Recent Neutronics Analysis for a China ITER HCSB NT-TBM

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Abstract. Recent neutronics analysis for China HCSB (Helium Cooling Solid Breeder) NT-TBM (Test Blanket Module) has been largely updated in view of adopting global TBM MCNP calculation modeland new module design with 3×6 sub-modules in 1/2 Port. New calculational results for 3×6 HCSB TBM show averaged neutron wall loading of 0.72 MW/m^2, total tritium generation rate of 0.0127 g/day with duty factor of 22% for ITER, peak power density of 5.85 MW/m^3 and total power deposit of 0.705 MW/m^3 on TBM module.

1. Introduction

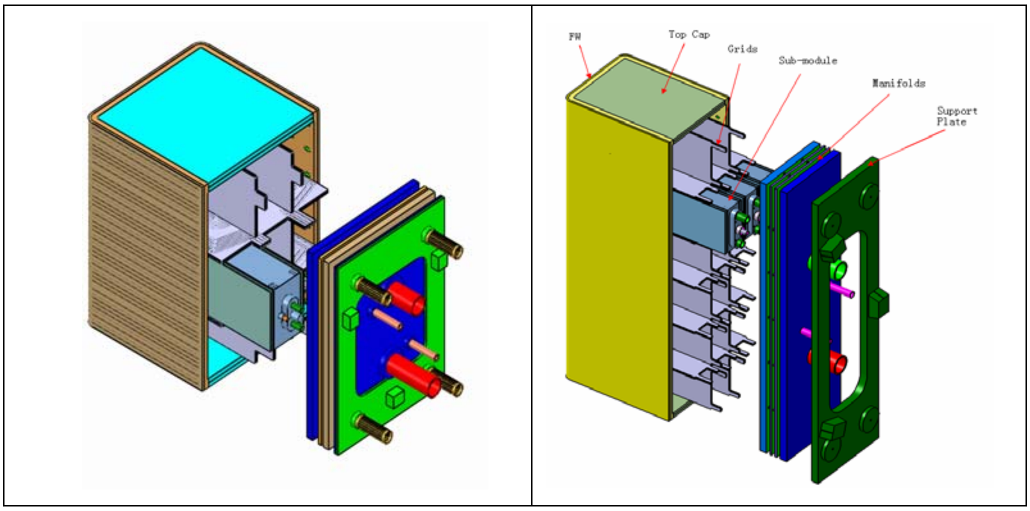
Neutronics calculation[1][2] for ITER NT-TBM is the most important one of all calculations because it lays a basis on design and analysis for other systems. Recently, there are two important progress of neutronics analysis for China HCSB NT-TBM[3]:

Firstly, according to adjusted Chinese TBM development strategy, recent CH HCSB TBM design has been changed from 1/4 module to in 1/2 module. For a present design, 3×3 sub-modules has been substituted by 3×6 sub-modules in structure. Secondly, for previous version of preliminary 3-D neutronics design for HCSB NT-TBM, due to limited period to start working, although MCNP [4] code is used, but Chinese MCNP calculation model on HCSB TBM was a called local TBM model which temporarily simplified as one local box model without complex ITER structures around TBM. Its boundary conditions are assumed as full reflect or void one, but realistic MCNP model should be a called global TBM model including both ITER structure and TBM box. Definition of neutron and boundary conditions for two kinds of models is considerably different. For international [5] neutronics calculation, a called global TBM model with complex ITER structures around TBM must be required. So it is necessary and compulsory that neutronics analysis of HCSB NT-TBM should step into global TBM model.

In this paper, performance of 3-D neutronics for a 3×6 global HCSB NT-TBM module has firstly been completed by means of global ITER MCNP model offered by ITER design team. Nuclear data library based on FENDL2.0 [6] is used as well. A number of important neutronics parameters such as neutron flux, neutron energy spectrum, power density, power production, tritium breeding ratio and tritium production rate are given.

Also, introduced are main differences of MCNP models and results between a global TBM model and a local TBM model. Some meaningful conclusions and suggestions in view of neutronics for present 3×6 CH HCSB NT-TBM are presented.

2. Description of structure



(a) 3×3 HCSB TBM module in 2005 *(b) 3×9 HCSB TBM 2006*

FIG. 1 Schematic view of 3-D HCSB TBM module

Except that height, sub-module numbers of present HCSB TBM increases by 2 times, there are hardly other changes in structure and geometry. Fig.1 shows general schematic for 3-D structure of previous 3×3 and updated 3×6 HCSB TBM structure. Present 3×6 HCSB TBM box is mounted on 1/2 ITER testing port. It is with 48.4 cm in width, and 166 cm in height, 63 cm in depth, two 2cm of gaps on side faces between frame wall and TBM box. A frame wall thickness around TBM module is 20 cm. There are 18 sub-modules supported by grids of 1.1cm thick. Totally, they consists of 18×9 cooling slabs, 18×4 tritium breeding zones, 18×5 beryllium neutron multiplication in parallel and 18×1 beryllium tiles. All structures such as cooling panels, caps, grids and manifolds in tritium breeding region are made as panels with inner helium cooing channels. Their flowing direction is toroidal. There is a layer of Be tiles of 0.2cm thick on the surface of FW. The FW with 3cm radial thickness is independently cooled by 1.45×2cm of the rectangular helium cooling channels. The cooling plates are 1cm thick. Diameter of circular cross section of cooling channels in the plates is 6cm. There are two caps of 3.8 cm thick at top and bottom. The rear plates of 4 cm are used to shield neutron. The rear manifold consists of 4 plates where thickness of plates are 3cm, 1.5cm, 1.5cm and 3.5cm, respectively and thickness of helium gas collecting are 2cm, 2cm and 2cm, respectively.

3. Layout of materials and geometry

Present 3x6 NT-TBM is almost same as prevous 3×3 NT-TBM in area of internal layout of materials and geometry. Low activation Ferritic/Martensitic (LAFM) steel – Eurofer[5] is still adopted as structure material. Helium gas is coolant, Li_4SiO_4 pebble beds are as breeder materials and beryllium pebble beds are neutron multiplier. Li-6 enrichment is 80%. Volume of Li_4SiO_4 pebble beds is largely reduced but the volume of Be pebble beds is largely increased. It is advantaged for improving the thermal conductivity because the thermal conductivity coefficient of Be pebble bed is much larger than that of Li_4SiO_4 pebble bed.

Table 1 Compositions of Impurities in theTBM Materials

Be (%)		Eurofer (%)		Li_4SiO_4 (%)	
Beryllium: Be	Bal.	Iron:Fe	Bal.	Iron:Fe	0.00830
Iron:Fe	0.0435	Oxygen:O	0.01	Manganese:Mn	0.00033
Oxygen:O	0.0512	Chromium:Cr	9.000	Oxygen:O	Bal.
Chromium:Cr	0.006	Molybdenum:	0.005	Lithium:^{6}Li	16.76
olybdenum:Mo	0.006	Manganese:Mn	0.400	Lithium:^{7}Li	4.19
		Nickel:Ni	0.005		
		Tungsten:W	1.100		
		Vanadium:V	0.200		
		Copper:Cu	0.005		

It likely leads to difficult heat removal because heat conducting coefficient of ceramic Li_4SiO_4 pebble beds is much small amount.

Fig.2 shows the plain layout of the geometry and materials component for one sub-module of CH HCSB NT-TBM. The ceramic lithium orthosilicate pebble beds are used in breeding tritium. The diameters of Li_4SiO_4 pebbles are 0.5~1mm. The packing factor of Li4SiO4 pebble bed is 0.82. Be pebble beds are used to multiply neutron. Be pebble beds are made from mixing two kinds of pebbles with diameters 0.1mm and 1mm. Their packing factor is 0.8.

The basis impurities considered in the beryllium neutron multiplier, Eurofer structure and Li_4SiO_4 breeder are described in Table 1.

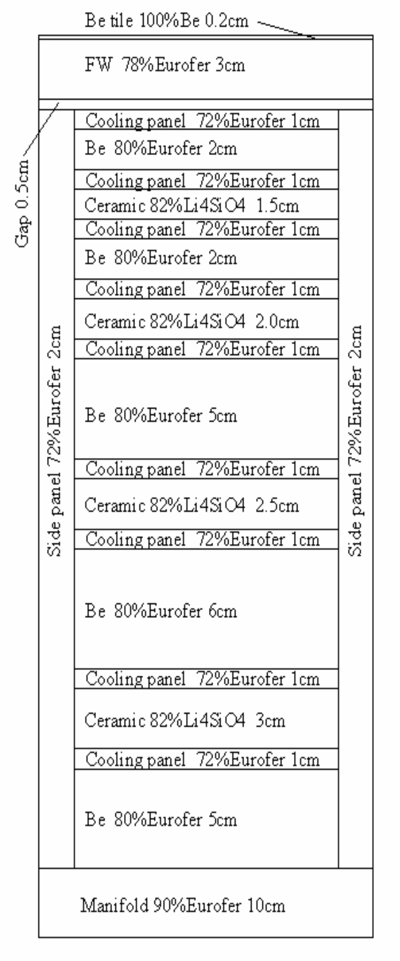


FIG.2 Layout of the geometry and materials for one sub-module of CH HCSB NT-TBM

4. MCNP model

Present global TBM MCNP calculation model is completely different from previous local TBM MCNP model. Both TBM models have been plotted. Fig. 3 shows local TBM model for 3×6 HCSB NT-TBM. Fig. 4 shows global TBM calculation model for 3×6 HCSB NT-TBM is mounted on global ITER models which are offered by ITER IT.

The definitions of boundary conditions and starting neutron source for local model and global model are quite different. For global model, there is no definition of TBM boundary conditions but a fusion 14MeV fusion neutron source in

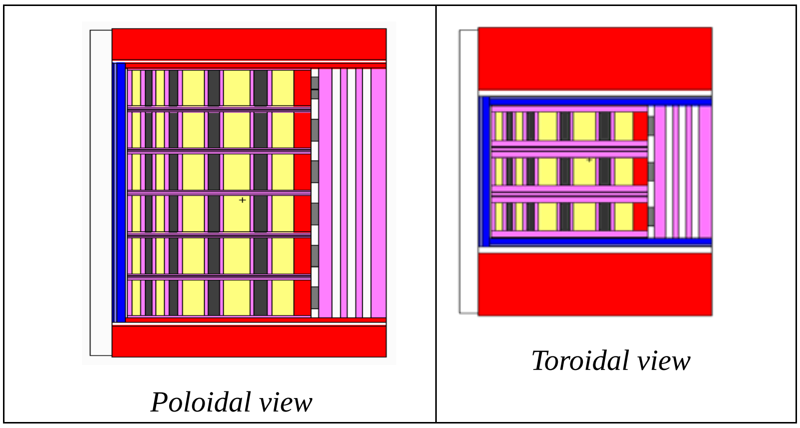


FIG. 3 Previous local TBM calculating model for 3x6 CH HCSB

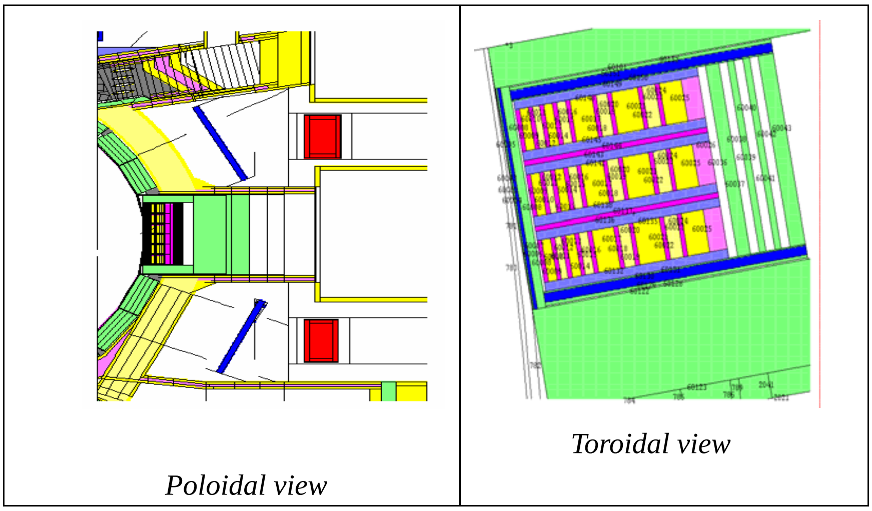


FIG. 4 Present global TBM calculating model for 3x6 CH HCSB

plasma zone with D-shaped distribution. For local box model, 4 side surfaces (top, bottom, left and right) are selected as reflect boundary, front surface is used as fixed source through one 14MeV incident neutron, and outside rear surface is vacuum boundary. Global TBM model is designed as a 1/18 cut or 20^{o} cut based on symmetrical structure of 18 TFC along ITER torus. CH HCSB TBM is put into an outside shielding blanket at equatorial plane and its structures and materials are the same as previous local TBM model consisting of 3×6 sub-modules. There are 452 TBM calculation models which are described based on different materials zones. The neutron source is designed by using SDEF definition referred to ITER IT.

6. Results

For present global TBM MCNP model, the calculation of neutronics transport is performed according to ITER full fusion power of 500 MW and neutron power of 400MW. Neutron generation rate for 1/18 ITER MCNP model is 9.89×10^{18} n/s. ITER geometry cells are successfully checked by means of VOID card resetting materials numbers in all cells as zeros. It is required that FOM errors of all results output from MCNP calculation are less than 10%

and 3,000,000 histories are sampled. For previous local TBM model, neutron wall loading is assumed as $0.78 MW/m^2$.

6.1 Neutron Current and Neutron Wall Loading

For global TBM model, the boundary conditions of TBM module needn't be defined. The neutron gong into FW from plasma could be rebounded to plasma again. Net neutron current (F1 card) is used to calculate the neutron wall loading. Fig. 5 shows results of angular distributions of neutrons scattered out through FW of 3×6 TBM. It is shown that the incident neutrons going into FW of TBM are larger than neutrons scattered back plasma. Neutron can be scattered to and fro through FW by many times. There are maximum neutron numbers at scattered angular of 40-50^o with respect to incident direction. The results show that net neutron current into FW is 2.10×10^{17} n/s, net power is 0.58 MW, area of surface of Be tile is 0.8034 m^2 and wall loading is 0.72 MW/m^2.

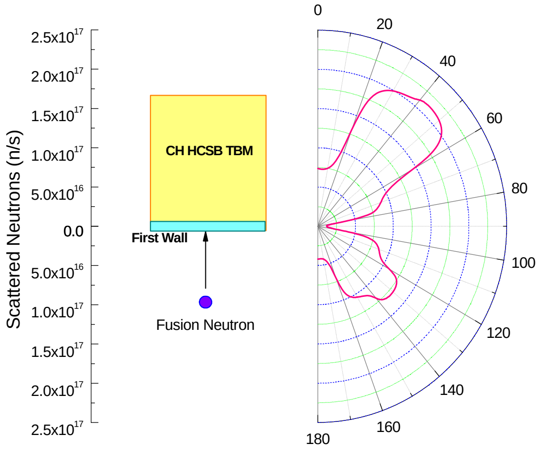
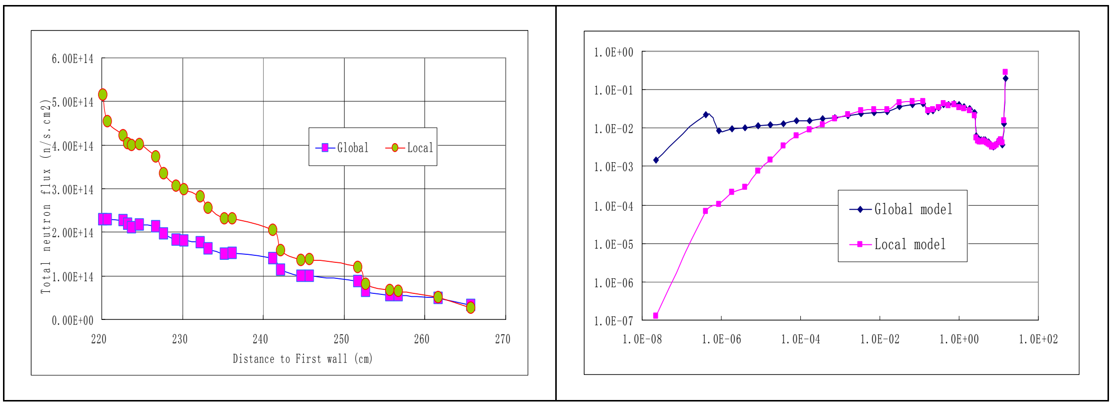


FIG.5. Angular distributions of neutrons through FW

6.2 Neutron flux and energy spectrum

Fig. 6(a) show neutron flux along radial distance to FW and Fig. 6(b) normalized energy spectrum at Be tile and the first zone of Li_4SiO_4 tritium breeding zone. Neutron flux is used to further calculate reaction rate of tritium and power production. Energy spectrum is used to help evaluation and analysis of neutron calculation. It is shown that peak neutron flux at Be tile is 2.28×10^{14} $n/s.cm^2$ for global model and global flux is much lower than 5.28×10^{14} $n/s.cm^2$ for local model. Neutron energy spectrum shows low energy neutrons for global model are more than those for local model.



(a) Flux distribution *(b) Normalized energy spectrum at Be tile*

FIG. 6 Neutron flux and normalized spectrum for global and local TBM model

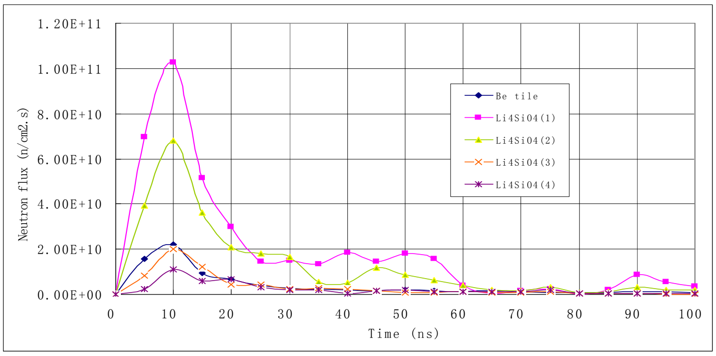


FIG. 7 Neutron flux at Be tile, Li_4SiO_4 1~4 zone vary with time for global model

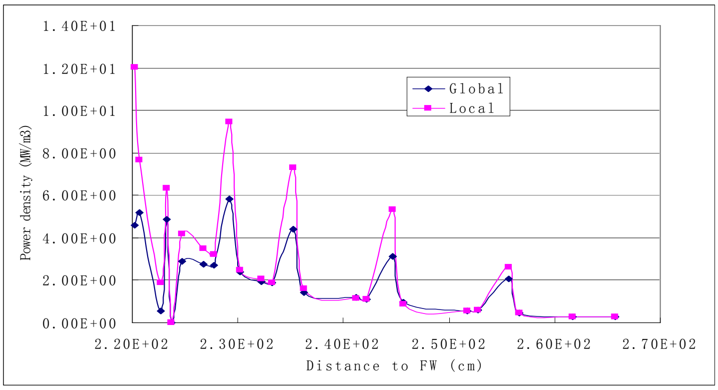


FIG.8 Power density ditribution for global and local TBM model

Fig. 7 shows neutron flux at Be tile, Li_4SiO_4 1~4 zone vary with time for global model. This results show that transient neutron flux has an intense pulses of neutron flux at about 10 ns (or 10^{-8}s) which is larger than steady flux by maximum over one order at Be tile. It is valuable for evaluation of safety analysis of materials as well as design of neutron measurement system.

6.3 Power production

Power production is used to perform thermal-hydraulic analysis. Fig. 8 shows distribution of power density for *global* and *local* TBM model. For global model, peak power density of 5.85 MW/m^3 takes place at the first Li_4SiO_4 zone, and power density at Be tile is 4.59 MW/m^3. The peak power density for global model is much reduced compared to local model. This is valuable result because it shows HCSB TBM is factually much safer than previous safe conclusion.

Table 2 gives power production on frame and main components of HCSB TBM. For global model, total power production for TBM module is 0.705 MW and power production on frame is 1.121 MW. From view of power deposit, results of both models are not largely different.

6.4 Tritium production

Tritium production rate is used to design the tritium extraction system. Table 3 lists tritium production rate per day at duty factor of 22% for sub-module 1-18 of both global and local

HCSB TBM. It is shown that, for global model, tritium production rate is 0.0127g/d at 22% of ITER duty factor. Tritium production for local model is large than that global model by 34%. It is shown that difference between both models is considerable.

Table 2 Power Deposit on HCSB TBM

	Power (MW) Global	Power (MW) Local
Frame	1.121E+00	9.970E-01
Up plus botom cap plates	2.470E-02	1.700E-02
Grids	4.440E-02	3.300E-02
Enclosures around 18 sub-modules	1.210E-01	1.510E-01
Be tiles	9.450E-03	1.900E-02
FW	1.610E-01	1.200E-01
3x6 Sub-modules	3.250E-01	3.740E-01
Manifolds	1.600E-02	1.600E-02
Total in TBM box	0.705	0.739

Table 3 Tritium Production Rate on 18 Sub-modules

Sub-module No.	Tritium production rate Global (g/d)	Tritium production rate Local (g/d)
1	3.198E-03	3.745E-03
2	3.144E-03	3.912E-03
3	3.172E-03	3.742E-03
4	3.585E-03	4.336E-03
5	3.048E-03	4.464E-03
6	3.376E-03	4.194E-03
7	3.244E-03	4.296E-03
8	3.111E-03	4.389E-03
9	3.556E-03	4.219E-03
10	3.124E-03	4.427E-03
11	2.828E-03	4.541E-03
12	2.922E-03	4.348E-03
13	3.412E-03	4.174E-03
14	3.586E-03	4.252E-03
15	3.215E-03	4.132E-03
16	3.112E-03	3.645E-03
17	2.994E-03	3.861E-03
18	3.119E-03	3.676E-03
Total (full power operation)	0.0578	0.0752
Total (duty factor of 22%)	0.0127	0.0170

7. Summary

3-D MCNP neutronics calculation of global model instead of local model for a 3×6 CH HCSB TBM has firstly been performed. Totally, main neutronics results for present global TBM model are summarized as follow: 1) Peak neutron flux at Be tile is 2.28×10^{14} n/s.cm^2 for global model. Transient neutron flux analysis shows there is likely safe issue of FW materials due to intense flux pulse at 10ns; (2) Power deposit and peak power density are 0.705MW and 5.85MW/m^3; (3) Tritium production rate is 0.0127g/d at 22% of ITER duty factor.

Comparison of 3-D MCNP neutronics calculation between global and local TBM model for a 3×6 HCSB TBM has been performed. It is found that both results are quite different in area of neutron flux, energy spectrum, power density and tritium production rate, etc., especially that new peak power density is reduced by two times. It means that present design of TBM still has a comparatively larger safety margin than one imagined in the past.

It concludes that global TBM MCNP model is very important and necessary for 3-D neutronics calculation because it is a much more realistic calculation model than local TBM model. Since now, all are only preliminary and new results, but they still show that HCSB TBM need be further optimized at next engineering design phase.

8. Acknowledgment

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References

[1] Zhang Guoshu, Feng Kaiming and Yuan Tao etc., Design and Analysis of Neutronics for China HCSB TBM. Nuclear Fusion and Plasma Physics (in Chinese) Vol.25, No.2, Jun 2005.

[2] Li Zengqiang, Feng Kaiming, Zhang Guoshu, Zhao Zhou. Tritium Generation Optimization of Chinese ITER Test Blanket Module. Science Technology and Engineering. Vol.5 No.21 Nov.2005.

[3] K.M. Feng, C.H. Pan, G..S. Zhang, etc. Preliminary design for a China ITER test blanket module. Fusion Engineering and Design 81 (2006) 1219-1224.

helium cooled pebble bed (HCPB) TBM. ITER TBM Project Meeting at UCLA,2004.

[4] J. Briesmeister et al.，MCNP, A Monte Carlo Neutron and Photon Transport Code, Los Alamos National Laboratory Rep. LA-7396-M, 1997.

[5] Boccaccini L. V., Hermsmeyer S, Meyder R. EU designs and efforts on ITER [8] K. Furuta, Y. Oka, S.Kondo, CCC-464/BISON1.5,RSIC,OAK Ridge National Laboratory,1987.

[6] H.Wienke, M. Herman, FENDL/2.0, The Processed Cross-Section Libraries for Neutro-Photon Transport Calculations, IAEA-NDS-176 Rev. 0, February, 1998.