Neutronics Performance Parameters for the US Dual Coolant Lead Lithium ITER Test Blanket Module

Mohamed Sawan[1], Edward Marriott[1], Mohamed Dagher[2]

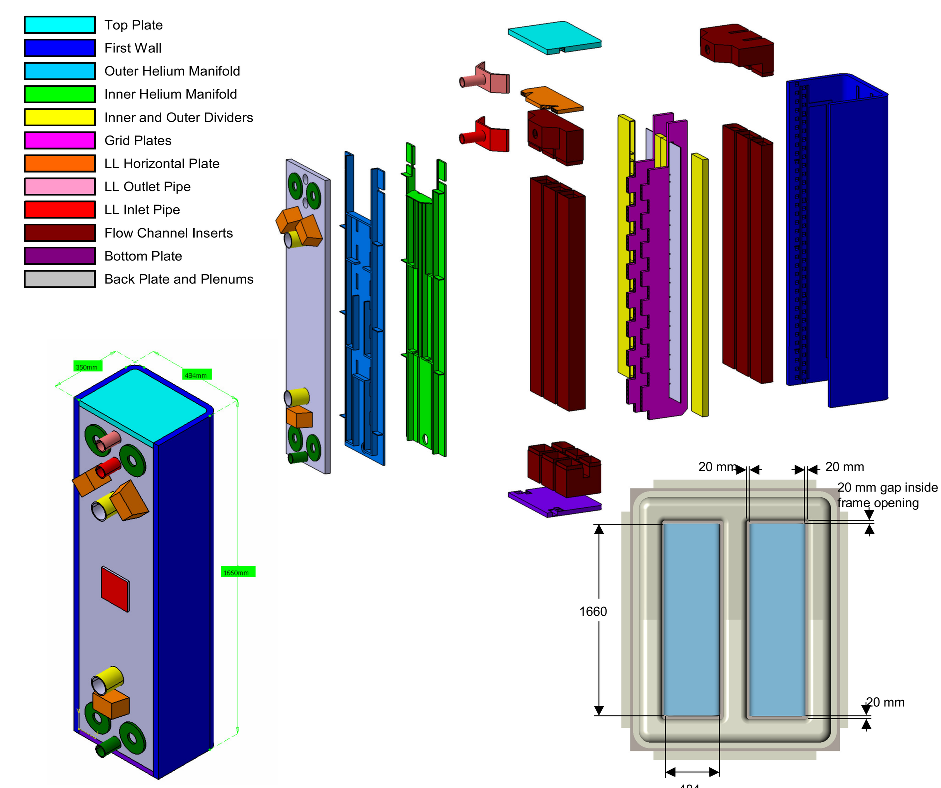
[1]*Fusion Technology Institute, University of Wisconsin-Madison,* [2]*University of California-Los Angeles*

Background

- DCLL concept uses He to remove heat deposited in FW and blanket structure and a flowing PbLi breeder to remove nuclear heat generated in the breeding zone at a high temperature for efficient power conversion
- DCLL is the preferred US blanket concept for commercial fusion plants
- The DCLL TBM went through major design changes since the last technical design review held in August 2006
- Detailed updated design configuration was released in April 2008
- The nuclear parameters for the DCLL TBM were updated for the current design

DCLL TBM Design Features

- Frontal dimensions 48.4x166 cm ($0.8\ m^2$)
- Radial depth 35 cm
- Neutron wall loading $0.78\ MW/m^2$
- 2 mm Be PFC on ferritic steel (F82H) FW
- Lead lithium $\{Li_{17}Pb_{83}\}$ eutectic enriched to 90% Li-6
- 5 mm SiC_f/SiC inserts (FCI) used in all PbLi flow channels



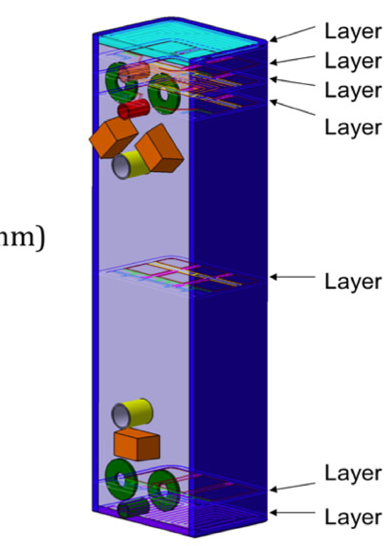
DCLL Radial Build and Material Composition

- The TBM is divided into seven vertical layers each representing a poloidal section of the TBM
- These sections are determined based on the internal design configuration of the TBM, in order to maintain a uniform vertical configuration in each vertical layer
- For each poloidal layer the radial zones are homogenized by determining the volume fractions of each material in the zone based on CAD models
- The material volume fractions for each zone were then used in neutronics calculations to determine relevant nuclear parameters throughout the corresponding poloidal layer
- Results for the 7 layers were combined using their heights to determine the overall integrated parameters

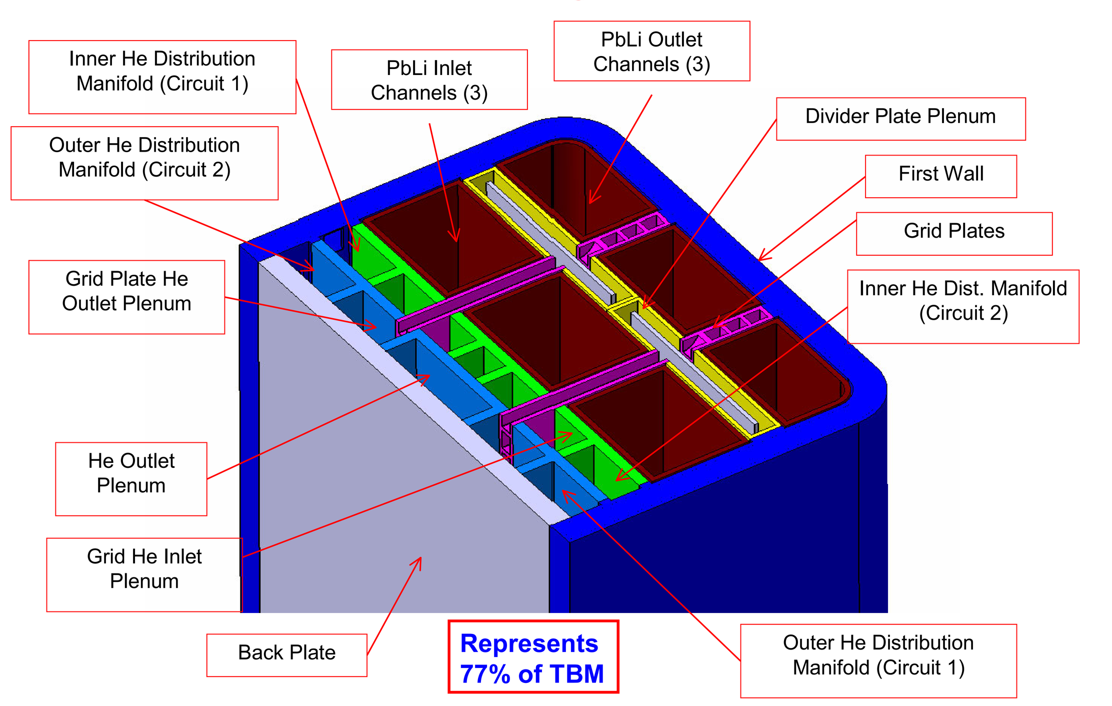
Seven Layers were used

(Layer height shown in parentheses):

1) Top Plate (28mm)
2) PbLi Outlet (100mm)
3) Horizontal Grid Plate (20mm)
4) PbLi Inlet (120mm)
5) Midplane (1275mm)
6) Bottom Zone (93mm)
7) Bottom Plate (24mm)



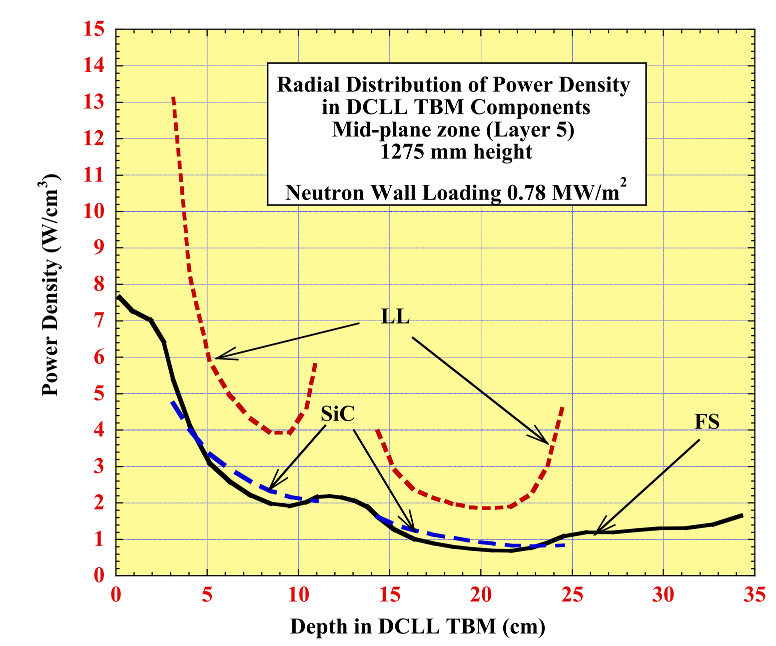
DCLL TBM Assembly Mid-Plane Section



Radial Build at Layer #5

Zone	Description	Thickness [mm]	% Be	% FS	% LL	% SiC	% He
1	PFC	2	100	0	0	0	0
2	Front wall of FW	4	0	100	0	0	0
3	FW cooling channel	20	0	17	0	0	83
4	Back wall of FW	4	0	100	0	0	0
5	FCI layer 1	7	0	6.3	24.7	55.4	13.6
6	Front breeding channel	66	0	6.3	73.9	6.2	13.6
7	FCI layer 2	7	0	6.3	24.7	55.4	13.6
8	Front wall of divider	4	0	86.4	0	0	13.6
9	Divider gap 1	10	0	31	0	0	69
10	Plenum layer	4	0	82.1	0	0	17.9
11	Divider gap 2	10	0	31	0	0	69
12	Back wall of divider	4	0	86.4	0	0	13.6
13	FCI layer 3	7	0	6.3	24.7	55.4	13.6
14	Back breeding channel	86	0	6.3	73.9	6.2	13.6
15	FCI layer 4	7	0	6.3	24.7	55.4	13.6
16	Inner He manifold	10	0	86.4	0	0	13.6
17	Inner He channel	30	0	12.6	0	0	87.4
18	Outer He manifold	10	0	88.4	0	0	11.6
19	Outer He channel	30	0	10.2	0	0	89.8
20	Back plate	30	0	90.4	0	0	9.6

Layer 5 Power Density Distribution



Total Nuclear Heating in TBM

- Power density in Be PFC 8.14 W/cm³ in layer 2
- Peak power density in FS structure 9.20 W/cm³ in layers 1,7
- Peak power density in PbLi 13.20 W/cm³ in layer 3
- Peak power density in SiC FCI 4.79 W/cm³ in layer 2

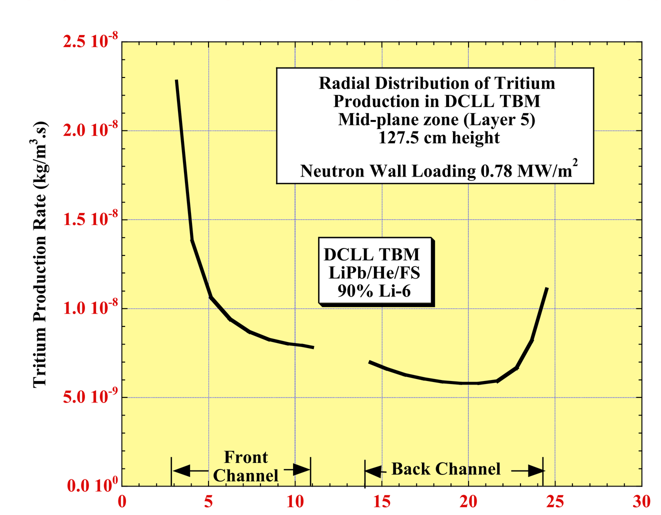
Vertical Layer	Height (mm)	Nuclear Energy Mult. (M_n)	Nuclear Heating (MW)
1	28	0.857	0.009
2	100	0.935	0.035
3	20	0.904	0.007
4	120	0.939	0.042
5	1275	0.920	0.441
6	93	0.917	0.032
7	24	0.857	0.008
Total	**1660**	**0.920**	**0.574**

Tritium Production in TBM

- Local TBR in the 35 cm thick DCLL TBM is only 0.561
- Tritium generation rate in the TBM is $1.55x10^{17}$ atom/s ($7.73x10^{-7}$ g/s) during a D-T pulse with 500 MW fusion power
- For a pulse with 400 s flat top total tritium generation is $3.25x10^{-4}$ g/pulse
- For the planned 3000 pulses per year the annual tritium production in the TBM is 0.97 g/year
- Tritium production in the Be PFC is $1.54x10^{-9}$ g/s ⇒ $6.47x10^{-7}$ g/pulse ⇒ $1.94x10^{-3}$ g/year

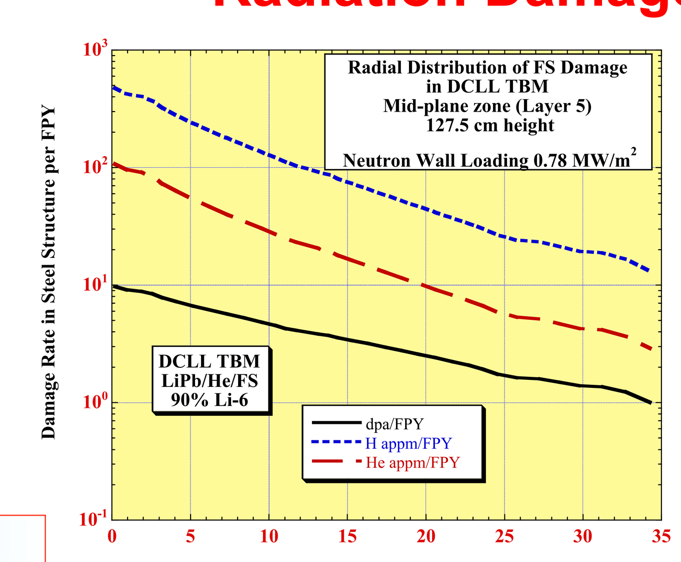
Vertical Layer	Height (mm)	Local TBR	Tritium Prod. (g/s)
1	28	0	0
2	100	0.733	$6,08x10^{-8}$
3	20	0.338	$5.61x10^{-9}$
4	120	0.662	$6.59x10^{-8}$
5	1275	0.560	$5.92x10^{-7}$
6	93	0.625	$4.82x10^{-8}$
7	24	0	0
Total	**1660**	**0.561**	$\mathbf{7.73x10^{-7}}$

Tritium Production Distribution



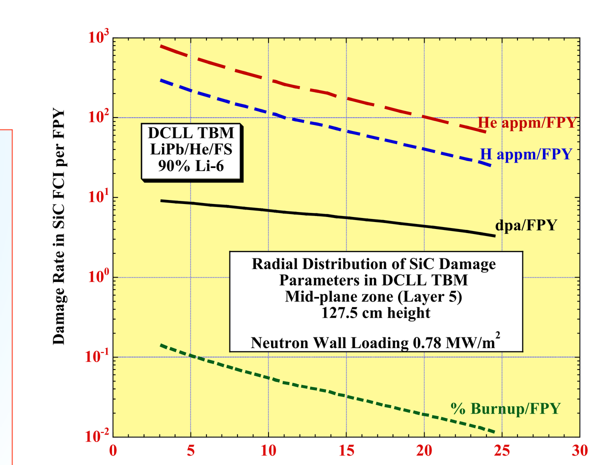
- Peak tritium production rate in PbLi is $2.3x10^{-8}\ kg/m^3s$ during the 500 MW D-T pulse

Radiation Damage in Steel Structure

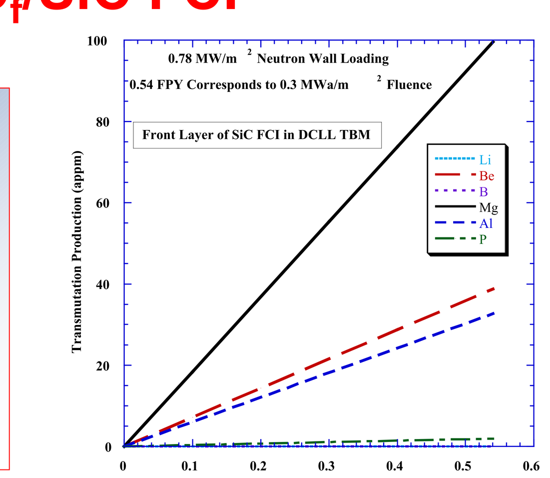


- Peak FS damage rates:
  - 9.73 dpa/FPY
  - 107 He appm/FPY
  - 472 H appm/FPY
- For $0.57\ MW/m^2$ average NWL and total fluence $0.3\ MWa/m^2$ total lifetime is 0.526 FPY
- Peak cumulative end-of-life dpa in FW is **5.1 dpa** and He production is **56.3 He appm**

Peak Radiation Damage in SiC_f/SiC FCI



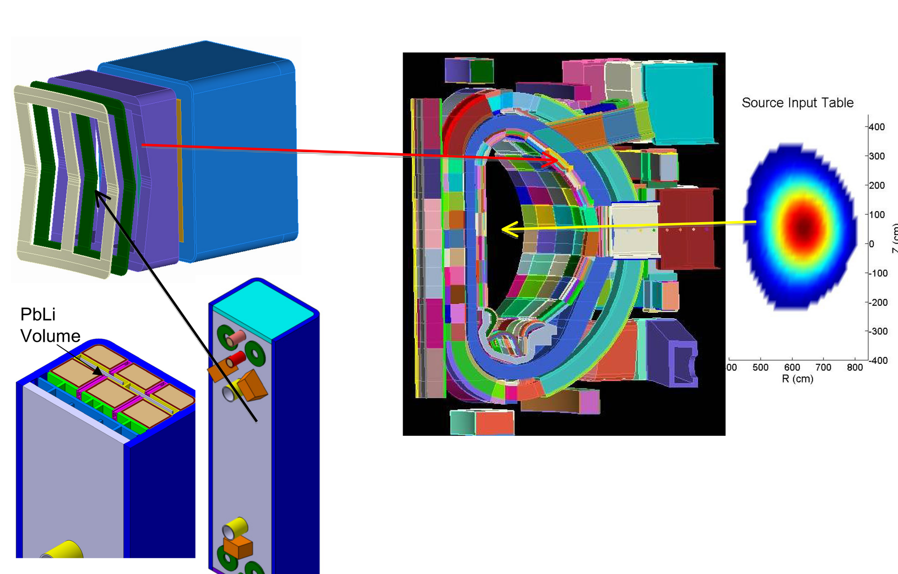
- Peak SiC damage rates:
  - 9.14 dpa/FPY
  - 777 He appm/FPY
  - 291 H appm/FPY
  - 0.14% burnup/FPY
- Peak cumulative end-of-life dpa in FCI is **4.8 dpa**, He production is **409 He appm**, H production is **153 H appm** burnup is **0.073%**



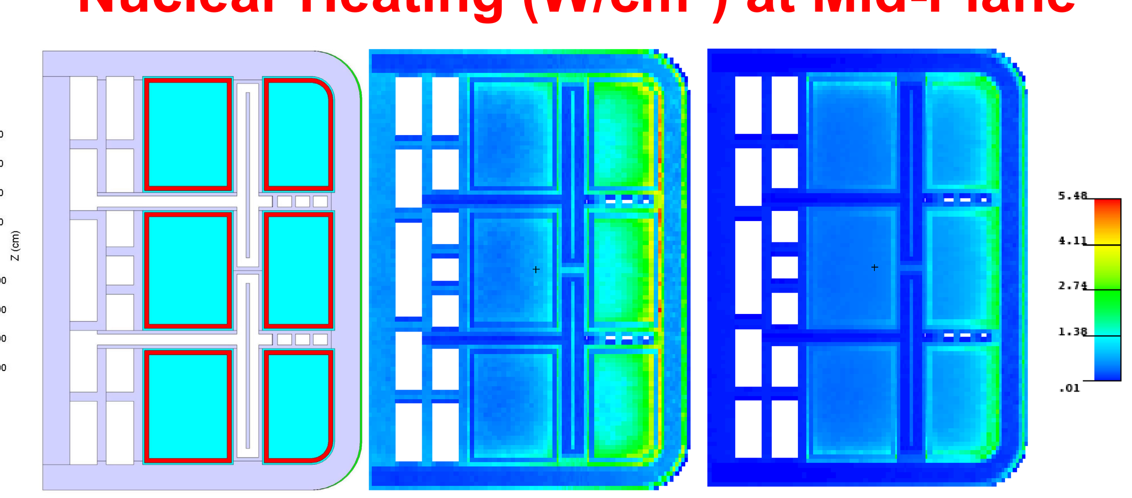
- Dominant metallic transmutation product is Mg
- When DCLL blanket is used in a power reactor Mg concentration in SiC FCI at end-of-life of blanket is 0.43 at%
- Impact on conductivity should be addressed

3-D Neutronics Analysis for DCLL TBM

- Calculations started using DAG-MCNP
- Detailed CAD model for DCLL TBM is utilized
- Helium in the current model is represented by void
- A full PbLi volume has been created for analysis
- A simplified CAD model with homogenized zones was generated for the frame (FW and shield regions)
- TBM and Frame CAD models will be combined and integrated model used in calculations

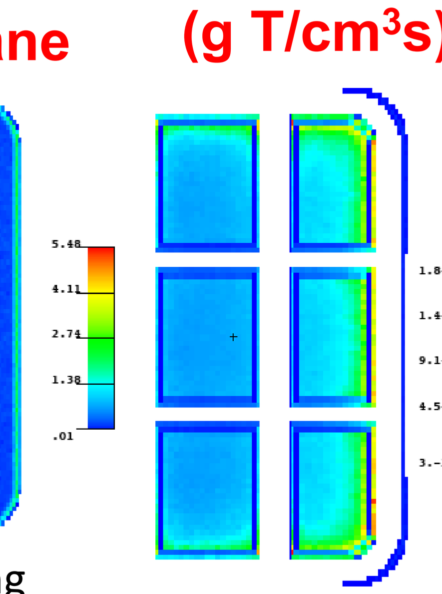


Nuclear Heating (W/cm³) at Mid-Plane

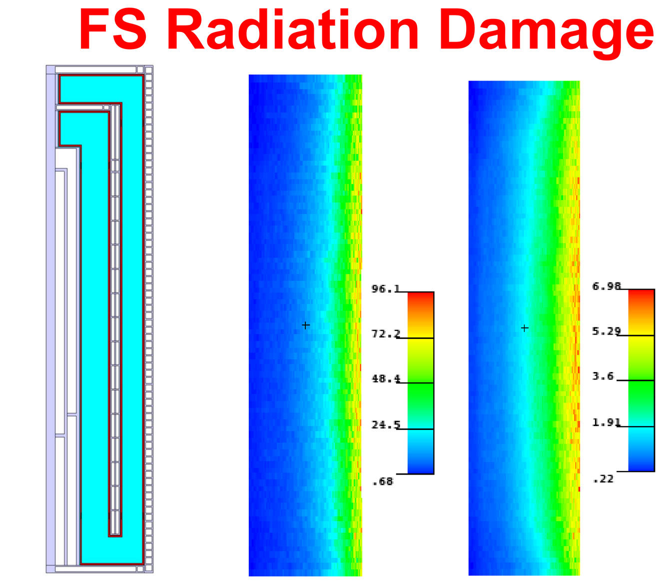


Cross section Gamma heating Neutron heating

Tritium Production (g T/cm³s)



FS Radiation Damage



Cross section He appm/FPY dpa/FPY

Conclusions

- Neutronics calculations performed to determine relevant nuclear parameters for reference US DCLL ITER TBM
- Calculated TBR in TBM is only 0.561 because of the relatively small thickness used
- Annual tritium production in the TBM is 0.97 g
- Total nuclear heating in TBM is 0.574 MW
- Peak cumulative radiation damage and He production in the FW are 5.1 dpa and 56 appm
- Dominant metallic transmutation product in FCI is Mg that builds up to ~100 appm at end-of-life of ITER
- We estimated that ~1.2 m thick shield is required behind the DCLL TBM to allow personnel access for maintenance
- ***Detailed 3-D analysis using the DAG-MCNP code is in progress***