Development of the FW Mobile Tiles Concept

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OUTLINE

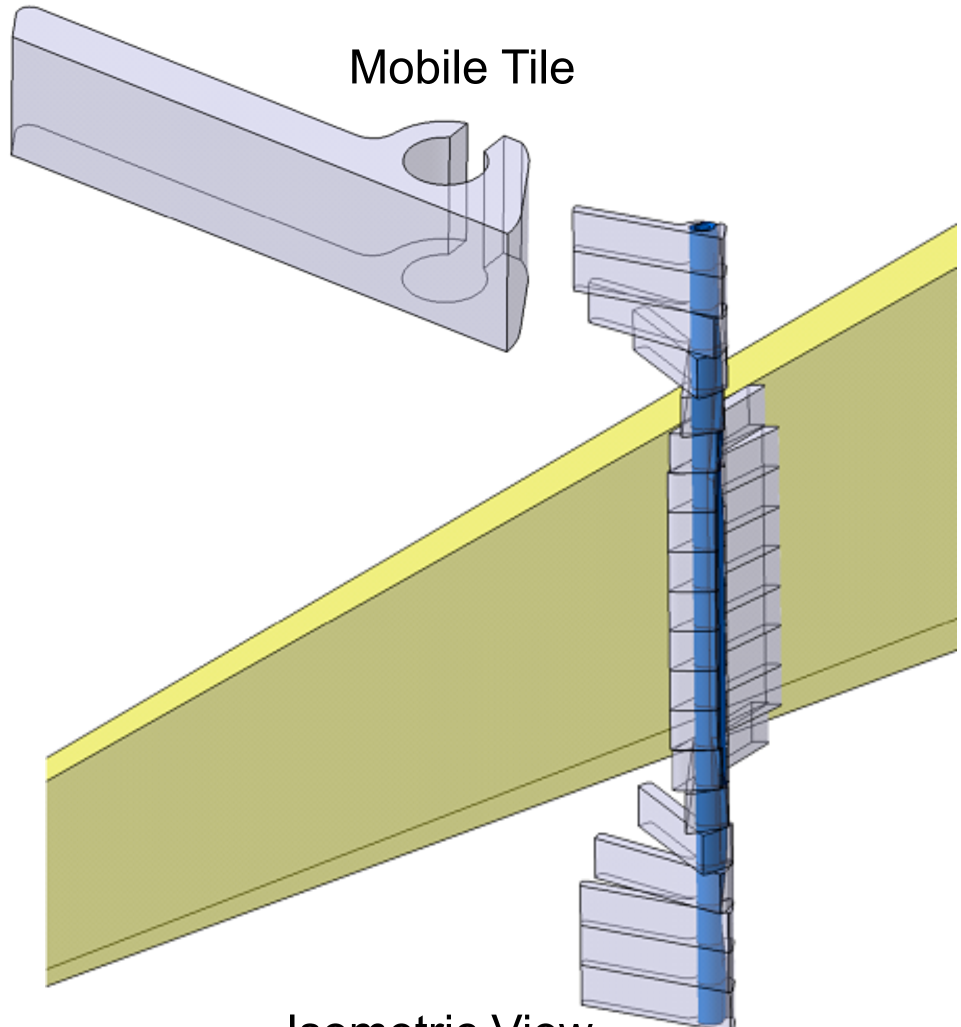
1. Configuration with consideration for laser beam port accommodation and tile insertion and removal
2. Neutronics assessment of blanket design options with FW mobile tiles

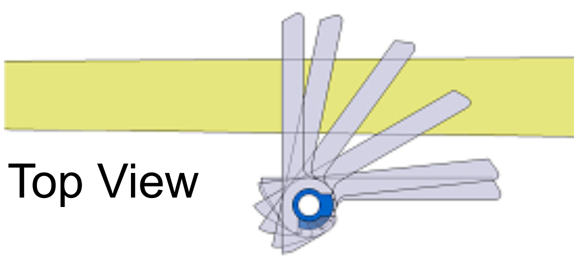
Concept

- Tiles will traverse the cylindrical chamber walls over a certain period of time
- Once removed, the tiles will be reprocessed for tritium removal and recycling
- Tiles will then be reinserted along the chamber walls
- Top and bottom chamber tiles will be stationary and will be removed and reprocessed as needed

Laser Port Tiles

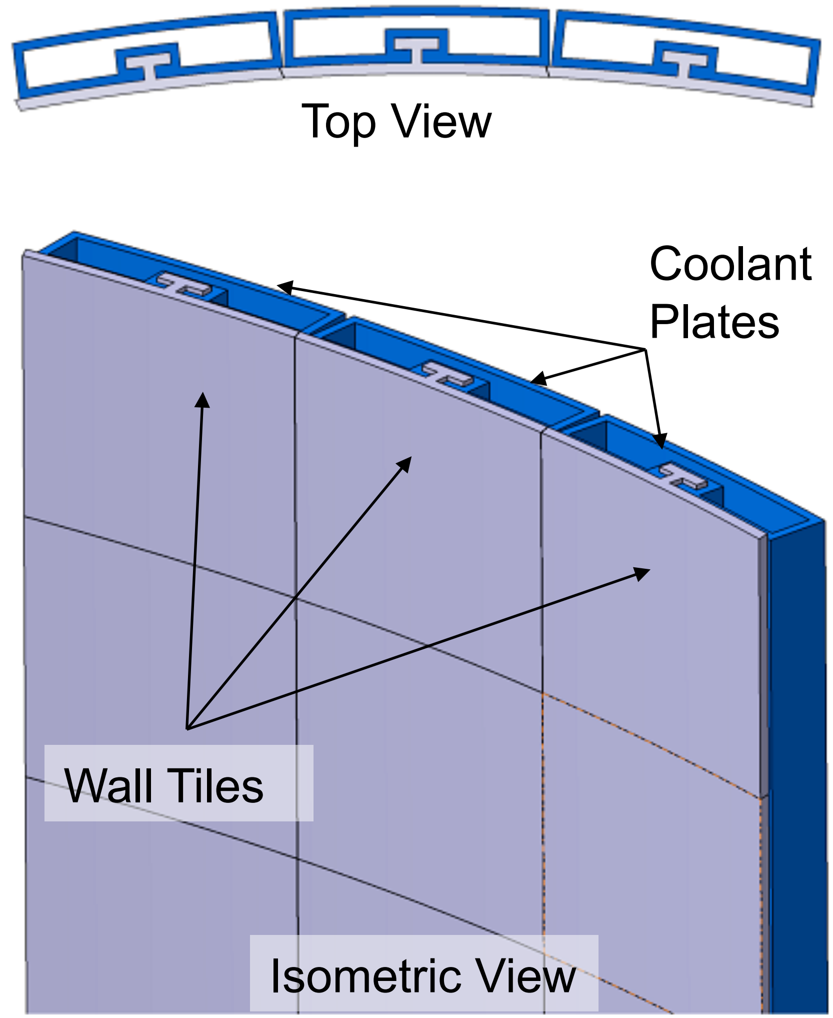
- These tiles traverse the chamber along a coolant rod (shown in blue)
- At the location of the laser ports, the tiles will rotate around the coolant rod by following a guiding rail on the coolant rod



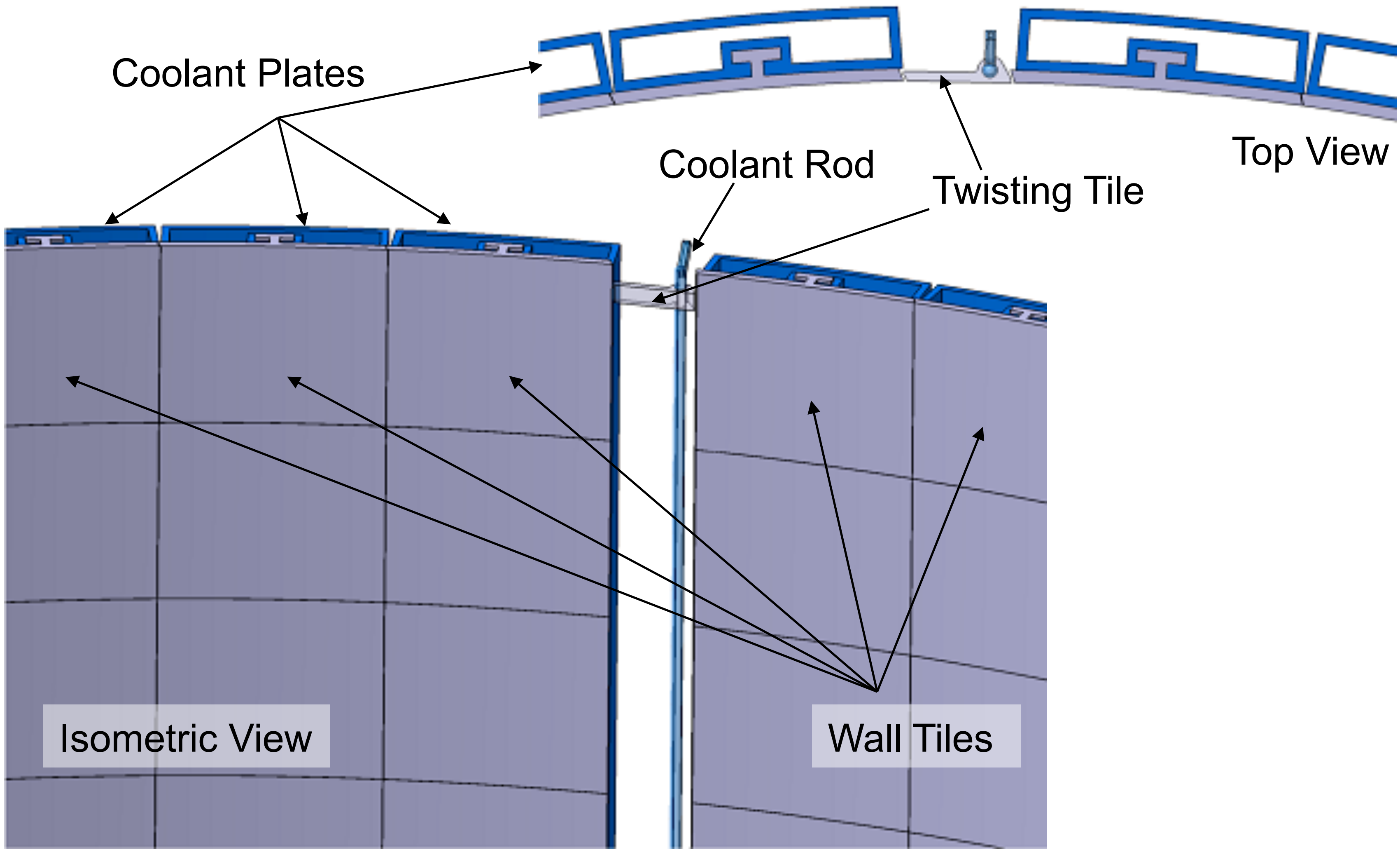


Chamber Wall Tiles

- For sections of chamber walls without laser beam penetration, larger tiles will be used
- These tiles will traverse vertically through the chamber without the need to twist to open for lasers

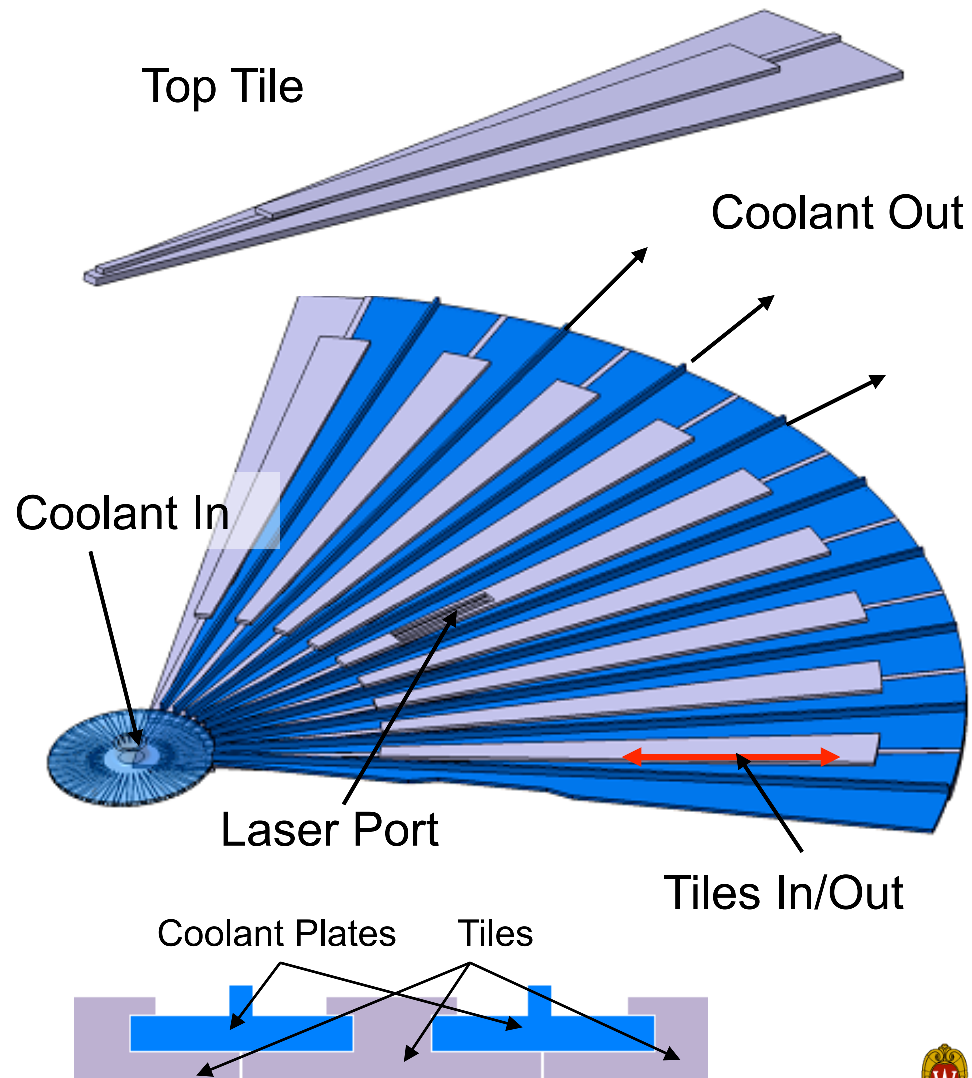


Overall Wall Geometry



Top and Bottom Geometry

- Top and Bottom tiles will be stationary
- Four tiles on the top and bottom each will have an opening for the lasers
- Tiles are installed by sliding them into place on the coolant plates (coolant plates shown in blue)



Representative Cross Section

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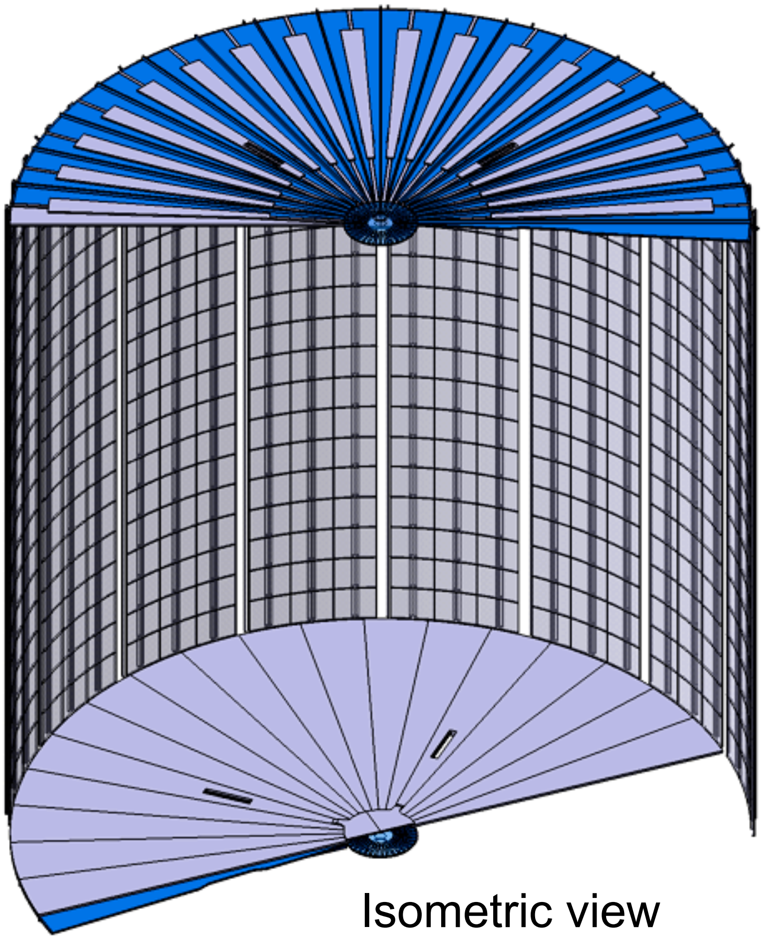
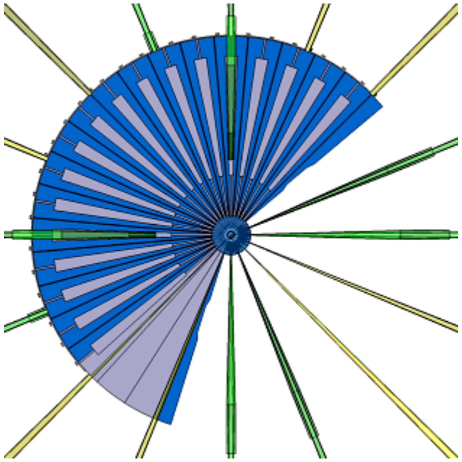
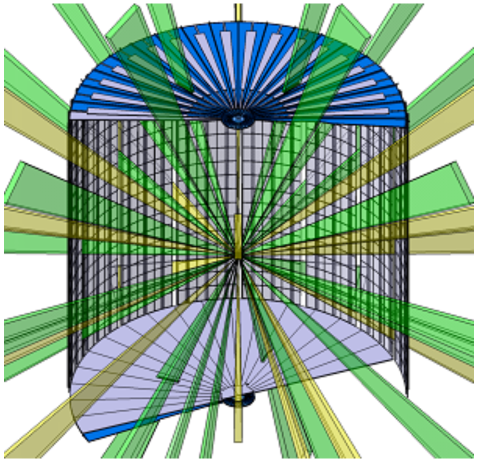
Full Chamber Representation



Isometric view without lasers



Top view with lasers



Isometric view with lasers

Neutronics Assessment and Assumptions

- Neutronics calculations performed to assess breeding potential for different design options
  - Breeder options: Ceramic breeder (Li_4SiO_4), Flibe, Liq. Li, LiPb
  - Coolant options: Liq. Na, Liq. breeder
  - Structure options: FS, V-4Cr-4Ti, SiC_f/SiC
  - Considered adding Be_2C in the graphite tiles to improve TBR
- 7 and 10 cm average tile thicknesses considered followed by a meter thick blanket
- Cylindrical chamber with 10-m radius
- Used HAPL target spectrum in 175 neutron, 42 gamma groups
- A zone consisting of 85% FS, 15% He used behind blanket to represent reflection from shield/VV
- Required TBR>1.1 for tritium self-sufficiency

TBR Results for Ceramic Breeder Options

- Li_4SiO_4 with 30% Li-6 enrichment was found in previous calculations to maximize TBR
- FS structure is used with Na coolant

FW Tiles				Blanket					FW Tile Thickness	
% FS	% Na	% C	% Be_2C	% FS	% Na	% C	% Li_4SiO_4	% Be_2C	7 cm	10 cm
10	15	75	0	10	10	10	70	0	**0.911**	**0.868**
10	15	55	20	10	10	10	50	20	**1.059**	**0.999**
10	15	55	20	10	10	10	40	20	**1.096**	**1.024**
10	15	45	30	10	10	10	40	30	**1.127**	**1.056**

- Adding 30% Be_2C in FW tiles and blanket is essential for achieving tritium self-sufficiency
- Average FW tile thickness should be kept at 7 cm or less

TBR Results for Liquid Breeder Options (Na in tiles)

- Three liquid breeder options were considered with three structural materials
- Natural Li is used except for LiPb where 90% Li-6 enrichment was also considered
- FW tiles consist of 75% C, 10% structure, 15% Na
- Blanket consists of 90% liq. Breeder and 10% structure

10 cm tiles

	Flibe	Li	LiPb (nat)	LiPb (90% Li-6)
FS	0.865	1.045	0.690	1.075
V	0.933	1.119	0.817	1.130
SiC	0.959	1.080	1.042	1.149

7 cm tiles

	Flibe	Li	LiPb (nat)	LiPb (90% Li-6)
FS	0.949	1.150	0.812	1.213
V	1.014	1.223	0.954	1.258
SiC	1.012	1.159	1.144	1.248

- Nat. Li and enriched LiPb yield adequate TBR with any structural material for 7 cm or less tiles
- V provides best neutron economy with FS giving the least
- Flibe does not allow tritium self-sufficiency with any structural material

TBR Results for Liquid Breeder Options
(breeder in tiles)

- To avoid using two coolants we considered the option of cooling the FW tiles with the same liquid breeder used in blanket
- FW tiles consist of 75% C, 10% structure, 15% liq. breeder
- Blanket consists of 90% liq. breeder and 10% structure

10 cm tiles

	Flibe	Li	LiPb (nat)	LiPb (90% Li-6)
FS	0.934	1.107	0.808	1.185
V	1.001	1.177	0.948	1.229
SiC	0.992	1.116	1.128	1.210

7 cm tiles

	Flibe	Li	LiPb (nat)	LiPb (90% Li-6)
FS	0.983	1.182	0.876	1.267
V	1.043	1.251	1.022	1.303
SiC	1.030	1.182	1.191	1.286

- Breeding increased by ~2-5% when liquid breeder is used instead of Na to cool FW tiles with conclusions regarding adequacy of TBR remaining the same

Enhancing TBR for Flibe Blanket

- Using Flibe as breeder does not provide adequate tritium breeding with any of the candidate structural materials
- We assessed the effect of adding Be_2C to the graphite FW tiles
- Tiles have 10% structure and 15% Na with the remaining 75% split between C and Be_2C
- Blanket consists of 90% Flibe and 10% structure

7 cm tiles

	0% Be_2C	20% Be_2C	30% Be_2C	40% Be_2C
FS	0.983	1.007	1.034	1.061
V	1.043	1.075	1.104	1.131
SiC	1.030	1.094	1.134	1.175

- Tritium self-sufficiency with a Flibe blanket can be achieved only with at least 30% Be_2C added in FW tiles and either SiC or V structure used

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Issues for Coolant/Breeder Choice

Coolant	T_m(˚C)	ρ(g/cm^3)	C_p(J/gK)	k(W/mK)
Na	98	~0.9	~1.3	~84
Li	181	~0.5	~4.2	~60
Flibe	459	~2	~2.4	~1
LiPb	234	~9.5	~0.18	~15

Physical properties depend on temperature range

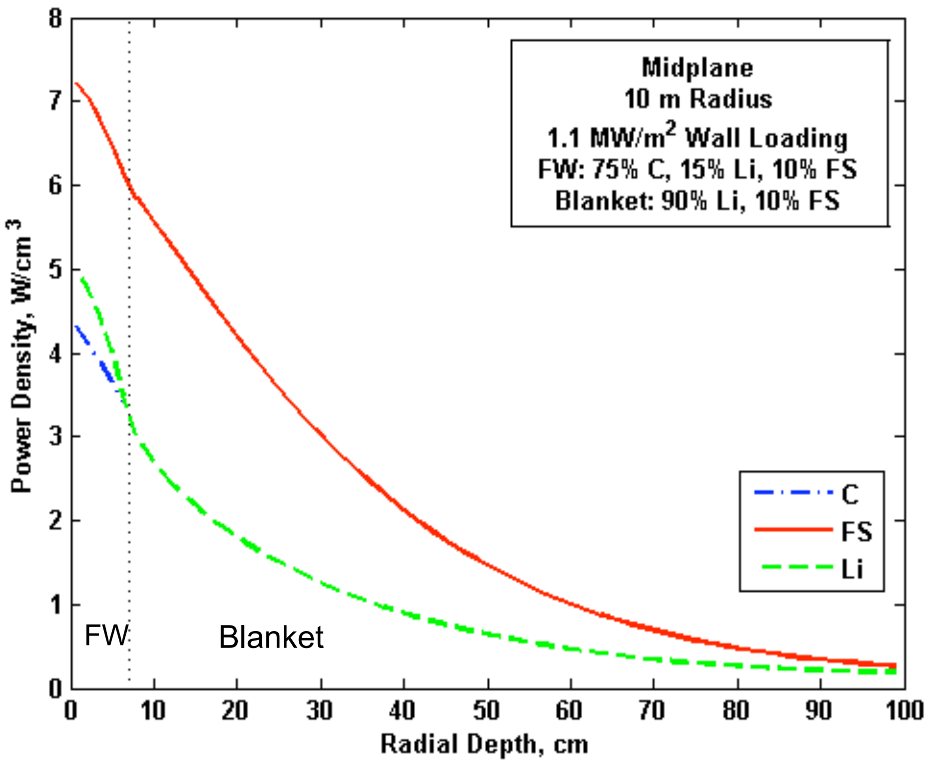
- High surface heat flux (~0.4 MW/m^2) and volumetric heating (~4 W/cm^3) in FW tiles require coolant with good heat removal capability. Liquid Na is the best with Li close second and Flibe being the worst
- With its low melting point and light weight, liq. Na is the preferred option for cooling the FW tiles but adds complication of having two coolants in the power cycle

Preferred Design Options

- To avoid the complexity of having two coolants in the power cycle, it is preferred to cool the FW tiles with the same liquid breeder used in the blanket
- While both Li and LiPb can provide adequate TBR, Li is the preferred option due to its better heat removal capability, light weight leading to less pumping power, and no need for enrichment. The main issue is safety concern that can be mitigated by using He cooling in shield/VV
- Choice of structural material depends on compatibility with Li. While V and SiC yield better TBR and can operate at higher temperatures than FS, they are more expensive, require more R&D and compatibility with Li could limit their operating temperature

Nuclear Heating in FW Tiles and Blanket

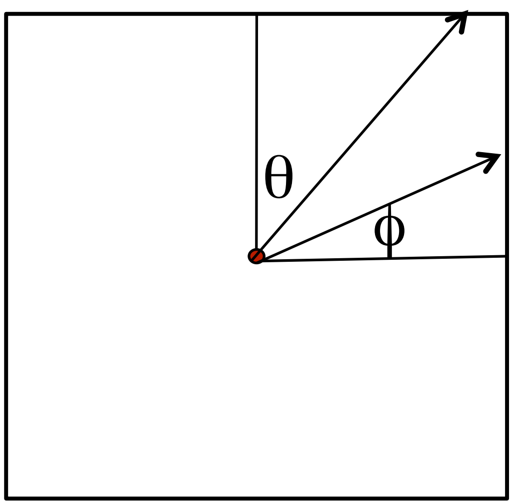
- Nuclear heating and surface heat flux calculated for use in thermal analysis
- Nuclear heating results scale with the neutron wall loading



- Peak surface heat flux at midplane =0.37 MW/m^2
  - Drops to 0.13 MW/m^2 at top/bottom with an average value of 0.26 MW/m^2
- Peak neutron wall loading at midplane =1.09 MW/m^2
  - Drops to 0.39 MW/m^2 at top/bottom with an average value of 0.77 MW/m^2

Surface Heat Load and Neutron Wall Load Distribution

Cylindrical chamber assumed with 10 m radius and 20 m height



- Distributions of surface heat flux and neutron wall loading peak at mid-plane and centers of chamber's top and bottom
- Peak surface heat flux =0.37 MW/m^2
- Peak neutron wall loading =1.09 MW/m^2
- Axial values drop as one moves away from mid-plane scaling as $\cos^3\phi$
- Radial values at top/bottom drop as one moves away from center scaling as $\cos^3\theta$
- Average surface heat flux
  - Side 0.26 MW/m^2
  - Top/bottom 0.22 MW/m^2
- Average neutron wall loading
  - Side 0.77 MW/m^2
  - Top/bottom 0.64 MW/m^2

Conclusions

- **Conceptual configuration developed with consideration for laser beam port accommodation and simple tile insertion and removal scheme**
- **Tritium self-sufficiency can be achieved with a variety of options employing FW mobile tiles**
- **Using ceramic breeders or Flibe is not recommended due to requiring at least 30% Be_2C added in FW tiles**
- **While liquid Na has the best heat removal capability for FW tiles, it adds the complexity of having two coolants. Either Li or LiPb can be used also to cool the FW tiles**
- **Li is the preferred breeder/coolant due to better heat removal capability, lighter weight, and no enrichment**
- **Choice of structural material depends primarily on compatibility with Li**