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***Abstract*— Neutronics analysis was performed for a dual coolant lithium lead blanket module to be tested in ITER. The total radial depth of the TBM is 41.3 cm followed by a 30 cm thick inlet/outlet piping zone. The calculated local tritium breeding ratio in the DCLL TBM is 0.741. The annual tritium production in the TBM is 2.4 g. The total nuclear heating in the TBM is 0.982 MW. The total thermal power to be removed from the TBM is 1.357 MW.**

Keywords-neutronics; ITER; test blanket module; dual coolant lithium lead; nuclear heating

I. Introduction

In support of the ITER Test Blanket Module (TBM) program [1], the U.S. has been developing a TBM design based on the dual coolant lithium lead (DCLL) blanket concept. Helium is used to cool the first wall (FW) and blanket structure, and the LiPb breeder is circulated for power conversion and tritium breeding [2]. SiC flow channel inserts (FCI) are used in the LiPb flow channels to reduce the MHD effect on the circulating LiPb and thermally isolate the high temperature LiPb from the low temperature helium cooled structure. The ferritic steel (FS) alloy F82H is used for structural material [3]. The concept will be tested in one half of a designated test port as shown in Fig. 1. It is mounted inside a water-cooled frame designed to hold two different test modules. The front surface of the module is 64.5 cm wide and 194 cm high. The total radial depth of the TBM is 41.3 cm followed by a 30 cm thick inlet/outlet piping zone. A separate 316SS/H_2O shield plug is used behind the TBM. A 2 mm-thick beryllium layer is utilized as a plasma facing component (PFC) material on the FS first wall. A drawing of the DCLL sub-assemblies is shown in Fig. 2. The sub-assemblies will form the box structure of the TBM. The TBM was designed to accommodate the two fluid flows internally and maintain the total separation between them. Neutronics calculations were performed to determine the relevant nuclear performance parameters for the DCLL TBM. These include tritium breeding, nuclear heating, radiation damage, and shielding requirements. The results are presented in this paper.

II. Calculation Procedure

The neutron wall loading at the TBM is 0.78 MW/m^2. The front surface area of the module is 1.25 m^2. The lithium in the lithium lead ($Li_{17}Pb_{83}$) eutectic is enriched to 90% Li-6. 5 mm thick SiC flow channel inserts (FCI) are used at the inner walls of all LiPb flow channels. In this phase of the analysis, one-dimensional (1-D) neutronics calculations were performed to allow for frequent iteration in the early stage of the TBM design process. The ONEDANT module of the DANTSYS 3.0 discrete ordinates particle transport code system [4] was used to perform the calculations utilizing the FENDL-2 nuclear data library[5]. Both the inboard (IB) and outboard (OB) regions were modeled simultaneously to account for the toroidal effects. The IB shielding blanket is modeled with its radial configuration including the Be tiles and Cu heat sink.

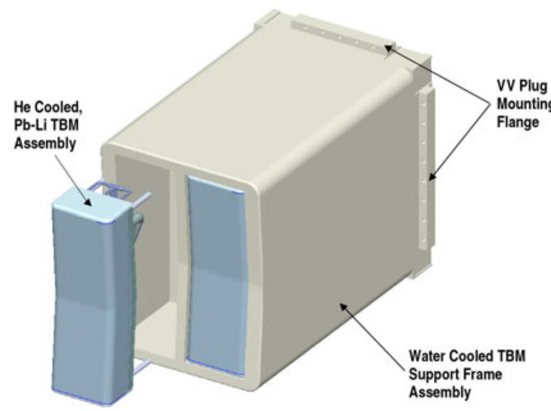

Figure 1. DCLL TBM assembly installed in one of the half ports.

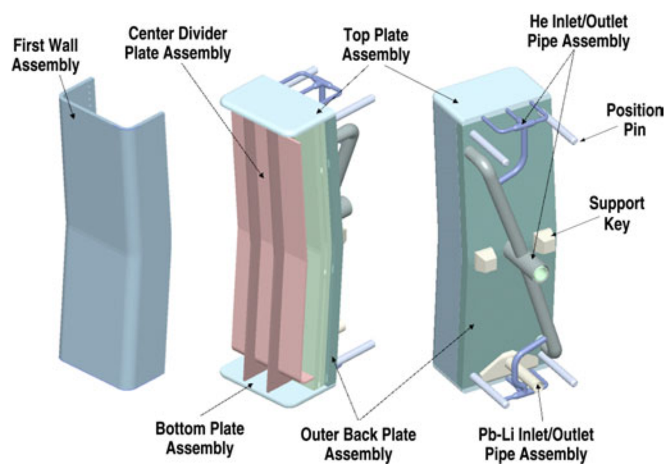

Figure 2. DCLL TBM sub-assemblies.

The radial configuration of the DCLL TBM is modeled in the OB region. Material composition in the radial layers of the TBM was carefully determined to account for the detailed configuration and material variation in both the toroidal and poloidal directions based on the current CAD drawings of the TBM as shown in Fig. 2. Table I gives the radial build and composition used in the calculations. The total radial depth of the TBM is 41.3 cm. The TBM inlet/outlet piping zone behind the TBM is 30 cm thick with 5% FS, 1% LiPb (LL), 0.2% SiC, 10% He, and 83.8% void. A separate 316SS/H_2O shield plug is used behind the TBM piping zone. The shield is assumed to consist of 75% 316SS and 25% H_2O. A 1.2 m thick shield plug was used in the initial calculation.

Once the DCLL TBM design is finalized a detailed 3-D model will be developed for the TBM. This TBM model will be integrated with the full ITER basic device 3-D model. 3-D neutronics with the detailed integrated model will be performed to update the neutronics parameters provided here.

TABLE I. RADIAL BUILD AND COMPOSITION USED IN THE NEUTRONICS CALCULATIONS

Zone Description	Thick (mm)	% Be	% FS	% LL	% SiC	% He
PFC Layer	2	100	0	0	0	0
Front wall of FW	4	0	100	0	0	0
FW cooling channel	20	0	17	0	0	83
Back wall of FW	4	0	100	0	0	0
SiC insert 1	5	0	8.1	0	80	11.9
Front breeding channel	70	0	8.1	75.7	4.3	11.9
SiC insert 2	5	0	8.1	6.1	73.9	11.9
Flow divider plate	15	0	54.8	6.1	0.4	38.7
SiC insert 3	5	0	8.5	6.1	73.3	12.1
Back breeding channel	110	0	8.5	74.7	4.7	12.1
SiC insert 4	5	0	8.5	1	78.4	12.1
Back wall	170	0	62.8	1	0.2	36
Total	**413**					

III. TRITIUM BREEDING

The calculated local tritium breeding ratio (TBR) in the DCLL TBM is only 0.741 because of the relatively small thickness used (41.3 cm). During a D-T pulse with 500 MW fusion power, tritium is produced in the DCLL TBM at the rate of 3.2×10^{17} atoms/s (1.59×10^{-6} g/s). Figure 3 shows the radial variation of tritium production rate in the LiPb during the 500 MW D-T pulse. The peak tritium production rate in LiPb is 2.94×10^{-8} kg/m^{3}s. For a pulse with 400 s flat top preceded by 100 s linear ramp up to full power and followed by 100 s linear ramp down the total tritium generation in the TBM is 7.97×10^{-4} g/pulse. For the planned 3000 pulses per year the annual tritium production in the TBM is 2.4 g/year. The tritium inventory in the TBM at any time will be much smaller since tritium will be continuously extracted from the LiPb. The tritium production rate in the Be PFC is only 2.2×10^{-9} g/s during the 500 MW D-T pulse with total annual generation of 3.3×10^{-3} g/year representing only 0.14% of the total tritium production in the TBM.

IV. NUCLEAR HEATING

Nuclear heating radial profiles in the different blanket constituent materials were determined for use in the thermal hydraulics analysis. The results are shown in Fig. 4 for LiPb, SiC, and ferritic steel structure. Table II compares the peak power densities in the TBM constituent materials. The nuclear energy multiplication in the TBM is 1.006. This includes the energy deposition in the inlet/outlet piping behind the TBM. The neutron power incident on the TBM front surface is 0.976 MW during the 500 MW D-T pulse. This results in total nuclear heating of 0.982 MW in the TBM. Table III and Fig. 5 show the breakdown of nuclear heating in the different components of the DCLL TBM.

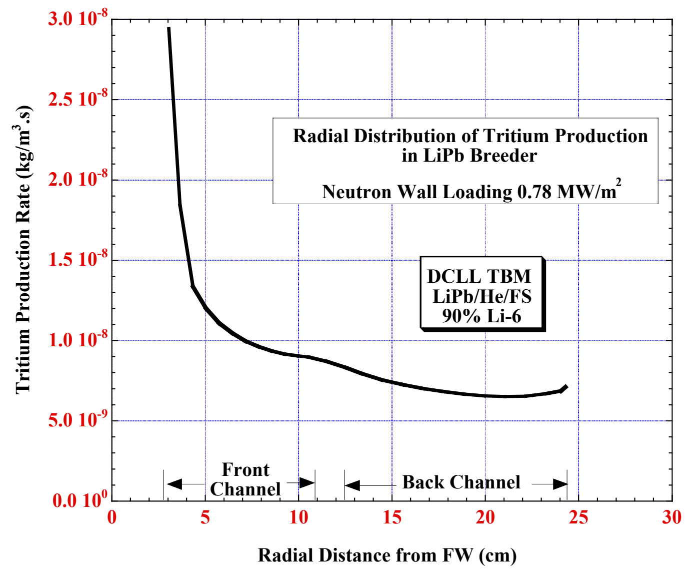

Figure 3. Radial variation of tritium production rate in LiPb.

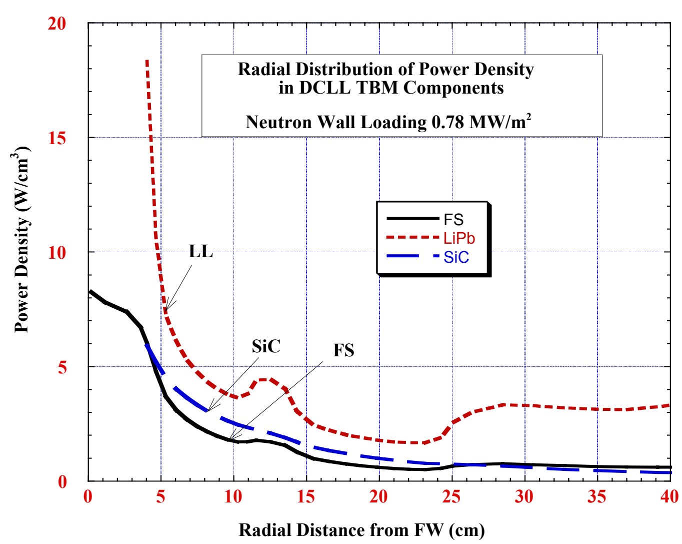

Figure 4. Radial distribution of power density in constituent materials of the DCLL TBM.

TABLE II. PEAK POWER DENSITIES (W/CM^3) IN TBM CONSTITUENT MATERIALS

Constituent Material	Peak Power Density (W/cm^3)
Be PFC	8.6
Ferritic Steel	8.2
LiPb	18
SiC	5.9

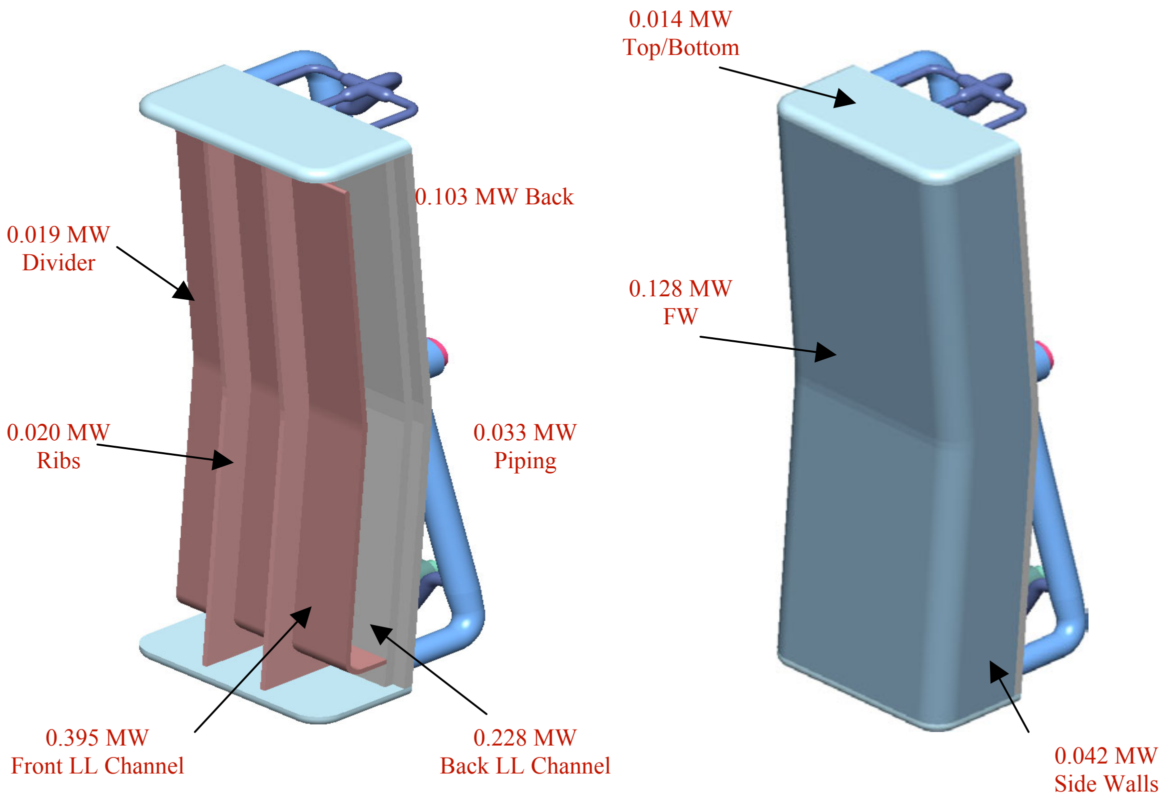

Figure 5. Nuclear heating in TBM components.

TABLE III. NUCLEAR HEATING IN TBM COMPONENTS DURING 500 MW D-T PULSE

Component	Nuclear Heating (MW)
First Wall	0.128
Side Walls	0.042
Top/Bottom Walls	0.014
Flow Channel Divider	0.019
Radial Ribs	0.020
Back Wall	0.103
Inlet/Outlet Pipes	0.033
Front LiPb Channel	0.395
Back LiPb Channel	0.228
Total	**0.982**

V. STRUCTURE RADIATION DAMAGE

The radial variation of the dpa, helium production, and hydrogen production rates in the ferritic steel structure of the DCLL TBM were determined and are shown in Fig. 6. The results are given for the 0.78 MW/m^2 neutron wall loading corresponding to the 500 MW D-T pulse. For the average ITER neutron wall loading of 0.57 MW/m^2 and the total fluence goal of 0.3 MWa/m^2, the total full power lifetime is 0.526 FPY. The peak cumulative end-of-life dpa in the FW is 5.7 dpa and the peak end-of-life helium production is 64 He appm. Figure 7 shows the radial variation of steel damage rates in the piping zone and shield plug behind the TBM. The cumulative end-of-life He production in the inlet/outlet pipes is 0.34 He appm. This is less than the limit of 1 He appm adopted in ITER for rewelding.

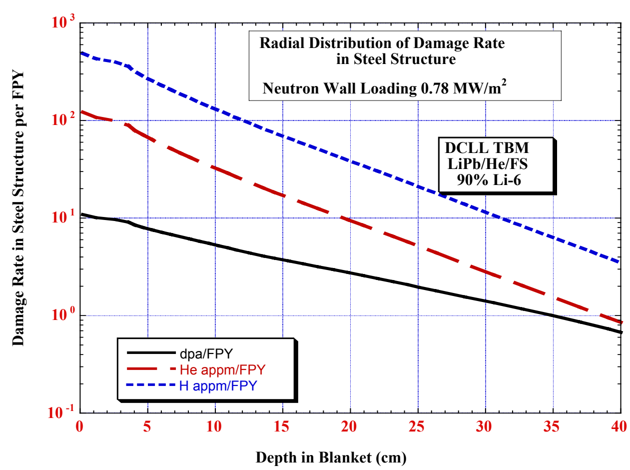

Figure 6. Radial variation of damage rates in the ferritic steel structure of the TBM.

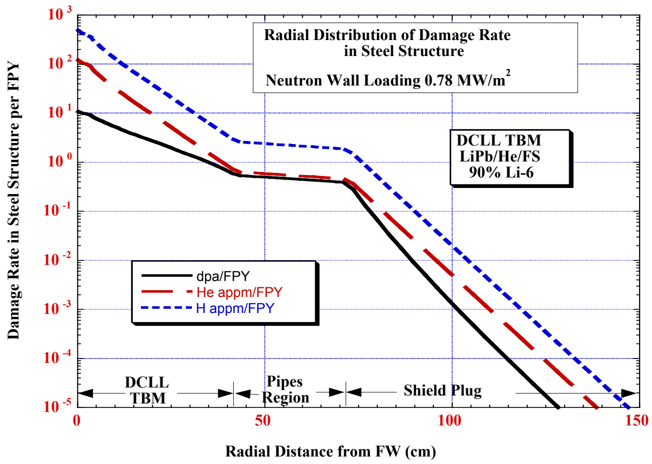

Figure 7. Radial variation of damage rates in the piping region and shield plug behind the DCLL TBM.

VI. Shielding Requirement

The required size of the shield plug is determined primarily by the need to have hands-on access behind it after shutdown for disconnecting components. Past experience with neutronics and activation calculations for fusion designs indicated that the activation of the shield and outlying components will be low enough to result in shutdown dose rates <25 μSv/h (allowing hands-on access) if the neutron flux at the back of the shield is kept below ~2x10^6 n/cm^2 during operation. This rule of thumb was found to be applicable to within a factor of 2. Figure 8 gives the effect of shield plug thickness on the neutron flux behind it. Based on these results we estimate that ~1 m thick shield plug is required behind the DCLL TBM. This needs to be confirmed by performing detailed activation analysis that accounts for streaming in the shield plug penetrations. Another requirement for the shield plug is to provide adequate shielding for the adjacent TF coils. This will be assessed in the future using detailed ITER 3-D models.

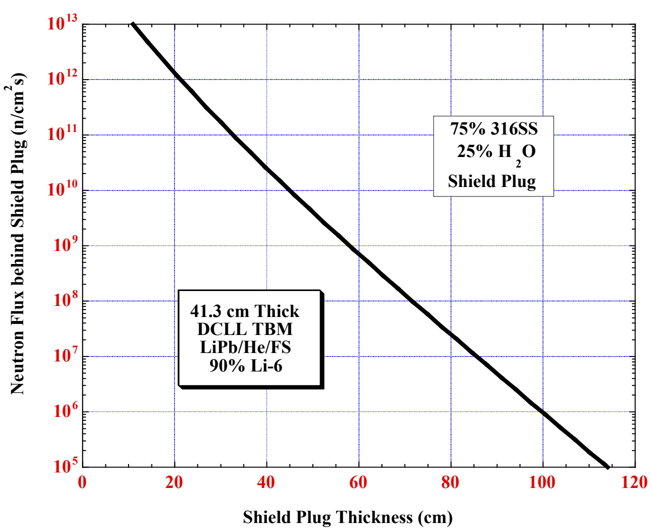

Figure 8. Variation of neutron flux with shield plug thickness.

VII. Summary and Conclusions

Neutronics calculations were performed to determine the relevant nuclear performance parameters for the DCLL TBM developed by the U.S. for testing in ITER. These include tritium breeding, nuclear heating, radiation damage, and shielding requirements. The neutron wall loading at the TBM is 0.78 MW/m^2. The front surface area of the module is 1.25 m^2. A 2 mm thick beryllium layer is utilized as a plasma facing material on the ferritic steel (FS) first wall (FW). The lithium in the lithium lead ($Li_{17}Pb_{83}$) eutectic is enriched to 90% Li-6. The FS alloy F82H is used for structural material. The total radial depth of the TBM is 41.3 cm followed by a 30 cm thick inlet/outlet piping zone. A separate 316SS/H_2O shield plug is used behind the TBM.

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Acknowledgment

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