Article ID: 1007-4627(2006)02-0119-04

Calculations of 3-D Neutronics for China HCSB TBM Module with 3×3 Sub-modules

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Abstract: By using three-dimension MCNP code and FENDL2.0 data library, the neutronics calculation for a HCSB (Helium Cooling Solid Breeder) TBM (Test Blanket Module) with 3×3 sub-modules has been performed. Under neutron wall loading of 0.78 MW/m^2 and duty factor of 22%, it is given for the tritium breeding ratio (TBR) of 0.907, total tritium generation rate of 0.0175 g/d, peak power density of 9.27 MW/m^3 and total power deposit of 0.422 MW/m^3.

Key words: fusion; neutronics; TBM; HCSB
CLC Number: TL631.2+4 **Document code**: A

1 Introduction

ITER jointly developed by 6 parties-China, US, Japan, South Korea, Russian and EU is coming to be built in France cause the more and more concern. The China HCSB TBM is designed as a test module on ITER for obtaining key data and technical parameters supporting the development of the future China DEMO fusion reactor. Neutronics design for China HCSB TBM is one of the most important designs in TBM design activities due to offering the input parameters for analysis and calculation of other systems such as thermal-hydraulics, activation, radioactive safety of environment, shielding, ventilation and so on[1].

China HCSB TBM module[2,3] is designed as a module with 3×3 sub-modules, which is more fixed and safe than that in single module but more structural complex. FW(first wall) is independently cooled. Considering that the neutron transport calculation is much important, it is required by ITER council that the results of neutron transport calculation must be given by 3-D MCNP code[4]. For this modularized TBM, a 3-D neutronics calculation by MCNP code should really been considered. FENDL2.0 is selected as calculation library for nuclear data library. Present design for China HCSB module is on the phase of conceptual design, but it will keep deeply and long influence on development of China HCSB TBM module in future.

In this paper, 3-D neutronics calculation and analysis have performed. Results of the neutron fluxes, peak power density, tritium breeding ratio and production rate are given.

2 Characteristics of 3-D Structure

The considering structural features of design for HCSB TBM module are modularized into 9 sub-modules with the same design of structures, geometries and material components. Each module has own relatively independent cooling system. In general, by means of magnitudes, the separated and independent helium gas can be easily allocated out or collected in through a lot of helium cooling channels and tritium gas channels etc. for all of 9 sub-modules. FW consisting of FW1,

Received date: 20 Nov. 2005; **Revised date**: 9 Jan. 2006
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FW2 and FW3 has its own independent cooling system beneficial to avoiding too strong neutron irradiation. The main advantages of modularization design are more fixed and reliable.

Fig. 1 (a) shows 3-D isometric structure of CH HCSB module. Fig. 1 (b) shows plain structure. HCSB TBM box is mounted inside a 20 cm of frame for a 1/4 of ITER test port with 66.4 cm in toroidal width, and 44.5 cm in poloidal height, and 67 cm in radial depth. There are two 2 cm of gaps on side faces. A frame thickness around TBM module is 20 cm. The size of a breeding sub-module is 19 cm (toroidal) × 26 cm (poloidal) × 42 cm (radial). 9 sub-modules have the same structures.

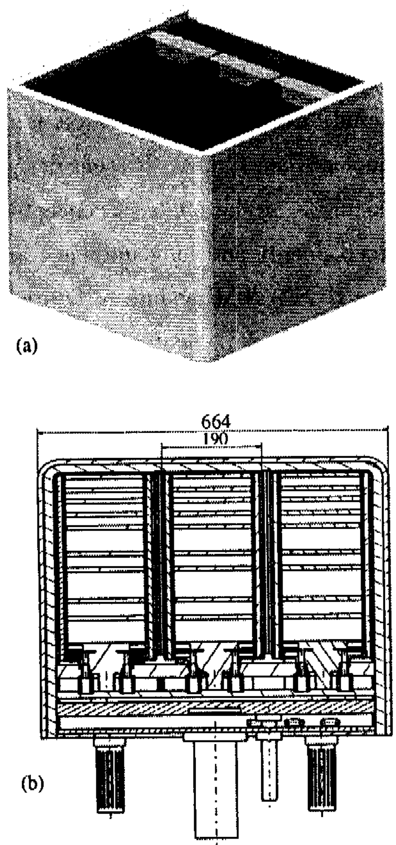

Fig. 1 Structure of the CH HCSB TBM unit module.

3 Computational Code and Data Library

MCNP/4C code is used as a main tool for the neutronics transport calculation. ONEDANT code is used as the tool of optimization and check calculation. The results of MCNP are used to offer other system designs as input parameters. FDKR and ADVBISON code are used in burn-up and activation analysis and calculation. The nuclear data library, FENDL1.0—2.0 (ENDF/B-VI, JENDL3.2, JEFF, CENDLE) is adopted in the calculation.

4 Material and Geometry

Fig. 2 shows compositions and geometries of material zones for the calculation model of HCSB TBM. Li_4SiO_4 pebble bed is used as tritium breeder zone.

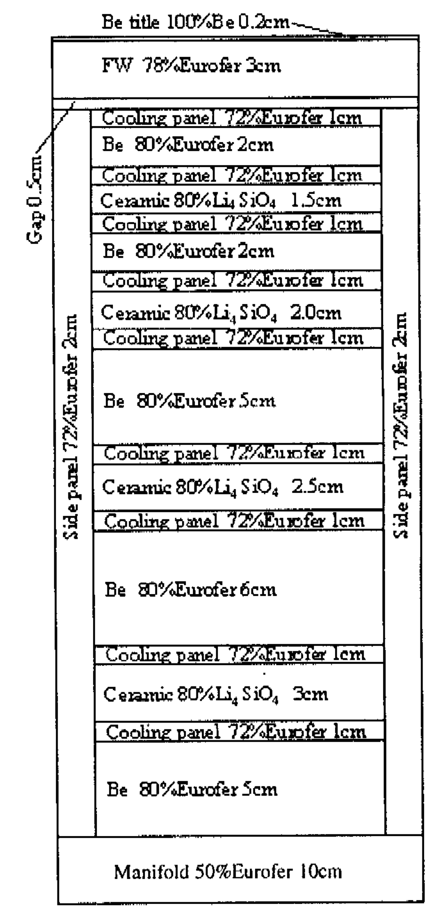

Fig. 2 Compositions and geometries of materials zones for the calculation model of HCSB TBM.

The packing factor of Li_4SiO_4 pebble bed is 0.62. Be pebble bed is used as neutron multiplication zone. The packing factor for Be pebble bed is selected as 0.8. The EUFER is selected as structural materials.

5 MCNP Model Description

Fig. 3 shows the simplifying process for HCSB TBM model from bird view. The up part is a simplified model through symmetry. The final results for general power and tritium generation are given by multiplying the MCNP calculation results by 4.

Defining boundary condition is a key issue. 33.2 cm × 44.5 cm × 1 cm of the rectangle on front of left plasma facing side of the TBM module is defined as the space region for producing neutrons. Except the face jointing TBM module, the other 5 faces of this source region are all boundaries with complete reflection. For the TBM module, 4 side faces of the module are enclosed by a frame 20 cm of thickness with EUROFER.

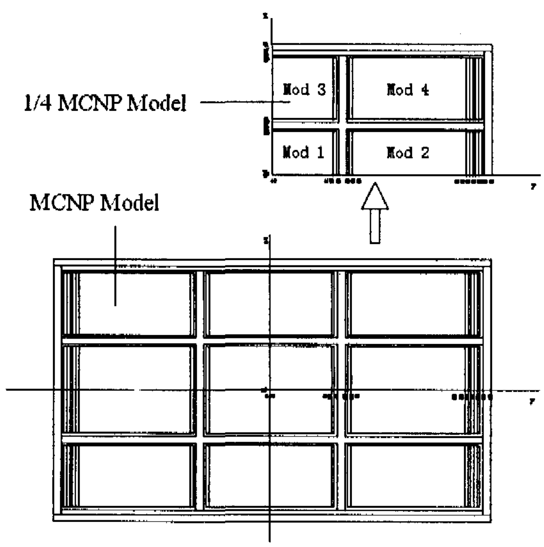

Fig. 3 The simplifying process for HCSB TBM module.

6 3-D Results

Factually, for MCNP calculation in this paper, it is assumed that the incident neutron source is limited only in area of the plasma facing surface of HCSM TBM module and 4 side surfaces of it are enclosed by a frame functioned as the reflections of side neutrons. It is a vacuum beyond the frame.

In calculation of neutronics transport, neutron load of FW is 0.78 MW/m^2, heat flux of FW is 0.5 MW/m^2 and duty factor is 22%. Table 1 gives tritium breeding ratio (TBR) for all the tritium breeder zones. Table 2 gives tritium generating rate (g/d) at 22% duty factor for all the tritium breeder zones. Table 3 gives results of the general neutron flux and production of power.

Table 1 Tritium breeding ratio (TBR) for different tritium breeding zones

	Mod 1	Mod 2	Mod 3	Mod 4
Li_4SiO_4 1($\times 10^{-2}$)	1.016 5	1.758 8	1.851 0	3.325 3
Li_4SiO_4 2($\times 10^{-2}$)	2.388 0	4.267 8	4.229 8	7.645 1
Li_4SiO_4 3($\times 10^{-2}$)	4.911 1	7.045 5	7.466 0	12.248
Li_4SiO_4 4($\times 10^{-2}$)	4.883 9	7.563 3	7.525 3	12.560
Total submodule($\times 10^{-1}$)	1.319 9	2.063 6	2.107 2	3.577 8
Total TBR($\times 10^{-1}$)	9.07			

Table 2 Tritium generating rate (g/d) for different tritium breeding zones

	Mod 1	Mod 2	Mod 3	Mod 4
Li_4SiO_4 1($\times 10^{-4}$)	2.23	3.86	4.06	7.30
Li_4SiO_4 2($\times 10^{-4}$)	5.24	9.37	9.28	16.8
Li_4SiO_4 3($\times 10^{-3}$)	1.08	1.55	1.64	2.69
Li_4SiO_4 4($\times 10^{-3}$)	1.07	1.66	1.65	2.76
Subtotal($\times 10^{-3}$)	2.90	4.53	4.62	7.85
Total T breeding rate($\times 10^{-2}$)	1.75			

Table 3 Results of the general neutron flux and power production

Names	Design Result (MCNP)
Peak Neutron Flux/(n/s · cm^2)	1.97×10^{14}
Peak Fast Neutron Flux/(n/s · cm^2)	1.67×10^{14} (> 1 MeV)
Peak Power Density/(MW/m^3)	9.27
Neutron Incident Power/(MW)	0.46
Total Power Generation/(MW)	0.422
Total Power in Be regions/(MW)	0.068 3
Total Power in EUROFERs/(MW)	0.101
Total Power in Li_4SiO_4 (s/MW)	0.131
Total Rear shielding/(MW)	0.105
Grids/(MW)	0.016 7

7 Summary

The nuclear analysis results for China HCSB TBM

module are calculated by three-dimensional calculations of MCNP. FENDL2.0 data library is adopted. The main parameter results are: TBR is 0.907; tritium production rate is 0.017 5 g/d; peak power density is 9.27 MW/m^3 under 0.78 MW/m^2 and 22% duty factor for ITER. These neutronics calculation parameters are used as input data for thermal hydraulics calculation, tritium system design, radioactivity, afterheat helium system and so on.

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具有3×3子模块结构的中国HCSB TBM的三维中子学计算

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摘 要：采用三维中子学程序MCNP及FENDL2.0数据库，对具有3×3子模块结构的中国氦冷固体增殖剂(HCSB)的氚增殖包层模块(TBM)进行了三维中子学计算。计算条件是：壁负载因子是0.78 MW/m^2、运行因子是22%。计算得到的TBM氚增殖比(TBR)是0.907、总氚产生率是0.017 5 g/d、最大功率密度9.27 MW/m^2及总功率沉积0.422 MW/m^3。

关键词：聚变；中子学；氚增殖包层模块；中国氦冷固体增殖剂