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Neutronic design optimization of ITER TBM port#2 bio-shield plug

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ABSTRACT

Indian Lead Lithium Ceramic Breeder (LLCB) Test Blanket Module (TBM) will be tested in one-half of the equatorial port #02 of ITER. The TBM systems demand the opening through bulk bio-shield boundary for installation & removal of TBMs from the port. In order to serve the requirement of TBM system, a Bio-Shield Plug (BSP) is placed at biological shielding location of the equatorial port. The neutronic design of BSP is important because it serves the purpose of biological shield boundary of ITER port and has to limit the ITER occupational radiation exposure behind the bio-shield up to 10 μSv/hr 1 day after shutdown. The BSP has to be removed and reinstalled during the removal and installation of TBM Sets from the port. The design of BSP should be compatible with TBM set installation & removal plans. It should also allow the TBMs coolant and instruments pipes to pass through. The shielding capability of BSP has to be adequate enough to limit the exposure. The engineering constraints like the feasibility of BSP removal/reinstallation & passage for pipes affect the shielding capability of BSP. The scope of this paper is to investigate the limitation of existing BSP and assess the better options for shielding capability improvement. The shielding capability of advanced shielding materials like B4C and Ferro-boron for BSP application is also assessed. The neutronic analyses have been performed using the MCNP radiation transport code and FENDL-2.1 nuclear cross section data library. The Activation code FISPACT-2007 has been employed to estimate the contact dose rates. The outcome suggests that B4C and Ferro-boron would be better candidate materials for the bio-shield plug of TBM port.

1. Introduction

ITER is providing the unique opportunity to test breeding blanket concepts. ITER has dedicated three equatorial ports for Test Blanket Modules (TBM) [1]. India is also placing its LLCB TBM, in one-half of equatorial port#2 [2–4]. TBM has many ancillary systems in order to provide the required coolants, breeders, and tritium extraction gas.TBM is also associated with many instruments for process parameter measurements and nuclear safety. Ancillary systems of TBM have to be placed in the adjacent port cell region and other locations of the tokamak building of ITER as per specified zones and all supplies for TBM have to be given through pipes [5]. A schematic diagram of LLCB TBS with the location of ancillary systems has been given in Fig. 1 [6,7]. The TBM systems demand the opening through bulk bio-shield boundary for installation & removal of TBMs from the port [8,9]. In order to serve the requirement of TBM system, a Bio-Shield Plug (BSP) is placed at biological shielding location of the equatorial port which also serves the purpose of direct radiation shielding for port cell region [8–12]. As per the requirement and the functionality of BSP, it has to be compatible with removal and installation of TBMs and also accommodate the penetration of the TBM pipes. The constraints imposed on BSP design reduce the shielding capability of BSP and make the engineering design of it challenging [12–15].

The scope of this work is to bring out the limitation of reference BSP design (BSP made of normal concrete) and assess the other candidate options for design which can enhance the shielding capability. Some advanced shielding materials like B4C [16] and Ferro-boron [17] have been also considered here for BSP. The comparison of the shielding capability of all candidate materials considering BSP radiation environment is also done. Few design variants with enhanced shielding capability are also proposed through this paper. The neutronic assessments are done using MCNP5 [18] and nuclear cross section library FENDL 2.1 [19]. The results were obtained by tracking 1×10^9 particle histories and statistical error is less than 3% in all cases. Data of contact dose rates were generated using FISPACT-2007 [20].

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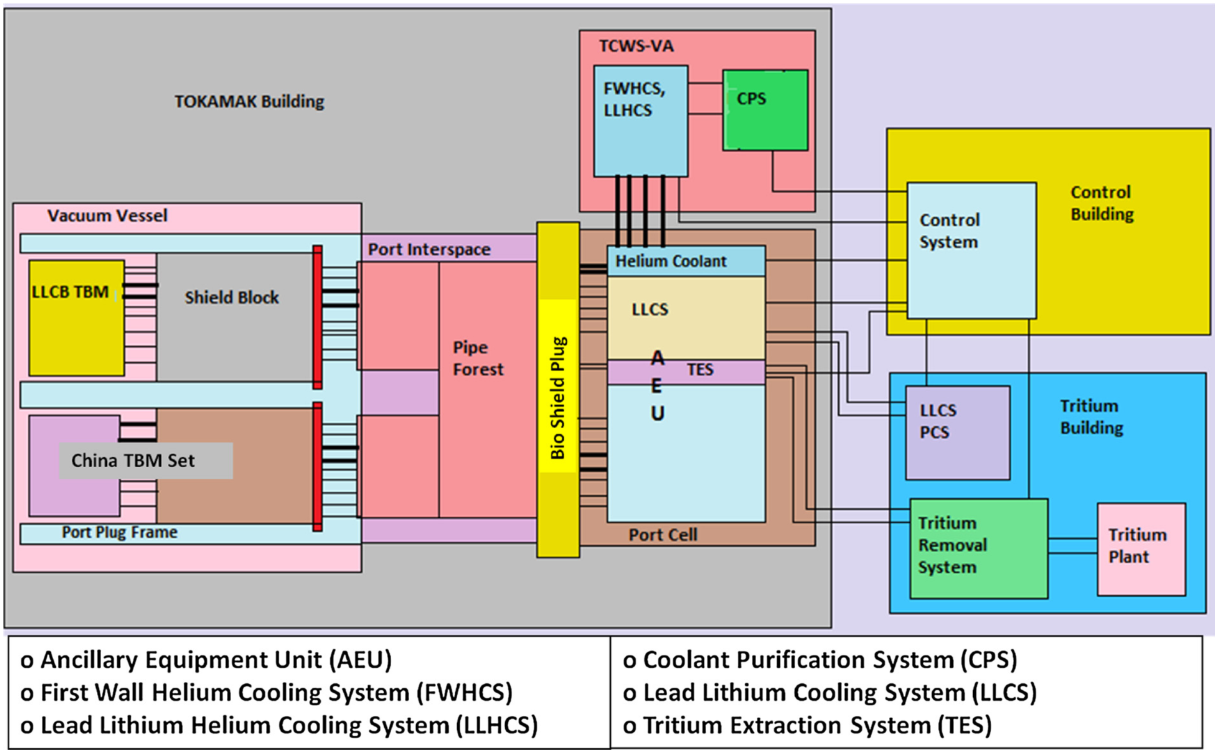

Fig. 1. LLCB TBS Schematic view with location details.

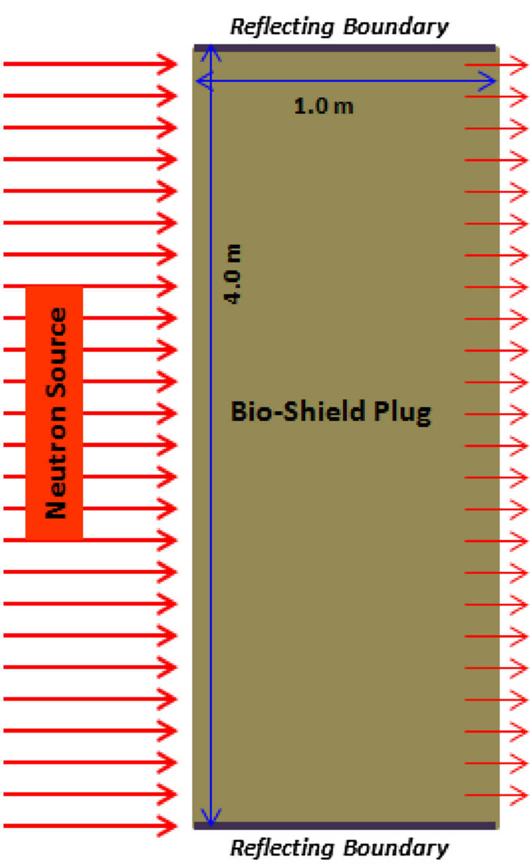

Fig. 2. Schematic model of neutron attenuation study in candidate materials of BSP.

Table 1
Candidate Materials for BSP design optimization.

Sr. No.	Material	Density (gm/cc)
1	SS 316LN [21]	7.8
2	Concrete [14]	2.2
3	B4C [16]	2.51
4	Ferro-boron (Powder) [17]	4.0 (60% of theoretical density)
5	Water	1.0

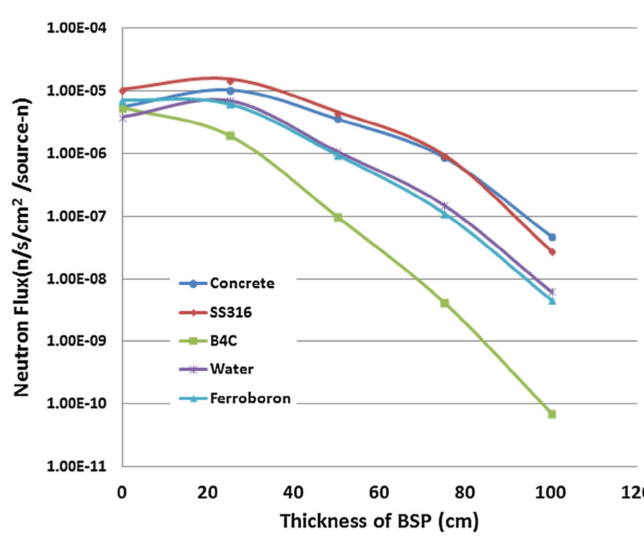

Fig. 3. 14 MeV neutron attenuation profile in candidate materials of BSP.

2. Shielding capability of candidate BSP materials

The shielding capability of candidate bio-shield materials has been assessed. The assessment has been made using a block of 4.0 m × 4.0 m × 1.0 m. Schematic of calculation model is shown in Fig. 2. The