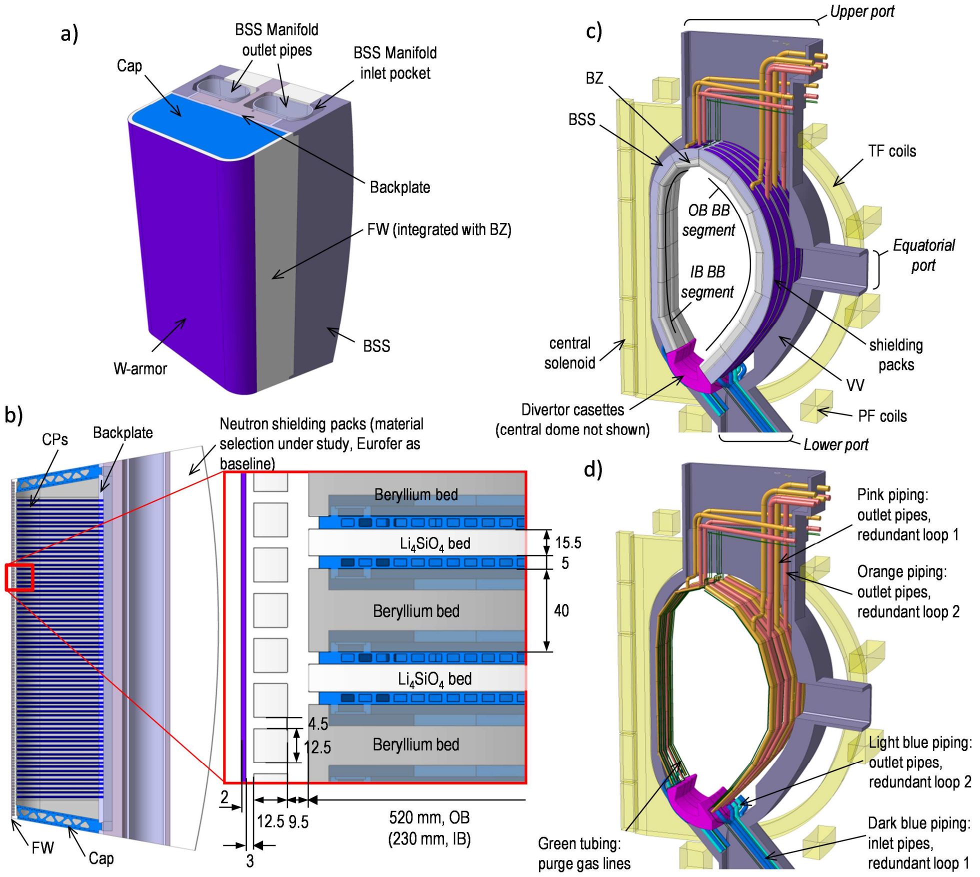

Fig. 2-a, -b, -c, -d: HCPB 2015 Breeding Blanket concept. -a: isometric view of the equatorial OB module OB4; -b: section cut of the OB4 and detail of the BZ; -c: isometric view of a 20° DEMO sector with the baseline HCPB-I; -d: detail of the coolant and purge gas pipework of the baseline HCPB-I.

3. Blanket Concepts Considered for the Initial Integration Study

In this first phase of the integration studies, we have considered two blanket concepts, namely the Helium-Cooled Pebble Bed (HCPB) and the Water Cooled Lithium Lead (WCLL). With this choice we assess integration aspects for systems based on different technologies, i.e. Helium or Water as coolants, and solid or liquid breeders.

The HCPB concept [11], shown in figures 2 –a, –b, –c, –d, is using lithium ceramic pebbles as breeder material (lithium orthosilicate) and beryllium as neutron multiplier. These functional materials are in form of pebble beds (polydisperse pebbles for the Li_4SiO_4 with pebble diameters ranging from 0.2 mm to 0.6 mm and monosize pebbles for the Be of Ø1 mm). Each module box is attached to the Back Supporting Structure (BSS), which serves as coolant and purge gas manifold, as well as structural support for the blanket modules.

The WCLL concept [12] is using water at Pressure Water Reactor conditions, i.e. 285-325 °C at 15.5 MPa, as coolant and Pb-Li as liquid breeder. As shown in, it is based on the single module segment architecture. Pb-Li and water manifolds systems (figure 3-a) are in charge to connect the Breeding Zone (BZ) cell with the main pipelines. The Pb-Li inlet manifold is “internal” to the module box, between the BSS and the BZ. Pb-Li pipelines are routed through the upper and lower ports (see figure 3-b). These are two of the four breeding blanket concepts under investigation in Europe within the PPPT Programme, the others being the Helium Cooled Lithium Lead (HCLL) with the Pb–Li eutectic alloy acting both as breeder and neutron multiplier and the Dual Cooled Lithium Lead (DCLL).

For an all-encompassing overview of the four blanket concept, see [13]. Since the project is in a pre-conceptual phase, the same methodology implemented in this work is applicable not only to the HCPB and WCLL, but also to the other two blanket concepts.

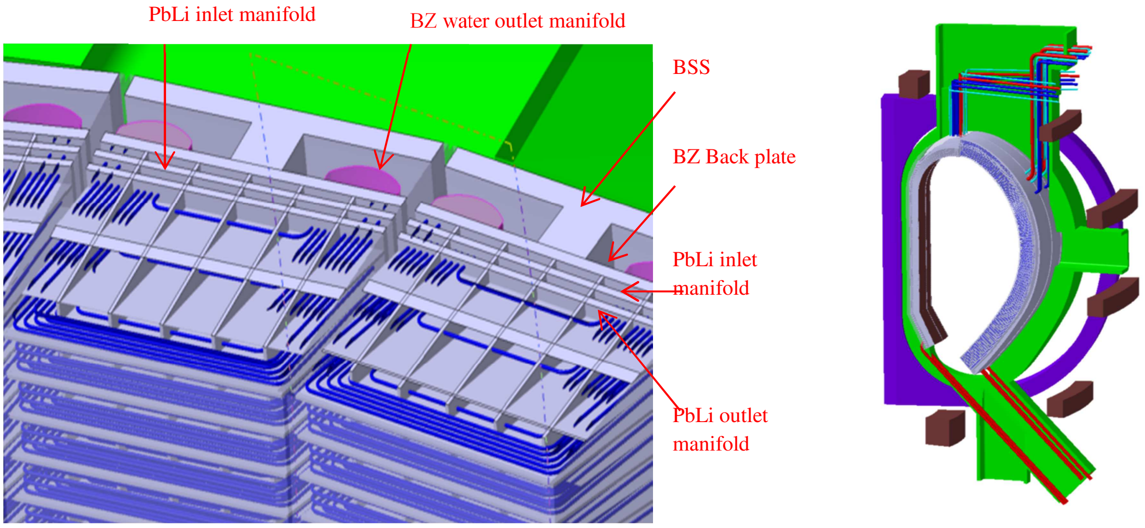

Fig. 3 –a (left): WCLL2016 blanket concept: manifolds and BSS, -b (right) detail of the integration. Pb-Li pipes in red. FW water coolant pipes in light blue. BZ water coolant pipes in dark blue.

As shown in figures 2 and 3, the blanket system is rather complex. It is therefore important to underline that any modification of such system will not be limited to the openings required by systems hosted in port plugs, but will likely affect the entire breeding module that contains such openings, with consequences on the amount of Tritium that can be breed and to the shielding capabilities of the breeding blanket system. More specifically since the impact on the overall TBR is expected to be acceptably small (see chapter 5), dummy blanket modules of non-breeding material can be implemented where openings are required, in place of the breeding modules.

4. Port Plug concepts

In the first part of this chapter we will provide some generalities on the port plug concepts we are currently considering. In the specific paragraphs (§4.1 and §4.2) we will provide details on the different port plug concepts as well as their integration schemes under assessment. The specific examples we mention here are dealing with the Electron Cyclotron Heating and Current Drive system (ECH&CD). However, we want to underline that the issues on the integration we are facing in this early phase of design development have a general validity and are not ascribable to a specific system to be hosted into the port plugs. In particular, the issue related to TBR, shielding capabilities and maintainability are relevant for diagnostic systems [14] and for other additional heating systems (e.g. the Neutral Beam [15]), although they can be resolved differently depending on the system one considers.

According to the design guidelines defined in chapter 2, from the mechanical point of view the port plug is cantilevered off the flange that interfaces the port and due to the high neutron flux, that requires the blanket to be designed for a lifetime corresponding to up to 50 dpa in EUROFER at the FW outboard mid-plane, labyrinths are also required. Their design shall allow sufficiently large gaps for accounting components thermal expansions, as well as movements of port plugs due to forces by eddy currents resulting from plasma off-normal behavior, like plasma disruptions.

Two port plug options are currently under investigation and applied to the equatorial port plugs (EPP) with different integration schemes with the OB-MMS. They are called Blanket Separated Design (BSD) and a Blanket Integrated Design (BID), and they are more detail discussed in §4.1 and §4.2, respectively. The former stops behind the BSS of the OB-MMS, while the latter follow a similar design implemented for ITER port plugs for diagnostics and ECH&CD systems (see [16] and [17], respectively), that is it physically penetrates the OB-MMS up to the plasma. For this reason a blanket shield module is integrated into the port plug structure. Although not discussed in this paper, a similar approach can be applied for the integration of vertical port plugs, where the integration is complicated by the presence of blanket pipes and remote handling services, as well as for upper port plug *à la ITER* [18] (a solution under consideration as a possible alternative to the integration from the vertical port).

In both BSD and BID concepts, the port plug system forming the structural component of the launcher assembly is composed by a main frame, two shields and a plug flange. A closure plate at the port plug back end will also be included in a second phase of the assessment.

4.1. Blanket Separated Design - BSD

As mentioned previously, in the BSD concept the port plug stops behind the BSS. The main rational behind this concept is to maintain the structural integrity of OB-MMSs so that they can be removed from the Vacuum Vessel according to the Vertical Maintenance Scheme (VMS), i.e. lifted from the vertical port. In addition, benefits in terms of stresses are expected because of the shielding effect of the blanket in front of the port plugs.

Cut outs in the OB-MMS shall be included to provide a radial access for the electron cyclotron waves. The gaps between the port and port plug have been assumed to be 60 mm (lateral and upper) and 100 mm (lower), in order to give room for remote handling equipment like the one described in section 7. In this configuration the port plug front end has a minimum gap of 20 mm with the central OB-MMS and all the waveguides are kept within the port plug structure.

For the BSD concept, two different configurations for the mm-wave system when using a Remote Steering Antenna (RSA) concept [19] are presently considered. The rationale behind assessing different geometrical RSAs distribution is mainly related to ECH&CD system performances (not within the scope of this paper), i.e. injection points and angles which are strongly dependent from the plasma scenario, and to preliminary consideration on the integration with HCPB and WCLL blanket concepts, i.e. how to provide openings into the blanket system while routing the necessary cooling an (in case of WCLL) breeding channels.

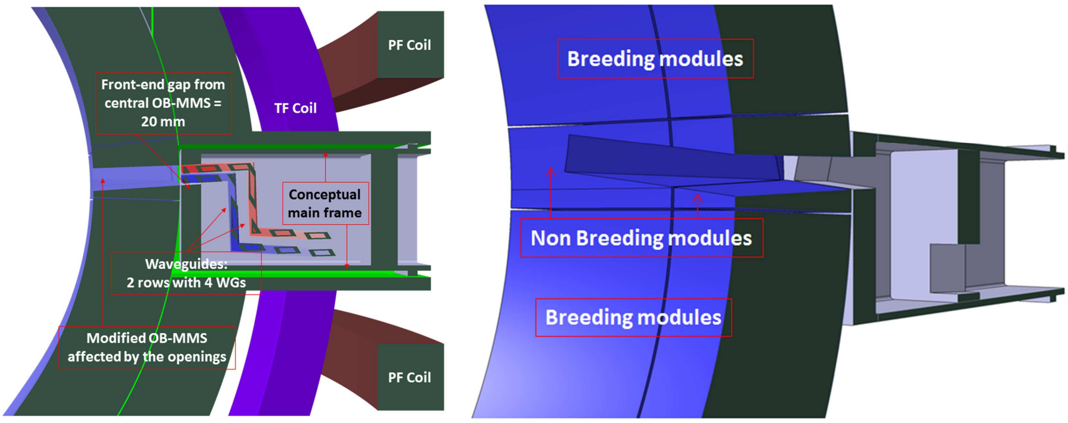

Fig. 4: -a (left) Cutout of a side view of the EPP (BSD-cfg1 concept); -b (right) Isometric/cut out view of the blankets affected by the openings.

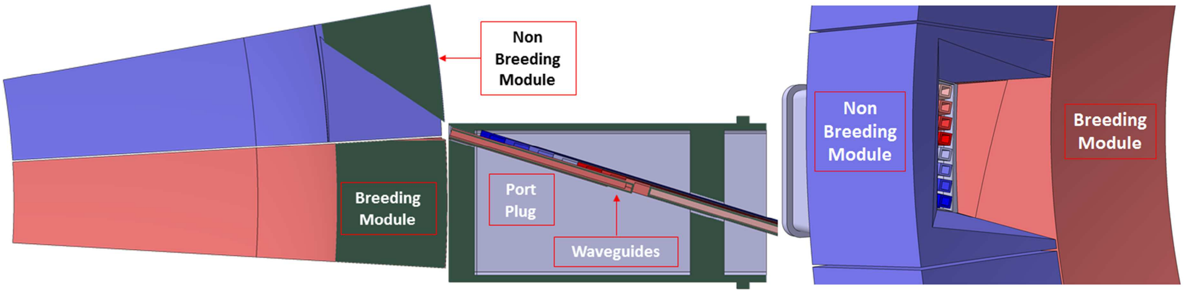

Fig. 5: -a (left) top view of the EPP (BSD-cfg2 concept) and –b (right) isometric view of the blanket affected by the openings.

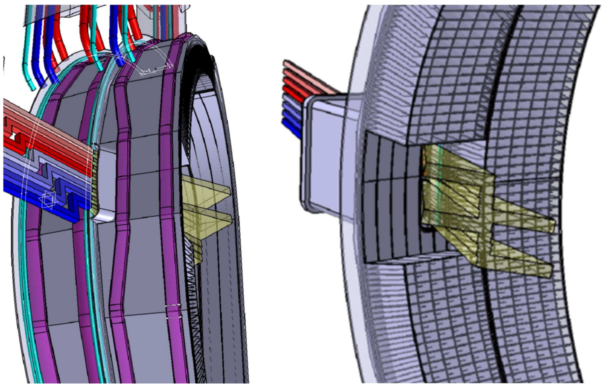

Fig. 6: Integration of EPP (BSD-cfg2 concept) in the WCLL blanket. The dummy blanket module is not shown

The first RSA configuration, hereafter called BSD-cfg1 (figure 4-a), foresees 2 *quasi*-horizontal rows with 4 RSAs each. Assuming that each RSA will drive 2 MW (we do not account for losses in this discussion), the total amount of power handled by each port plug would be up to 16 MW. This design will presently affect 2 OB-MMSs per sector where an EPP is included. Assuming (as indicated in [20]) 5 EPPs, this will lead to 10 OB-MMSs impacted. The two OB-MMSs per sector affected (central and right one in front of the port plug) are cut into three sections (see figure 4-b), two of which contains breeding modules and one is made by a non-breeding block containing the openings. It is worth to note that in order to mitigate the impact on the TBR, a different blanket segmentation is proposed. We wish to underline that this design will need to be further assessed in the upcoming years in order to check its compliancy with the TBR target values (which are strongly dependent on the machine aspect ratio and reference design, and the blanket concept considered). Future studies will aim to reduce the impact of this configuration to a single OB-MMS.
In figure 5 –a, and –b are reported a top view of the BSD-cfg2, hosting a vertical stacked array of 8 truncated squared waveguides and the relative blanket opening. Also with this configuration, the total amount of power handled in the port plug is up to 16 MW, while the OB-MMS affected is one (right one in front of the port plug). The cut into the BSS is expected not to compromise its structural integrity. This solution might be relevant for the remote maintenance scheme foreseen for the Breeding Blanket system, i.e. the VMS. The structural components (shields, main frame and flange), as well as gaps, are kept identical to the ones defined for BSD-cfg1.

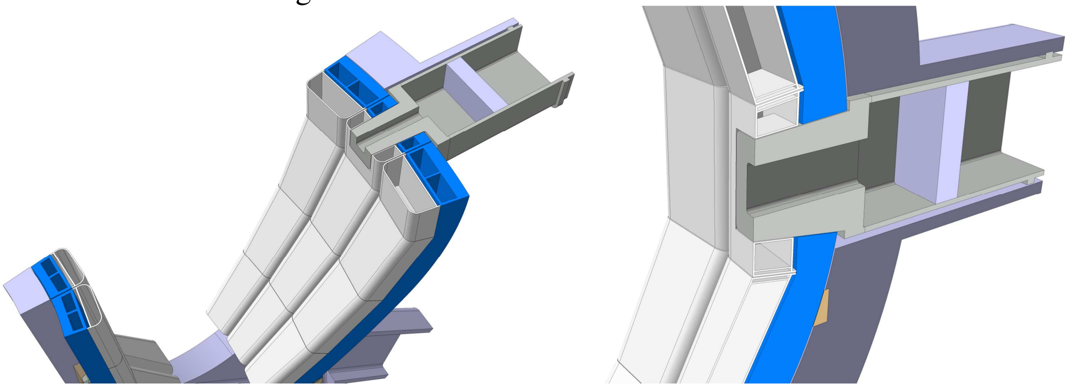

Fig. 7: Equatorial cutout (left) and poloidal cutout (right) of the BID concept, integrated into the HCPB blanket system

In figure 6 is shown the integration of the EPP in the BSD-cfg2 concept with the WCLL blanket. The position of the cooling manifold at the BSS (figure 6-a) has been adjusted near the module which is geometrically affected by the presence of the EPP. In this first phase of the integration, we have focused more on the mechanical aspects and on the impact to the overall TBR, using as driving force for the design the physics requirements. In a later phase, other neutronic aspects (e.g. nuclear heating in various neighbor components, neutron flux in various locations and its impact on the material selections) will need to be considered.
It is important to underline that RSA is one of the possible launcher configurations assessed in the WPHCD, the other based on truncated waveguides and in combination with multipurpose multi-frequency and step-tunable gyrotrons [21, 22].

4.2. Blanket Integrated Design - BID

In the BID concept (figure 7) the port plug extends through to the first wall, penetrating the central OB-MMS, following a similar approach than the one used for the ITER port plugs.

In this first phase of the study, the BID design cuts the OB-MMS into two independent parts containing breeding modules. In this configuration the two breeding sections of the Central OB-MMS might require that the inlet and outlet of the cooling channels are located either in the vertical (for the upper section of the breeding module) and in the lower port (for the lower section of the breeding module). Depending on the system which is hosted by the port plug, design with smaller impact on the OB-MMS will be study in the future. Similarly to the breeding modules, the FE will need to be cooled. This aspect has not been assessed yet however, as first concept one can consider the solution reported in [23] applied for the ITER ECH&CD upper port plug.

On the one hand, this design offers advantages on the shielding capabilities (labyrinths could be better designed) and in managing the issues due to the thermal expansion. On the other hand, assuming that the protruding element into the OB-MMS, the "nose" cuts the blanket segment into two parts, implies that the VMS might need to be applied to separate OB-MMS sections.

In addition, space constraints imposed by the "nose" size might limit the use of systems to specific tasks. Its shape and thickness depends on the functionalities of the system hosted in the port plugs (e.g. diagnostic systems can require different openings than ECH&CD) therefore it could be adapted to the hosted system. For the example reported in figure 10, the "nose" is acting as placeholder defining a possible volume required by the BID concept into the OB-MMS.

As it is difficult to draw conclusion on the port plug concepts design already in this phase, particularly because functions of systems which will be hosted by the port plugs as well as requirements are not yet fully consolidated, we explored different possible configurations for port plugs, highlighting costs and benefits, that will be used in due time to initiate a tradeoff aiming to select the port plug option(s) to be included into the DEMO design.

5. Preliminary assessment on impact to TBR for HCPB blanket concept

As we are still in an early phase of the integration studies, precise evaluation of the impact on TBR by port plugs devoted to host EC launchers is so far not possible.

However, the worst-case impact on TBR can be estimated by removing completely the volumetric contribution of the breeding modules geometrically affected by the presence of the port plugs.

More specifically, based on preliminary consideration about mechanical and thermo-hydraulic integration, the most conservative approach (worst-case) has been used for the TBR assessment for the HCPB blanket concept, i.e. excluding breeding material into the affected blanket modules and surrounding the EC penetration with shielding material, i.e. a steel/water mixture.

In figure 8 is shown a sketch of the modules attached to the BSS (in pink on the Inboard and Outboard). The modules geometrically affected are in the OB4 positions.

A preliminary estimation on TBR impact due to EC port plugs has been done for BSD-cfg2 (see figure 9-a) following the approach described above. It can be expected that the spectrum of neutrons is perturbed by the presence of the openings located in OB4 (see figure 9-b) and thus the neutronic heat loads on surrounding components need to be assessed carefully in future work.

As previously assumed, considering 5 equatorial port plugs to be hosting EC systems, the total TBR impact is estimated to be $\Delta TBR_{tot,EC}$ = -0.022. As said, this value is obtained considering a conservative approach and can be reduced as the design will improve.

This methodology, although being a first conservative estimation, confirms that the achieved values meet the present Heating and Current Drive (H&CD) design targets, i.e. total TBR for HCPB = 1.214, $TBR_{DEMO} > 1.1$, $\Delta TBR_{HCD} \leq 0.04$ [24].

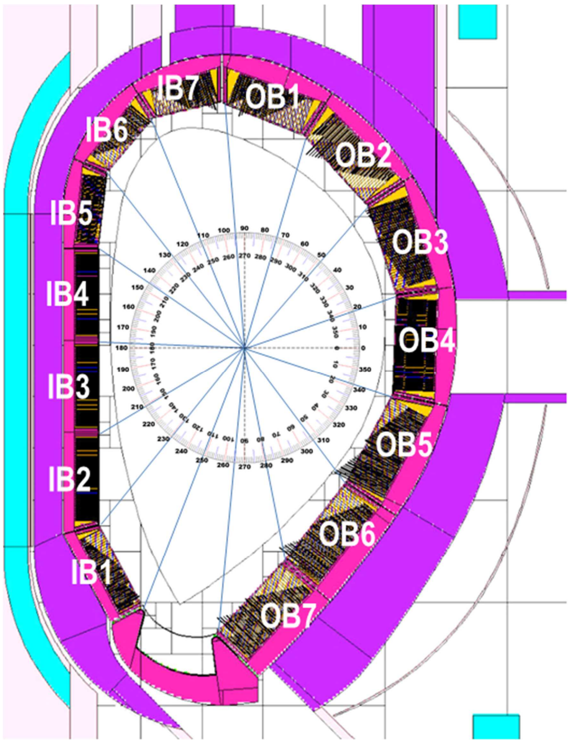

Fig. 8: Sketch of the breeding modules attached to the Inboard and Outboard MMS.

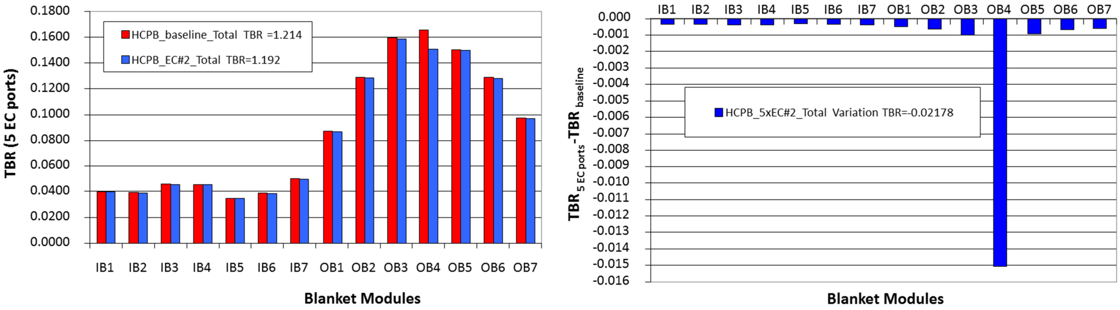

Fig. 9: -a (left) Impact on TBR due to openings in OB4 positions and –b (right) total TBR reduction for all 5 modules in front of the EPP.

6. Electromagnetic and Structural Analyses

A set of preliminary analyses of the BSD concept have been run to compare its two configurations. The analyses consist of electromagnetic (EM) simulations of a 70 ms fast disruption of 19.6 MA plasma current, for calculation of Lorentz's forces and moments, and subsequent structural analyses of the port plug.

The aim of the simulation is to assess the EM loads on a component that is located at the equatorial level and therefore a central disruption was simulated. If, for example, the component had been located at the upper level, we would have simulated an upward Vertical Displacement Events. As far as the disruption time is concerned, a rule of thumb is scaling a known disruption time using the tokamak's cross-sectional area. A typical category III linear fast disruption in ITER has a time constant of 36 ms. Using the results of the PROCESS code for this configuration of DEMO and the formulas given in [25], we calculated the equivalent disruption time as follows:

$$T_{DEMO} = T_{ITER} * A_{DEMO} / A_{ITER}$$

Where:

- T_{DEMO}: equivalent disruption time for DEMO
- T_{ITER}=36 ms: duration of a category III linear fast disruption in ITER
- A_{DEMO} =~45 m^2: DEMO's cross sectional area
- A_{ITER} =~23 m^2: ITER's cross sectional area

The calculation returns T_{DEMO}=68.7 ms, which we rounded to 70 ms.

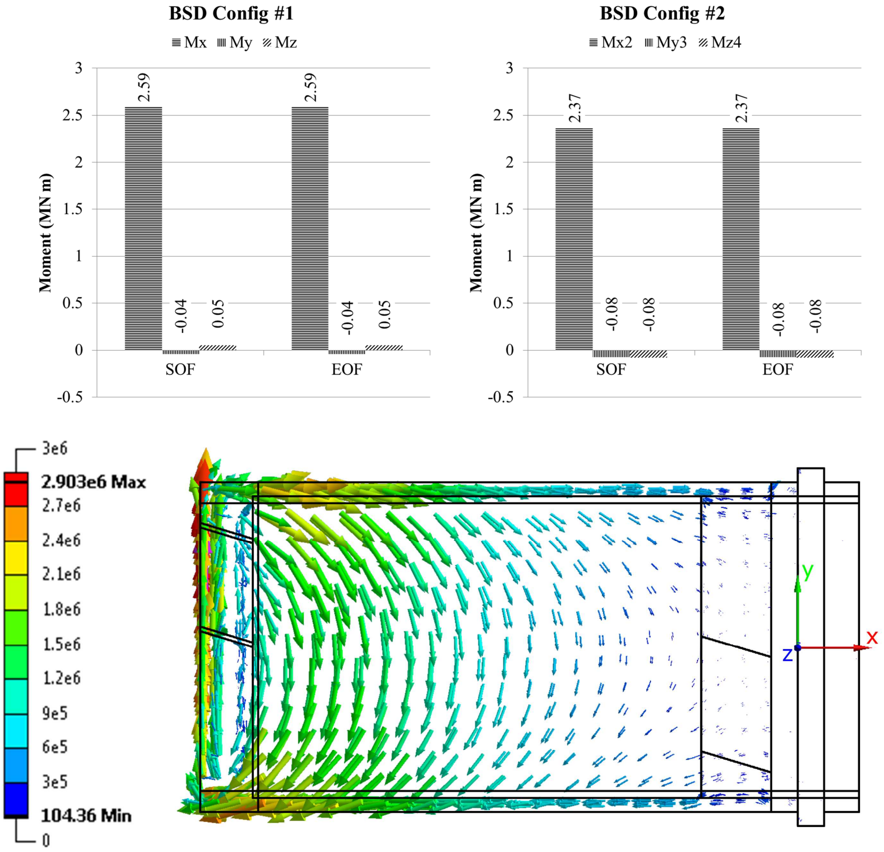

Fig. 10: EM loads (moments) acting on the two configurations of the EPP (top) and eddy currents (A/m^2) on configuration 1 (bottom) during a 70 ms disruption of a 19.6 MA plasma current.

The analysis has been performed including shielding blocks into the port plug structure, being these the most massive components. Other components have been excluded as their contribution to forces and momenta are comparable with the error margins of the analysis. Obviously, once the design will reach a higher level of maturity these contributions will need to be taken into account.

For sake of simplicity, the analyses have been run in the same fashion as reported in [26] that is assuming no ferromagnetic properties and modelling the plasma using an elliptic cross-section and quadratic formulation for the current density distribution. As far as the Central Solenoid, the Poloidal Field and Toroidal Field coils are concerned, two possible scenarios provided in plasma equilibrium description document, i.e. SOF (start of flat top) and EOF (end of flat top), have been implemented and the results are here compared.

The results of the EM analyses have shown no significant difference between the two equilibrium scenarios, as shown in figure 10 where the moments acting on both configurations of the port plug are compared. The loads are calculated with respect to the coordinate system also shown in figure 10: the x-z plane is coincident to the sector's vertical mid-plane with the z-axis pointing up in vertical direction and the x-axis pointing outwards.
The current density (A/m^2) induced in the plug forms loops that lay mainly on the horizontal plane and therefore the dominant load is a radial moment (torque aligned to the plug's axis).
The different sizes and orientations of the front openings in the port plug have shown to have no influence on the overall behavior of the structure, the magnitude of the stresses being in any case less than 20 MPa (figure 11). This is the obvious advantage of having the entire plug placed behind the blanket segments that, in turn, screen it from the effects of the electromagnetic transients.

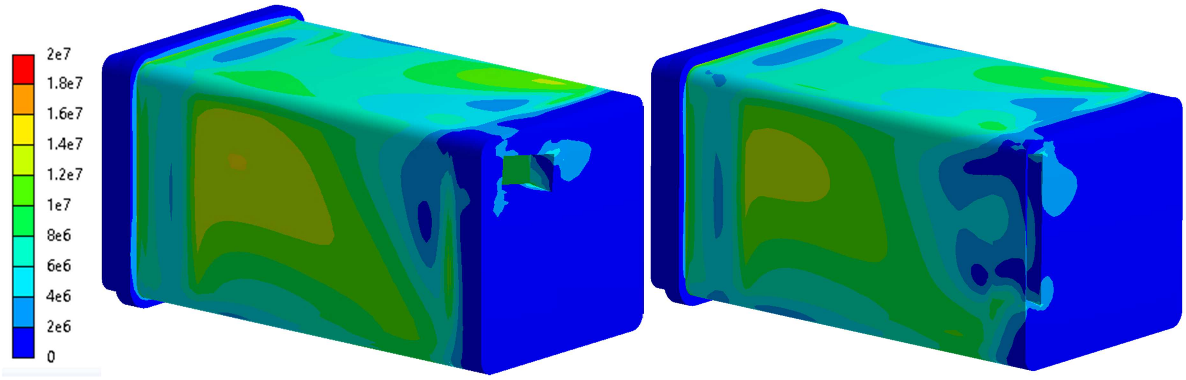

Fig. 11: Von Mises Stress distribution (MPa) in the configuration 1 (left) and 2 (right) of the BSD EPP during a 70 ms disruption of a 19.6 MA plasma current.

7. Port Plug installation/removal

One of the key issues in designing a prototype of a fusion power plant like DEMO is represented by maintainability of in-vessel systems. This is particularly valid in areas like the once in the vicinity of the ports, where due to irradiation man-made operations will be likely strictly forbidden. Therefore, the integration of port plugs with the blanket shall take into account maintainability considerations from the very beginning of the design assessment for both the port plug and the blanket systems [27], since large openings into the blanket may drive towards modifications of the VMS [28].
Here we present a concept design of two removable rails given with ceramic wheels aiming to support the installation and removal of EPPs (i.e. simpler withdrawal by dragging). The use of ceramic is justified by the fact that this material have some attractive properties compared to metals and polymers, e.g. low electrical and thermal conductivity, high strength and wear resistance, which make them used as roller bearings in nuclear fusion technology applications, in which no oil/grease lubricants are allowed in neutron environment.
As shown in figure 12 the rails foresee a modular design, composed by four modules, each one having seven ceramic wheels in a 3 to 4 wheel distribution. With this configuration there are three wheels on the top side which realize the connection to the plug and four on the bottom side which are in contact with the port. The modules are connected by steel plates that provide supports for lifting systems.
The rails are considered as part of a possible Cask Transfer System (CTS) responsible to transport each EPP from the Active Maintenance facility (AMF) to the allocated port area. In this frame, the installation procedure consists in the following (very general) steps:

- The cask approaches the port area and docks and the rails are extended from the CTS inside the port (figure 13 - left)
- The EPP is moved onto the rails and slowly inserted into the port (figure 13 - center)
- The EPP is attached to the port flange and the interfaces (feedthroughs) at the CP are restored (not shown in figures)
- The rails are retracted into the CTS (they are not permanently installed in the port), which is then move to the AMF (figure 13 - right)

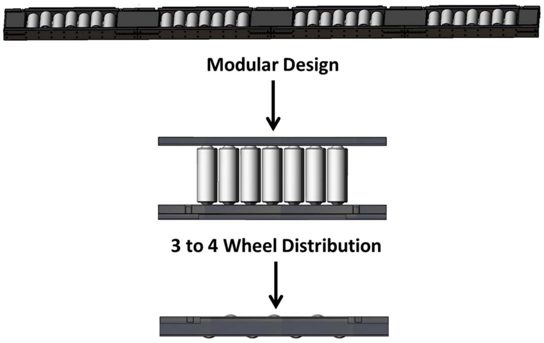

Figure 12: Concept for a possible rail system for the insertion and removal of EPPs

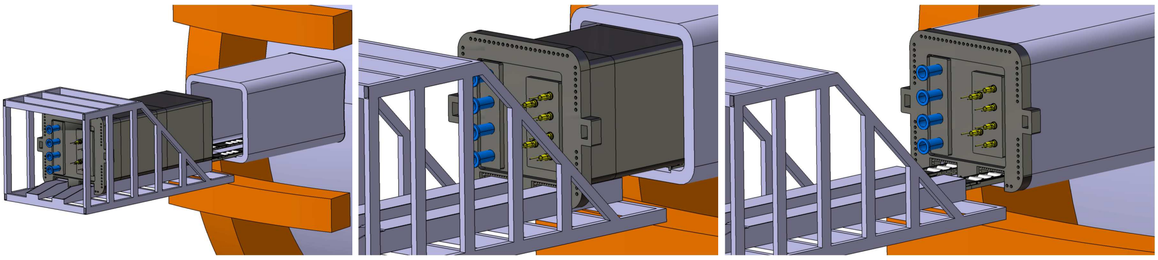

Figure 13: sequence of operation for installation/removal of EPPs

In this scheme, the channels where the rails can slide into will need to be sealed with extra plates and possibly also filled with proper shielding. These features have not been considered yet into the design but will need to be addressed as the concept design will improve.

It is also worth to mention that at the present stage the interfaces have not been assessed yet. The reason is that the overall design of the plant and its subsystems is indeed in pre-conceptual phase. Although it well acknowledged that the design at the Closure Plate will have strong impact on the port plug design, we decided to address the issue of installation/removal of port plug in a simplified way.

In addition, it is also important to recall that characteristics like brittleness and side effects like dust production will need to be carefully addressed before implementing the design beyond this conceptual level.

8. Summary

The development of a complex project like DEMO requires careful design and integration studies, in order to evaluate the interdependencies and interfaces among the different parts of the DEMO system.

The study we have presented is the first step in approaching the definition of integrated solution for EC port plugs used for heating and current drive systems, particularly for the required penetrations on the breeding blanket system.

The methodology we have shown here, that consists in assessing different possible configurations satisfying the set of functions that the system *port plug* shall achieve, is based on a version of DEMO which is presently available during the pre-conceptual phase. This step is preparatory in order to run in a later phase of the assessment system analysis and synthesis and for performing tradeoffs on the different design options leading to a down-selection of concept(s) by the end of the conceptual phase.

The two port plug architectures presented in this paper, BSD and BID, both promising with respect to the impact on TBR will be further studied and developed, refining their design according to the progress of the plant design. More work for example should include issue on neutronics, safety, remote handling, etc… In addition to the tradeoffs on the structural components, also assessments on different solutions and integration schemes for systems to be hosted into port plugs such as different concepts for the EC launchers (e.g. including systems compatible with step-tunable gyrotrons), other additional heating systems and diagnostics will need to be run for granting design consistency.

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