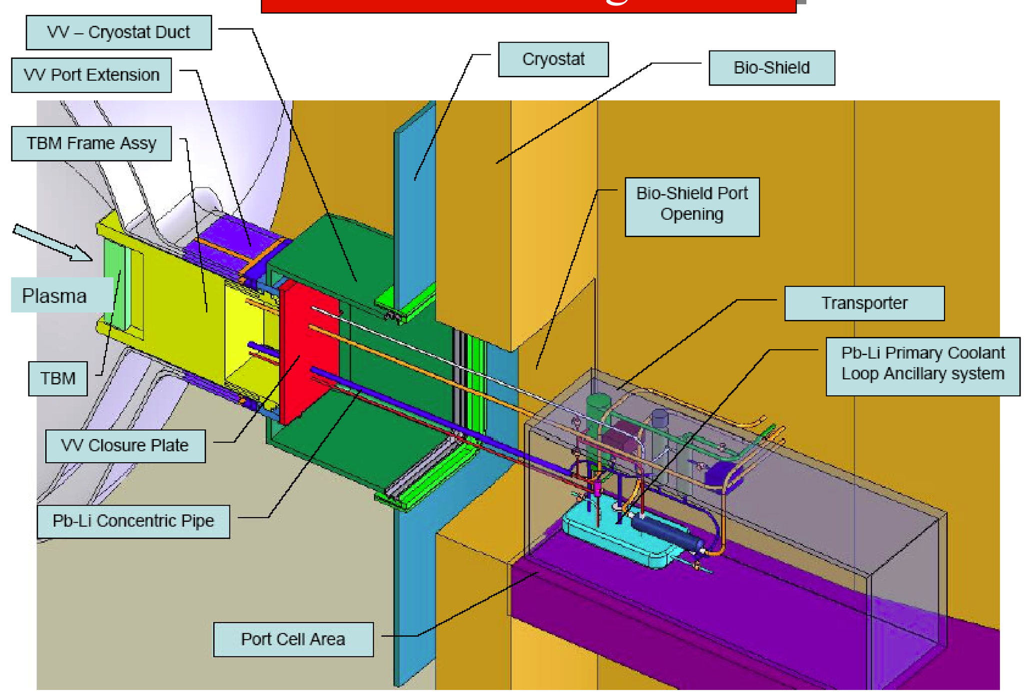
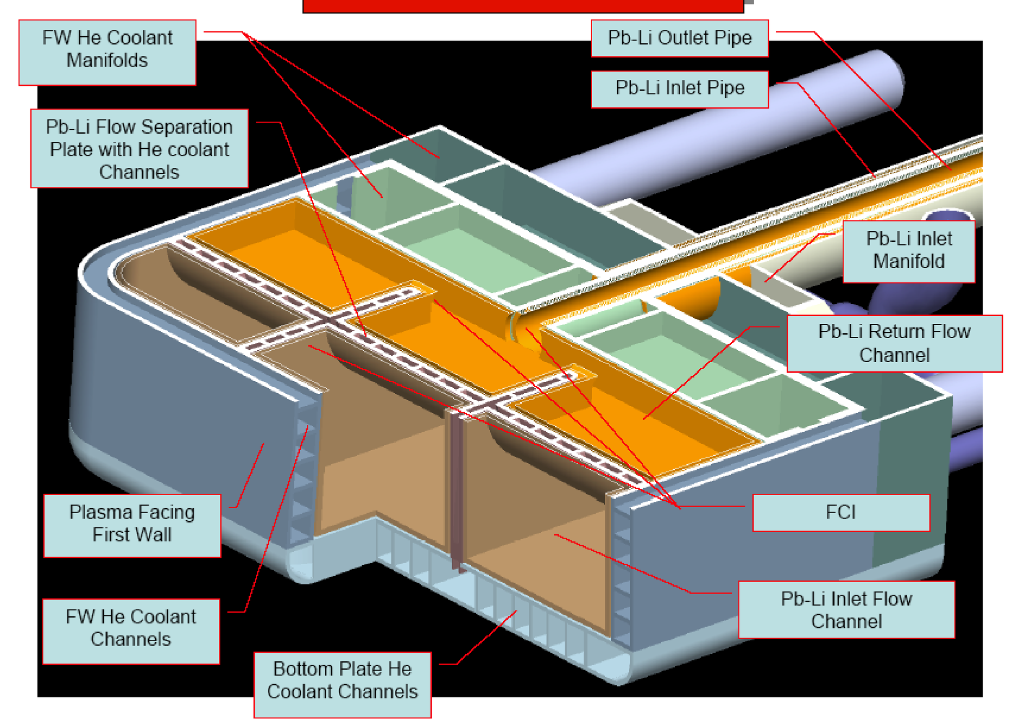
Neutronics Features of a Dual Coolant Lithium Lead Test Blanket Module for ITER

M.E. Sawan, University of Wisconsin-Madison **M.Z. Youssef**, University of California-Los Angeles

TBM Port Configuration

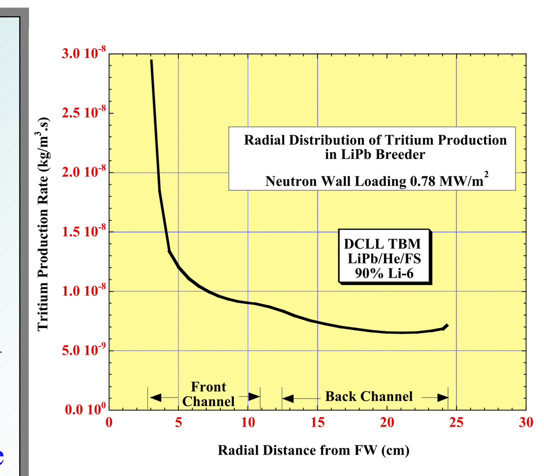


DCLL TBM Details



Tritium Production

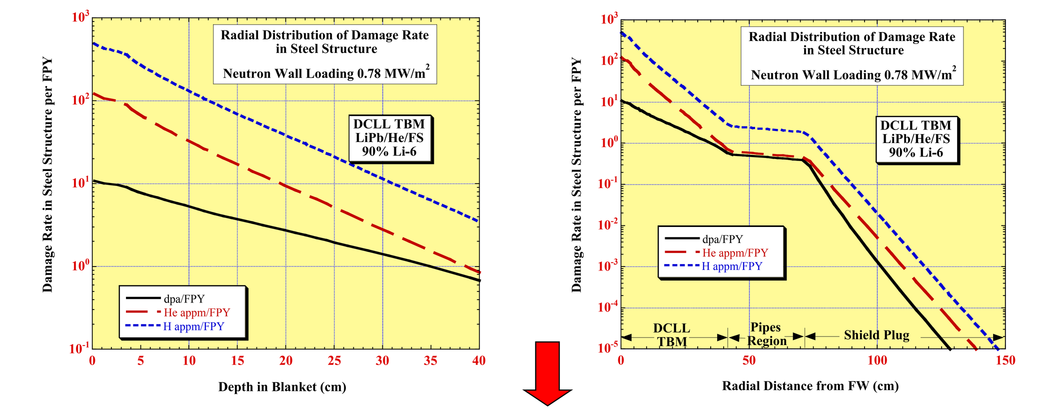
- Local TBR in the DCLL TBM is only 0.741 because of the small thickness (42.3 cm)
- Tritium generation rate in the TBM is 3.2×10^{17} atom/s (1.59×10^{-6} g/s) during a D-T pulse with 500 MW fusion power
- For a pulse with 400 s flat top preceded by 100 s linear ramp up to full power and followed by 100 s linear ramp down total tritium generation 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
- Tritium production in the Be PFC is 2.2×10^{-9} g/s ⇒ 1.1×10^{-6} g/pulse ⇒ 3.3×10^{-3} g/year (only 0.14% of total)



Peak tritium production rate in LiPb is 2.94×10^{-8} kg/m³s during the D-T pulse

Radiation Damage in Steel Structure

Determined radial variation of dpa, He production, and hydrogen production rates in structure

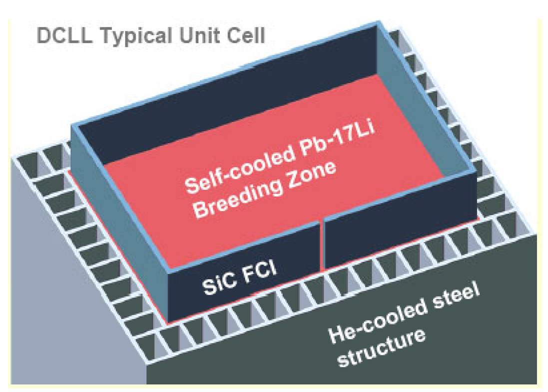


- For 0.57 MW/m² average NWL and total fluence 0.3 MWa/m² total lifetime is 0.526 FPY
- Peak cumulative end-of-life dpa in FW is **5.7 dpa** and He production is **64 He appm**
- Peak cumulative end-of-life He production in inlet/outlet pipes is **0.34 He appm**
  ⇒ Pipe connections at back of TBM are reweldable

Dual Coolant Lead-Lithium (DCLL) FW/Blanket Concept

Idea of "Dual Coolant" concept –
Push for higher performance with present generation materials (FS)

- Ferritic steel FW and structure cooled with helium
- Breeding zone is self-cooled LiPb
- Structure and breeding zone separated by SiC_f/SiC composite *flow channel inserts (FCIs)* that
  - Provide thermal insulation to decouple Pb-17Li bulk flow temperature from FS wall
  - Provide electrical insulation to reduce MHD pressure drop in the flowing liquid metal



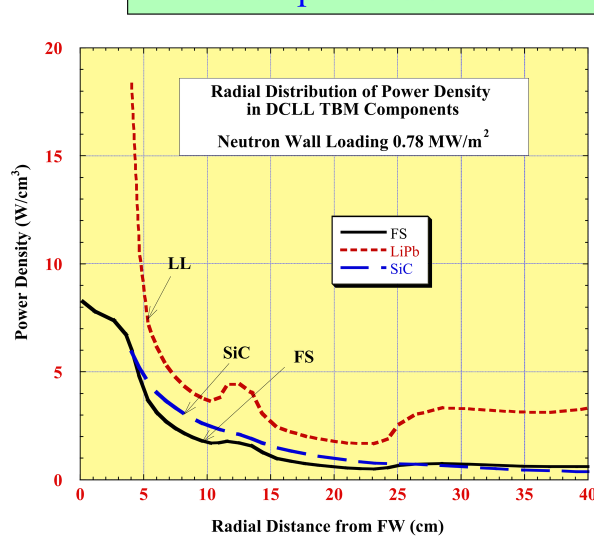
LiPb exit temperature can be significantly higher than the operating temperature of the steel structure
⇨ High Efficiency

Basic Assumptions

- Frontal dimensions 64.5 x 194 cm (1.25 m²)
- Neutron wall loading 0.78 MW/m²
- 2 mm Be PFC on ferritic steel (F82H) FW
- Lead lithium $\{Li_{17}Pb_{83}\}$ eutectic enriched to 90% Li-6
- 5 mm SiC inserts (FCI) used in all PbLi flow channels
- Total radial depth of TBM is 41.3 cm followed by a 30 cm thick inlet/outlet piping zone
- Material composition in radial layers carefully determined to account for detailed configuration and material variation in toroidal and poloidal directions based on the current CAD drawings
- Neutronics calculations performed to determine the relevant nuclear performance parameters for the DCLL TBM

Nuclear Heating

Radial variation of nuclear heating (W/cm³) determined in the components of the DCLL TBM



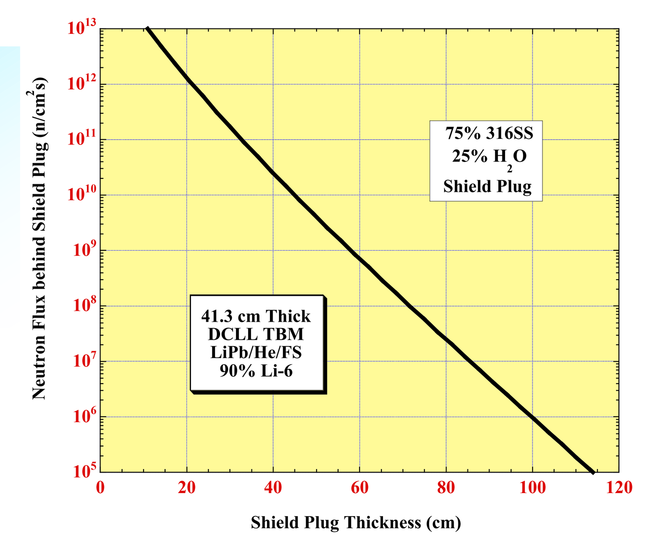
- Power density in Be PFC 8.6 W/cm³
- Peak power density in FS structure 8.2 W/cm³
- Peak power density in LiPb 18 W/cm³
- Peak power density in SiC FCI 5.9 W/cm³

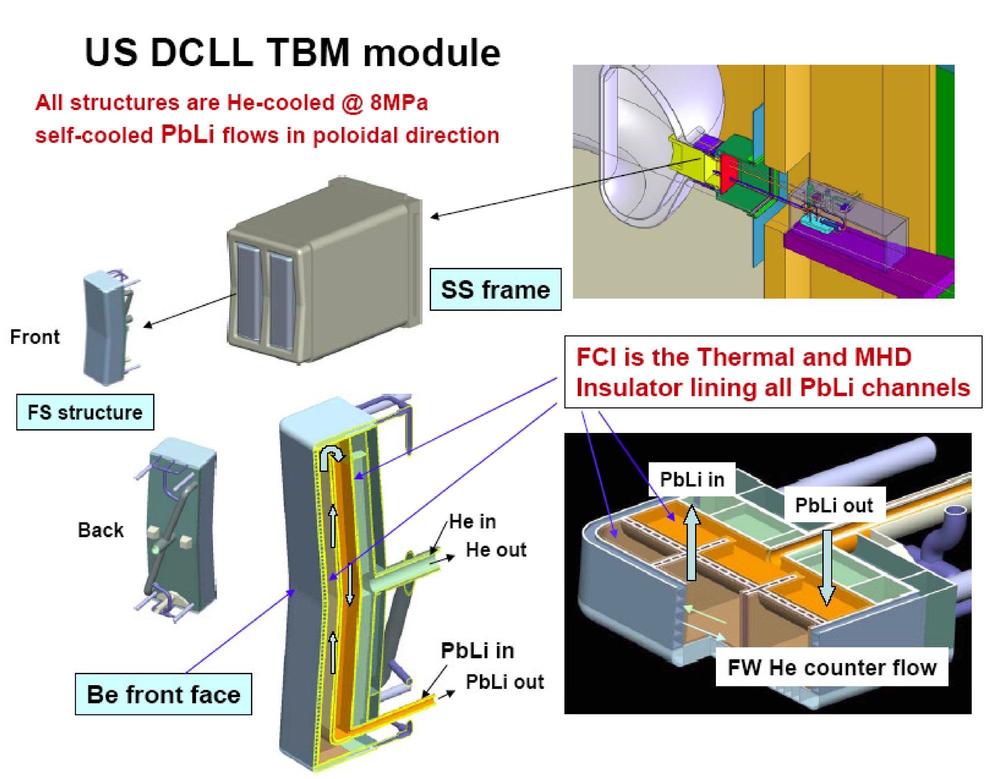
Required Shield Plug

Rule of Thumb

Past experience indicated that activation of 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 back of shield is kept below $\sim2\times10^{6}$ n/cm²s during operation

~1 m thick plug shield is required behind the DCLL TBM





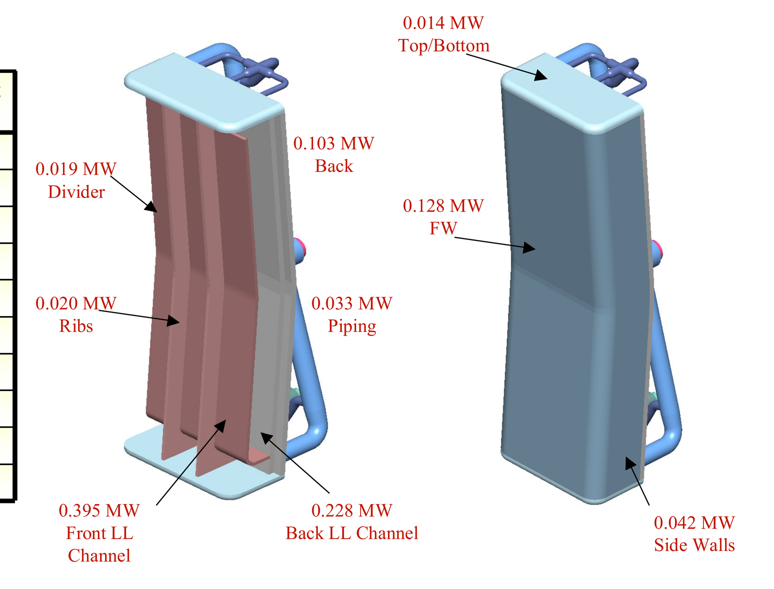
Radial Build and Material Composition

Zone	Description	Thick (mm)	% Be	% FS	% LL	% SiC	% He
1	PFC Layer	2	100	0	0	0	0
2	Front wall of FW	4	0	100	0	0	0
3	FW coo ling channel	30	0	17	0	0	83
4	Back wall of FW	4	0	100	0	0	0
5	SiC insert 1	5	0	8.1	0	80	11.9
6	Front breeding channel	70	0	8.1	75.7	4.3	11.9
7	SiC insert 2	5	0	8.1	6.1	73.9	11.9
8	Flow divider plate	15	0	54.8	6.1	0.4	38.7
9	SiC insert 3	5	0	8.5	6.1	73.3	12.1
10	Back breeding channel	110	0	8.5	74.7	4.7	12.1
15	SiC insert 4	5	0	8.5	1	78.4	12.1
16	Back wall	170	0	62.8	1	0.2	36
	Total	415					

- Assumed TBM inlet/outlet piping zone behind TBM is 30 cm thick with 5% FS, 1% LL, 0.2% SiC, 10% He, and 83.8% void
- Separate SS/H_2O shield plug used behind TBM (25% H_2O)

Nuclear Heating in TBM Components

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 Pb-17Li Channel	0.395
Back Pb-17Li Channel	0.228
Total	**0.982**



Summary and Conclusions

- Local TBR in the DCLL TBM is only 0.741
- For the planned 3000 D-T pulses per year annual tritium production in the TBM is 2.4 g/year
- Total nuclear heating in TBM is 0.982 MW and total thermal power is 1.357 MW with He coolant carrying about 54% of it
- For ITER fluence goal of 0.3 MWa/m² peak cumulative dpa and He production in FW are 5.7 dpa and 64 appm
- Cumulative end-of-life He production in inlet/outlet pipes is 0.34 appm allowing for rewelding
- ~1 m thick shield plug is required behind the DCLL TBM to allow personnel access for maintenance