Neutronics Analysis for the Test Blanket Modules proposed for EAST and ITER

S.L. Zheng, Y.C. Wu, M.L. Chen, J.J. Li, Q. Zeng, L. Lu, Y. Li, A.P. Ding, H.M. Hu
Institute of Plasma Physics, Chinese Academy of Sciences
P.O. Box 1126, Hefei, Anhui, 230031, China
E-mail: slzheng@ipp.ac.cn

Abstract

The Dual-Functional Lithium Lead - Test Blanket Module (DFLL-TBM) system, which is designated to demonstrate the integrated technologies of both He single coolant (SLL) blanket and He-LiPb dual coolant (DLL) blanket, is proposed for test in ITER to check and validate the feasibility of the Chinese LiPb blankets. So far, the construction and operation of ITER will still take a period of ten years, but EAST, the superconducting tokamak device, in China, has been in operation. In EAST D-D phase, the neutron yield is about 10^{15}~10^{17} n/s and about 10^{17}~10^{18} n/s in ITER D-D phase. Therefore, EAST is expected to serve as a valuable pre-testing platform for TBMs, which is not only for electro-magnetics(EM) and thermo-mechanics but also for neutronics. The neutronics analysis for the TBMs is performed by using the coupled three-dimensional (3D) Monte Carlo - Deterministic code MCSN and the nuclear data library FENDL2.1. The activation calculations will be carried out with the home-developed multi-functional neutronics analysis code system VisualBUS and multi-group data library HENDL. The real 3D neutronics calculation model of the middle-scale(1/3 size-reduced) TBM testing in the EAST super-conducting tokamak and full-scale consecutive TBM testing in the ITER machine have been developed with the Chinese home-developed CAD/MCNP interface code MCAM, which can be used as a converter of large complex 3D CAD models into MCNP models and vice versa as well as an analysis tool of MCNP models by the way of visualization to contribute the QA of neutronics analysis. Neutronics calculations, which include neutron spectra and flux distributions, tritium generation, nuclear energy deposition and D-D phase activation, of the TBMs in EAST are carried out and be made an analogy to those in ITER for the close extent of the neutron yield in D-D phase. Further, the foreseen D-D operations in ITER can be treated as an initial nuclear phase including D-T operation. So the presented nuclear performance estimates for TBM in EAST are important for radiation safety, maintenance and staged ITER construction for it in ITER.

Keywords: EAST, ITER, test blanket module, MCAM, neutronics

1. Introduction

The Dual-Functional Lithium Lead-Test Blanket Module (DFLL-TBM) system, which is designated to demonstrate the integrated technologies of both He single coolant (SLL) blanket and He-LiPb dual coolant (DLL) blanket, is proposed for test in ITER to check and validate the feasibility of the Chinese LiPb blankets. So far, it will still take a period of ten years from the construction to the operation of ITER, but EAST, the superconducting tokamak device, in China, has been in operation. The DFLL-TBM will be assessed and tested earlier under out-of-tokamak conditions and in the EAST superconducting tokamak before a final decision can be made for test in ITER.[1-3]

The main parameters of EAST and ITER are listed in Table 1. The neutron yield, which is about 10^{15}~10^{17} n/sec in EAST D-D phase, is comparable to it (about 10^{17}~10^{18} n/sec) in

ITER D-D phase. Therefore, EAST is expected to serve as a valuable pre-testing platform for TBMs, which is not only for electro-magnetics(EM) and thermo-mechanics but also for neutronics. The data and experiences deriving from EAST-TBM test can be applied to optimize and improve the design of DFLL-TBM system and the testing plan for ITER. Furthermore, the objective of the neutronics analyses for prediction and confirmation of expected neutronics parameters are an essential part of the TBM design and shielding capability assessment.[3-4] In this contribution, the nuclear responses of TBM in EAST will be compared with those in ITER D-D phase even in ITER D-T phase, which have been performed in the previous work, so that the TBM design and test scenarios for ITER D-T phase can be foreseen and improved by combined with the data and experiences deriving from the operational EAST tokomak.

TABLE 1 MAJOR PARAMETERS OF THE EAST-TBM

Device	EAST	ITER		
Phase	D-D	H-H	D-D	D-T
R (m)	1.95			6.2
A (m)	0.46			2
Bt (T)	3.5-4.0			5.3
Neutron rate (n/s)	10^{15}~10^{17}		10^{17}~10^{18}	1.77 x 10^{20}
Avg.HF(MW/m^2)	0.1~0.2	0.11		0.27
Port Size (H x W)	0.97m x 0.53m	2.2m x 1.7m		
Pulse (sec)	~1000	100-200		400

2. Basic Model and Code

The real three-dimensional (3D) neutronics calculation model of the middle-scale(1/2 size-reduced) TBM testing in the EAST super-conducting tokamak and full-scale consecutive TBM testing in the ITER machine have been developed with the Chinese home-developed CAD/MCNP interface code MCAM[5]. MCAM is the interface code between commercial CAD softwares and MCNP, which can support various neutral CAD file formats, such as STEP/IGES, and MCNP input syntax. It can be used as a converter of large complex 3D CAD models into MCNP models and vice versa as well as an analysis tool of MCNP models by the way of visualization to contribute the QA (Quality Assurance) of neutronics analysis. [6-7]
The neutronics analyses for DFLL-TBM in ITER and EAST are performed by using the MCNP/4C code[8] and the IAEA Fusion Evaluated nuclear data library FENDL2.1[9]. The activation calculations will be carried out with the home-developed multi-functional neutronics analysis code system VisualBUS, in which the transport calculation, burnup calculation, activation calculation and thermal-hydraulics calculation are coupled or streamed together to run in a batch way or interactively started, monitored and controlled by the user with the help of GUI (Graphical User Interface), and multi-group data library HENDL.[10]
The TBM modules occupy only a small fraction of the shielding blanket in ITER and EAST. In order to get the more accurate and reliable analysis, the calculation model is described by the 3D simulation code MCNP and placed in the detailed ITER and EAST calculation model.

The 3D views of the MCNP models of ITER and EAST and the relevant DFLL-TBMs converted from MCNP input file by MCAM, are shown in Fig.1 and Fig.2, respectively.

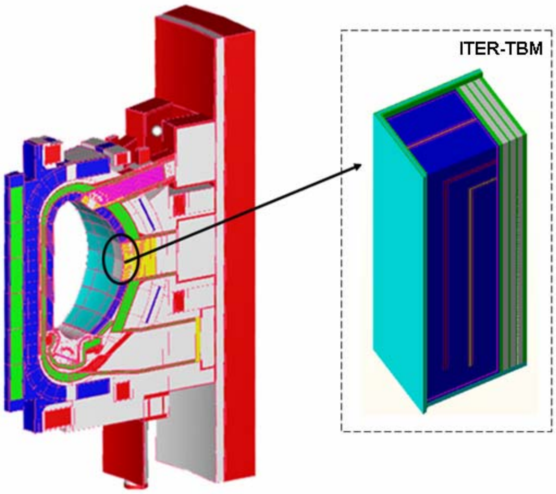

Fig.1 3D views by MCAM of ITER and DFLL-TBM

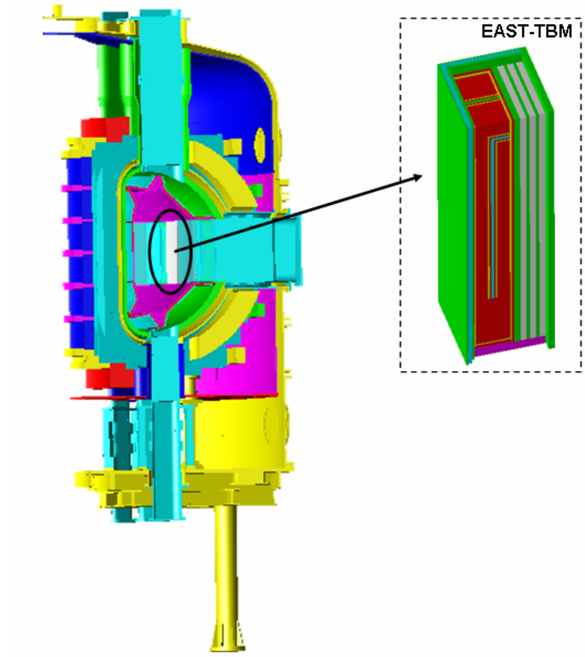

Fig.2 3D views by MCAM of EAST and DFLL-TBM

The DFLL-TBM will be installed in the equatorial position of the OB (Outboard Blanket) region in ITER and EAST devices. The 5mm thick SiC flow channel inserts (FCI) are used at the inside walls of all LiPb flow channels in DFLL-TBMs for the comparison between the tests in the D-D phase of EAST and ITER and the D-T phase of ITER. The Reduced Activation Ferritic/Martensitic (RAFM) steel, e.g., CLAM steel[11], is used for structural material. There are 5mm thick gap between FCI and grid plate or wall, filled with liquid LiPb eutectic. The nuclear analysis of DFLL-TBM in ITER during its D-T phase has been evaluated in the previous reference [12]. In this contribution, the nuclear evaluations of DFLL-TBM in ITER and EAST during its D-D phase are carried out. The detailed dimensions and material compositions of DFLL-TBM in EAST with the SiC FCIs are listed in Table 2.

TABLE 2 DIMENSION AND MATERIAL COMPOSITIONS OF DFLL-TBM IN EAST

Zone	Material	Radial thickness (cm)
FW front wall	100%FS	0.5
FW middle	20.4%FS; 79.6%He-gas	1.5
FW rear	100%FS	1
gap	100%LiPb	0.5
FCI	100%SiC	0.5
Tritium breeding zone	100%LiPb	4/4
“⅂”shape grid 1	72.3%FS; 27.7%He-gas	1
Back plate 1/2/3/4	100%FS	2/1/1/2
He gas zone	100%He-gas(void)	2/2/2
Cover plate (upper/bottom)	73.97%FS; 26.03%He-gas	3.05/3.05
r-p grid plate	71.4%FS; 28.6%He-gas	1/1

3. Neutronics Performance of TBMs

In cooling and maintenance periods, after reactor shutdown, radiation conditions are almost linear functions of the preceding fast neutron fluence. Thus, the nuclear performance both during pulse with D-D plasmas and after will be predetermined by both 2.45 and 14.1 MeV neutron source components. Neutronics calculations, which include neutron spectra and radial flux distributions, tritium generation, nuclear energy deposition and D-D phase activation, in the reduced scale TBM systems in EAST are carried out and be made an analogy to those in ITER for the close and comparable extent of the neutron yield in D-D phase. For the evolvement and update of ITER design and operation strategy, the neutron yield in D-D phase is 10^{17}~10^{18} n/sec in the calculations as well as the neutron yield in EAST is 10^{15}~10^{17} n/sec. The ITER D-T regime is normalized at 500MW fusion power.

3.1 neutron flux

As shown in Fig.3, on the assumption that the neutron yields are 10^{17} for D-D operation in EAST-TBM and 10^{18} for D-D operation in ITER-TBM, there are the approximate neutron spectra shapes in EAST-TBM and ITER-TBM during the D-D phase so that the neutron diagnostic method and measurement tools, which are proposed for ITER, can be validated and improved by the test in the EAST device in the similar experimental condition in advance. The flux in D-D phase is two orders of magnitude lower than it in D-T phase except for the additional ~2.45MeV peak presented in the D-D phase.

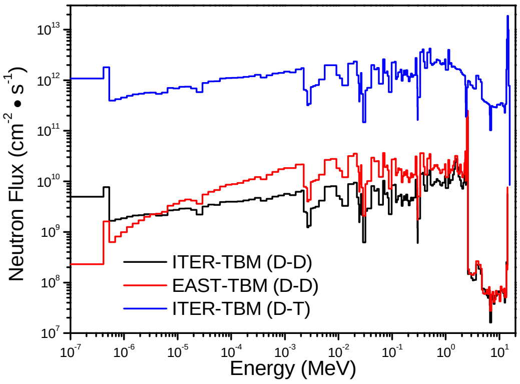

Fig.3 Neutron Spectrum in First Wall of TBM in EAST and ITER

3.2 tritium generation and nuclear heat

The accumulated tritium inventory and nuclear heat in them are calculated and compared to extrapolate the improvement of the relevant technologies, such as tritium recovery and control and heat extraction. In Table 3, the tritium production and nuclear heat of EAST-TBM and ITER-TBM are listed. There are some intersections between those in EAST-TBM and ITER-TBM with the different neutron yields extents of the D-D operation phase for the configuration and size of the devices. Since the size of EAST-TBM is 1/2 lower than ITER-TBM, the tritium production and the total nuclear heat in EAST-TBM are both lower than them in ITER-TBM. Both of them during D-D phase are about three orders of magnitude lower than them during D-T phase.

TABLE 3 TRITIUM PRODUCTION AND NUCLEAR HEAT IN DFLL-TBMS

DFLL-TBM		EAST-TBM (D-D)	ITER-TBM (D-D)	ITER-TBM (D-T)
Tritium production (mg/FPD)		1.69E-05~1.69E-03	3.61E-04~3.61E-03	56.42
Nuclear Heat(MW)	FW(a)	1.05E-06~1.05E-04	4.17E-06~4.17E-05	1.13E-02
	Back-Plate	4.29E-07~4.29E-05	1.48E-06~1.48E-05	2.34E-01
	T-breeder	2.69E-06~2.69E-04	6.78E-05~6.78E-04	2.83E-02
	FCI	2.06E-07~2.06E-05	4.31E-06~4.31E-05	1.18E-01
	Grid	5.70E-08~5.70E-06	1.08E-06~1.08E-05	9.08E-03
	Total	4.43E-06~4.43E-04	7.89E-05~7.89E-04	0.42

(a): FW include the cover plates of TBMs

3.3 activation effects of FW

The activation effects in DFLL-TBMs in EAST and ITER are evaluated to apply the management of the activated materials. After the irradiation time of 10^5sec, the contact dose rates as a function of cooling time for the FW (first wall) of EAST-TBM and ITER-TBM with different neutron yields are displayed in Fig.4. If the remote and hands-on handling limits of dose rate are considered as 10mSv/h and 10μSv/h[13-14], respectively, the contact dose rate decrease to the remote handling limit when cooling time is ~1.1 years for the FW of EAST-TBM at the neutron yield 10^{17}n/sec, or ~2 days for the FW of EAST-TBM at the neutron yield 10^{15}n/sec, or ~0.9 years for the FW of ITER-TBM at the neutron yield 10^{18}n/sec, or ~1.5 days for the FW of ITER-TBM at the neutron yield 10^{17}n/sec, respectively. To meet the hands-on handling limit, cooling times of ~30 years, ~5 years, ~25 years and ~8 years would be needed for FW of EAST-TBM at the neutron yield 10^{17}n/sec, the FW of EAST-TBM at the neutron yield 10^{15}n/sec, the FW of ITER-TBM at the neutron yield 10^{18}n/sec and the FW of ITER-TBM the neutron yield 10^{17}n/sec, respectively.

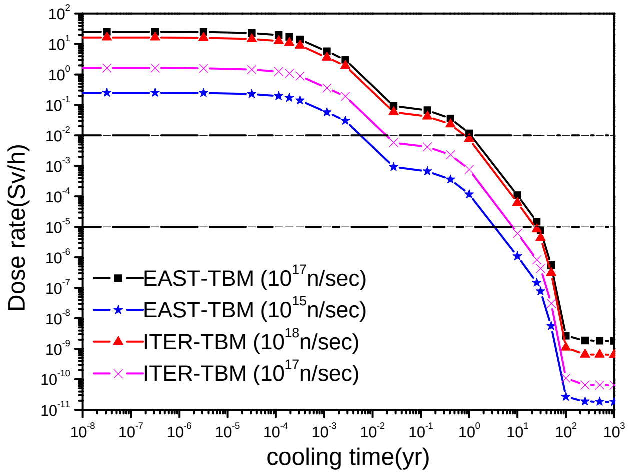

Fig.4 Dose rate as a function of cooling time for the FW in EAST and ITER during D-D operation phase

4. Summary

The TBM testing in EAST, which has been operating in China, is prior to it testing in ITER and can act as the pre-testing platform of ITER-TBM for their comparable experimental conditions. There are the similar neutron spectra shapes in EAST-TBM and ITER-TBM during the D-D phase and the successive D-T phase of ITER-TBM except that the additional ~2.45MeV peak is presented in the D-D phase and the fluxes in D-D phase is two orders of magnitude lower than it in D-D phase. The tritium production and the total nuclear heat in EAST-TBM are both lower than them in ITER-TBM for the middle-scale(1/2 size-reduced) EAST-TBM and about three orders of magnitude lower than them during D-T phase. There are approximate activation effects of the FW in DFLL-TBM tested in EAST and ITER for the similar neutron spectra. Therefore, the foreseen D-D operations in ITER can be treated as an initial nuclear phase including D-T operation. So the presented nuclear performance estimates for TBM in EAST are important for radiation safety, maintenance and staged ITER construction for it in ITER.

References

[1] Y. Wu, H. Chen, S. Liu, et al., Design and Analysis of the Chinese Dual-Functional Lithium Lead (DFLL) Test Blanket Module for ITER, presented at 24th Symposium of Fusion Technology, 11-15 Spet. 2006, Warsaw, Poland.

[2] WU Yi-can, WANG Wei-hua, LIU Song-lin, et al., The dual functonal lithium lead teat blanket module and the testing strategy for ITER, Chinese Journal of Nuclear Science and Engineering, Vol 25(2005), No.4, 347-360.

[3] Y. Wu, et al., Design concept and testing strategy of a DFLL-TBM for ITER and EAST, to be presented at 21st IAEA Fusion Energy Conferece, Otc. 16-21, 2006, Chengdu, China.
[4] Songlin Liu, Hongli Chen, Yunqing Bai Shanliang Zheng, Pengcheng Long, Yican Wu, Design and Analysis of Lithium Lead Test Blanket Module for the EAST Superconducting Tokamak, presented at 24th Symposium of Fusion Technology, 11-15 Spet. 2006, Warsaw, Poland.
[5] Q. Zeng, L. Lu, et al., Update of ITER 3D basic neutronics model with MCAM, to be published in Fusion Engineering and Design, 2006.
[6] Yican Wu, Ying Li, Lei Lu, et al., Research on MCNP modeling methods and implementations, Plasma Science & Technology, 2005.
[7] Ying Li, Lei Lu, Aiping Ding, Haimin Hu, Qin Zeng, Shanliang Zheng, Yican Wu, Benchmarking of MCAM 4.0 with the ITER 3D Model, presented at 24th Symposium of Fusion Technology, 11-15 Spet. 2006, Warsaw, Poland.
[8] J.F. Briesmeister (Ed.), “MCNP4C General Monte Carlo N-Particle Transport Code”, Los Alamos National Laboratory, LA-13709-M, 2000.
[9] The IAEA Nuclear Data Section, FENDL-2.1 Fusion Evaluated Nuclear Data Library,, Vienna, Austria, INDC(NDS)-467, version December 2004.
[10] Gao Chunjing, Xu Dezheng, Integral Data Test of HENDL1.0/MG and VisualBUS with Neutronics Shielding Experiments, Plasma Science&Technology, Vol.6, No.5,Oct 2004.
[11] Q.Y.Huang, J.N.Yu, F.R.Wan, et al., the development of low activation martensitic steel for fusion reactor, Chinese Journal of Nuclear Science and Engineering, Vol. 24, No. 1, 2004.
[12] ZHENG Shan-liang, ZENG Qin, WU Yi-can, Neutronics analysis of the dual functional lithium lead test blanket module for ITER, Chinese Journal of Nuclear Science and Engineering, Vol 26(2006), No.4.
[13] T.J. Dolan, G.J. Butterworth, Vanadium recycling, Fusion Technology, Vol.26 (1994) 1014.
[14] E.T. Cheng, D.K. Sze, J.A. Sommer et al., Materials recycling considerations for D-T fusion reactions, Fusion Technology, Vol.21 (1992) 2001.