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Tritium and heat management in ITER Test Blanket Systems port cell for maintenance operations

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HIGHLIGHTS

- The ITER TBM Program is one of the ITER missions.
- We model a TBM port cell with CFD to optimize the design choices.
- The heat and tritium releases management in TBM port cells has been optimized.
- It is possible to reduce the T-concentration below one DAC in TBM port cells.
- The TBM port cells can have human access within 12 h after shutdown.

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ABSTRACT

Three ITER equatorial port cells are dedicated to the assessment of six different designs of breeding blankets, known as Test Blanket Modules (TBMs). Several high temperature components and pipework will be present in each TBM port cell and will release a significant quantity of heat that has to be extracted in order to avoid the ambient air and concrete wall temperatures to exceed allowable limits. Moreover, from these components and pipes, a fraction of the contained tritium permeates and/or leaks into the port cell. This paper describes the optimization of the heat extraction management during operation, and the tritium concentration control required for entry into the port cell to proceed with the required maintenance operations after the plasma shutdown.

1. Introduction

Three ITER equatorial port cells are dedicated to test six different breeding blankets mock-ups, known as Test Blanket Modules (TBMs), two in each port cell [1]. Each TBM is part of a Test Blanket System (TBS) that includes also several ancillary systems located in the port cell and in other rooms of the Tokamak Complex. Because of the research program requirements, each TBM will be replaced several times during the ITER lifetime. The replacement will be done using a remote handling transfer cask during Long Term Maintenance (LTM) shutdowns, after the removal of the TBS components present in the port cell. Therefore, during each LTM shutdown, in the TBM port cells several operations have to be performed which require human access, e.g. pipes cutting and re-welding [2].

Because of the high temperature of the TBS coolants during operation, significant heat release occurs in the TBM port cells. Moreover, airborne tritium-concentration will also be present in the port cell because of permeation and leakage from the tritiated fluids. The requirements to be fulfilled in each equatorial port cell are the following:

(1) The air extraction temperature in the port cells should be below 35 °C and the concrete wall temperature below 50 °C at any time and, in particular, during plasma operations;
(2) The Detritiation System (DS) in the port cell during plasma operations should be able to reduce the Tritium concentration below the admissible limit for human access (regulatory maximum allowable value = 1 DAC, Derived Air Concentration;

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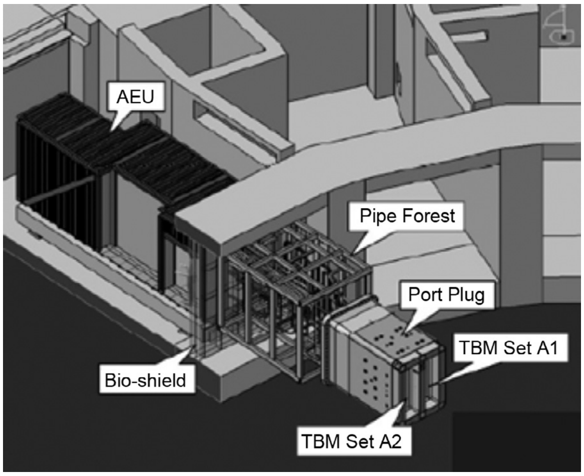

Fig. 1. View of the AEU, bio-shield plug, PF and of the TBM Port Plug.

for tritium 1 DAC corresponds to 3.4×10^5 Bq/m^3 of air). This admissible limit for human access has to be reached in a sufficiently short time after plasma shutdown (target = 12 h).

There are two systems that strongly impact the temperature of the ambient air and the level of tritium concentration: (i) the Local Air Cooler (LAC) that extracts the heat released by the systems operating inside the port cell; (ii) the Detritiation System (DS) that, in order to maintain a pressure difference between port cell and the adjacent gallery, allows clean air to be drawn in from the gallery, then extracts tritium-contaminated air back out of the port cell.

This paper describes the assessment performed for a typical TBM port cell by generating a Computational Fluid Dynamics (CFD) model of the port cell in order to understand and optimize the ventilation flow, tritium extraction rate and some design choices including LAC location and bio-shield plug design.

2. Main assumptions for the study

The analyses have been performed for the equatorial port #16 because it features the highest level of Tritium permeation due to the presence of the low-velocity LiPb pipes. In this way, the conclusions conservatively apply to all the 3 TBM port cells. In particular, the 2 TBSs present in port #16 are the Helium-cooled Lithium-Lead (LiPb) TBS and the Helium-cooled Pebble-Bed TBS [1]. Both the TBSs He-coolant loops operate at 8 MPa and at inlet/outlet temperatures of 300/500 °C.

2.1. Geometrical boundary conditions of the model

Each port cell is divided in two areas separated by the bio-shield plug: the Port Interspace (PI) area and the Ancillary Equipment Unit (AEU) region. Installed within the PI area is the Pipe Forest (PF), which is formed by the TBS pipes, the supporting structure and the removable part of the bio-shield plug. The volume of a port cell is approximately 200 m^3.

The typical layout of a TBM port cell is shown in Fig. 1. The port cell door is assumed fully airtight.

In the reference design, the LAC is located in the AEU region. DS is present in each port cell via an inlet and outlet pipe. During plasma operations the DS can ensure a flow-rate between 10 and 80 m^3/h, with the objective of keeping a pressure depression (100 Pa) between the port cell and the adjacent gallery; after plasma shutdown, an enhanced detritiation with a circulation mode can be activated with an additional flow-rate up to 100 m^3/h.

The bio-shield is a panel made of concrete and lead, allowing air exchange between the PI area and AEU region through engineered holes at the top and bottom of the bioshield. The bio-shield is also crossed by the TBS pipes and has a 5-mm gap around the door and around the steel manifold which holds all the TBS pipes.

2.2. Input data and specifications

The heat sources in the port cell are the TBSs equipment, the back of TBM Port Plug and the Vacuum Vessel port extension, all operating at relatively high temperatures and covered with thermal insulation material.

All hot surfaces have been assumed to be 100% covered in thermal insulation with different thicknesses (between 75 mm and 125 mm) depending on the equipment. The total external surface area of all insulated parts is calculated to be 155 m^2. The insulator thermal conductivity (k) is given by the following equation: $k = 3.035 \times 10^{-2} - 2.172 \times 10^{-5} T + 2.955 \times 10^{-8} T^2$ (W/m K), with the temperature T given in Kelvin [3].

The best estimate of tritium release in a representative port cell is about 0.21 mg/day in the PI area and 0.07 mg/day in the AEU region during back-to-back pulses operation, 24 h per day. Tritium absorption and desorption from the insulator and from the concrete walls are not considered [4].

The LAC is cooled by water with inlet/outlet temperatures of 7/15 °C and the standard heat extraction capability for equatorial port cell is about 43 kW, with a total air flow-rate of ~7000 m^3/h.

3. Overall CFD model description

The design parameters that can be optimized are the following: (i) the DS flow rates; (ii) the location of DS extraction points; (iii) the size and location of openings in the bio-shield plug; (iv) the flow-rate distribution from the LAC; (v) the potential addition of enclosing walls locally surrounding the heat and Tritium sources.

The study has been performed by generating a Computational Fluid Dynamics (CFD) model of the port cell in order to optimize the ventilation flow and tritium extraction.

3.1. Geometrical model and mesh

The complete initial CFD model used for this study is given in Fig. 2 showing the details of the geometry within the AEU region, the bio-shield plug and of the PI area and the additional components modeled.

The AEU region model contains the AEU structure with inside a representative number of TBS components, a LAC, various cable trays and pipework, and the DS inlet pipe providing ventilation into the room. The AEU equipment has been generated based on provisional schematics (e.g. LiPb tank, pipework, valves). However, they give representative blockage and heat release characteristics.

The bio-shield model is a shield panel made of concrete and lead and it includes the pipe penetrations and the concrete operator door. Additional holes between the AEU and PI areas are present to allow air circulation.

The PI area model contains the PF. The PI boundary is made by the bio-shield, the cryostat bellows, the vacuum vessel connecting duct and the back part of TBM Port Plug covered with 100 mm insulation. An example of the PF meshes is given in Fig. 3.

The overall CFD mesh contains 30.7 million cells, with cell sizes between 0.75 cm and 20 cm. The steady-state simulations were run on a 48-node cluster, taking between 2 and 3 days to converge.