Mobile Tiles for Inertial Fusion First Wall/Blanket Systems

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Introduction

- A critical issue facing inertial fusion power devices is the high heat and particle flux impinging on FW
- For solid wall designs the IFE environment produces extremely high pulsed temperatures and erosion/ablation of FW
- These conditions limit material choice and lifetime of FW materials
- In contrast to MFE machines, IFE allows greater design flexibility for FW and blanket to address the issue of FW survival
- This poster describes a concept of a solid FW (mobile tiles)
- By removing the graphite-based FW tiles on a predetermined schedule and post-processing these tiles the common problems associated with graphite-based solid walls can be mitigated:
  - Erosion is managed by continual replacement
  - Tiles are inspected and can be processed once removed
  - Irradiation degraded thermo-physical properties such as thermal conductivity can be restored through the same annealing step used to remove tritium
- Such a concept is decidedly low-tech, and similar to that employed in the Pebble Bed Modular Fission Reactors

Mobile Tiles Concept

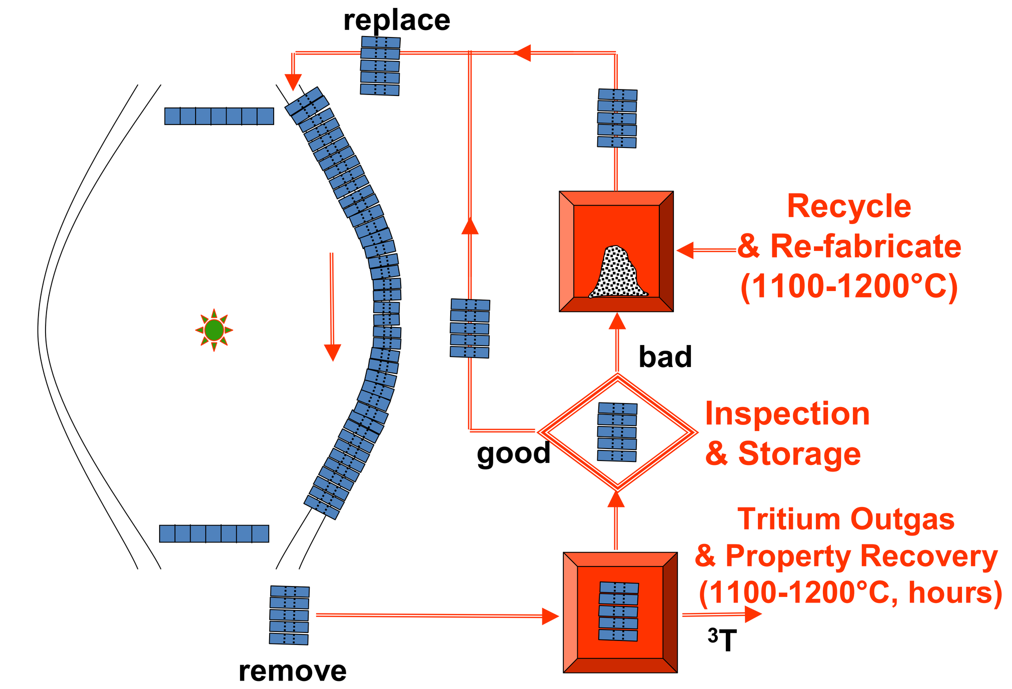
Snapshot of the HAPL Solid Wall Issues

- The high pulsed surface temperature limits us to select first wall materials
  refractory metals : tungsten, moly,…
  graphite or carbon fiber composites
  high conductivity ceramics : SiC

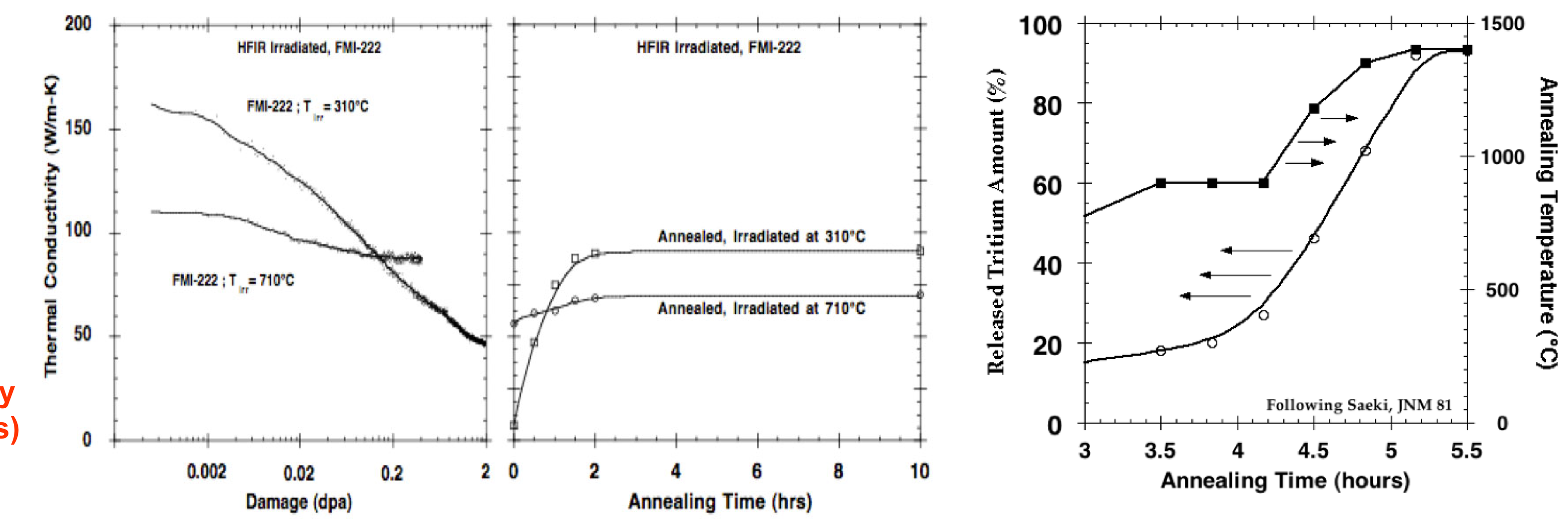
	Tungsten	Graphite	Carbon Fiber Composite	SiC	Refractory Armored Ferritic
Mechanical Integrity*	Poor	None (2 yr?)	None (1 yr?)	OK	Possible
Erosion	< 4 cm/year	tbd	tbd	Too High	< 4 cm/year
Tritium Retention	OK	Very High	High	OK	OK
Low Activation	Yes	Yes	Yes	Yes	Yes

* Assumes 3 year Replacement : 30 dpa Carbon (10 dpa W), 1000°C

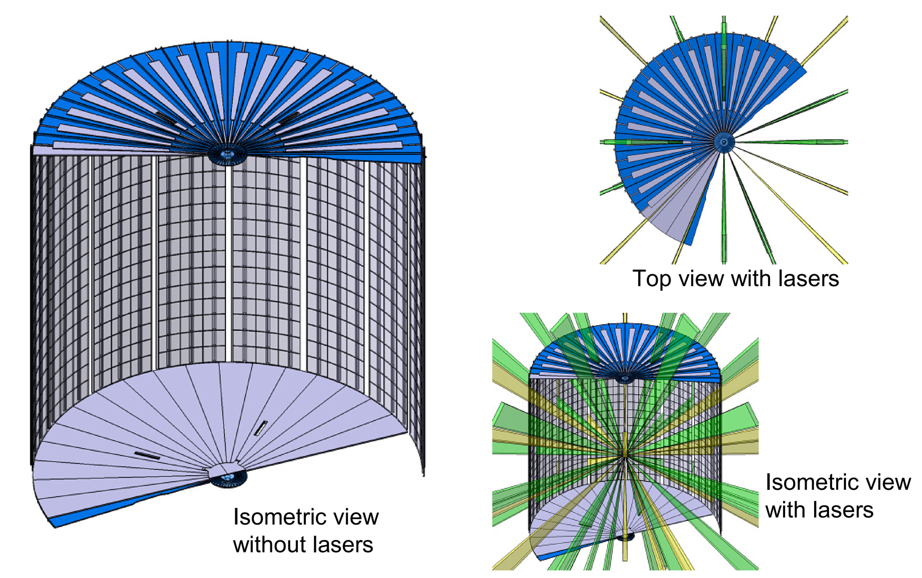
By periodically removing tiles, annealing them, and reinstallation tritium retention, surface erosion may be mitigated



Post-irradiation annealing of tile compact will recover thermal and mechanical properties of tile as well as recover

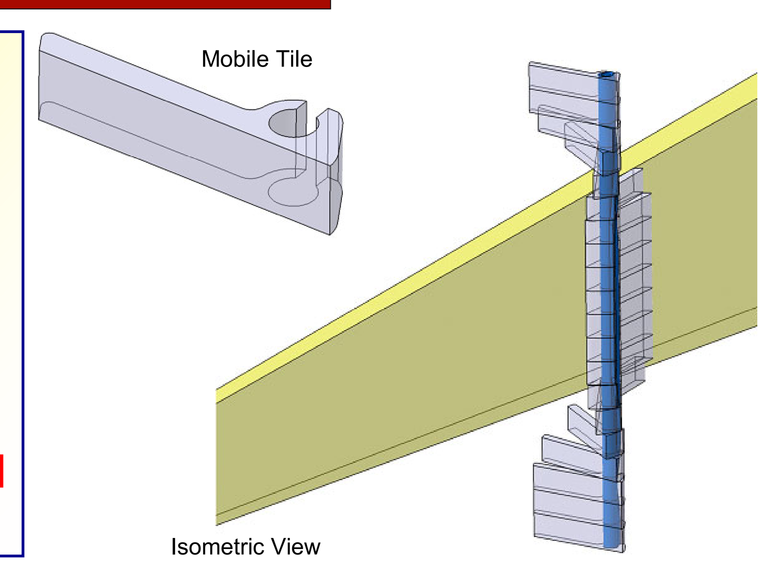


Full Chamber Representation



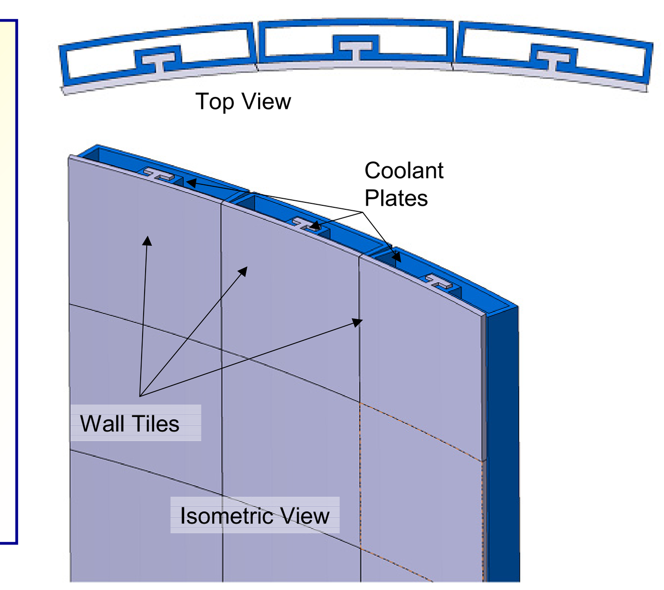
Laser Port Tiles

- 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



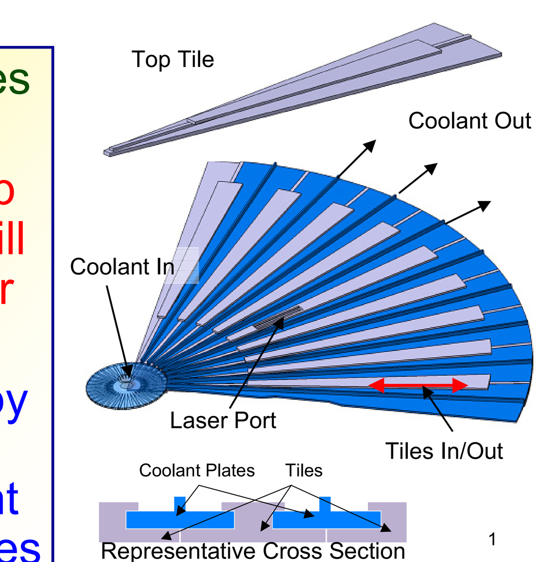
Chamber Wall Tiles

- 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



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)



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 Liquid Breeder Options (Na in tiles)

- Three liquid breeder options considered with three structural materials
- Natural Li 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

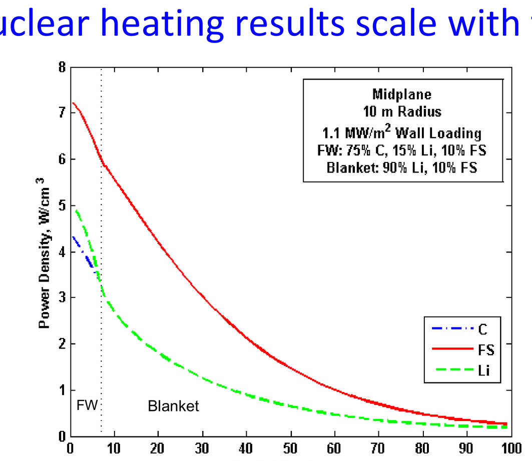
- Breeding increased by ~2-5% when liquid breeder is used instead of Na to cool FW tiles

Preferred Design Option

- 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

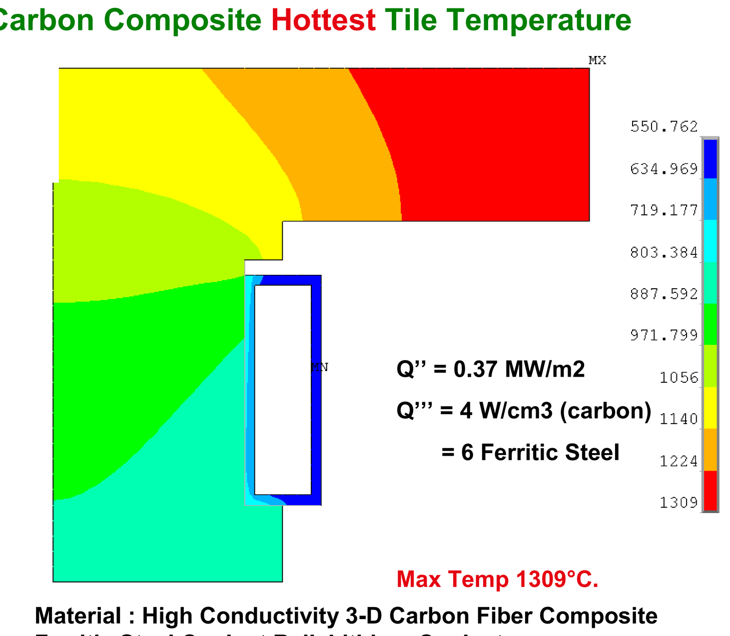
Nuclear Heating in FW Tiles and Blanket

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



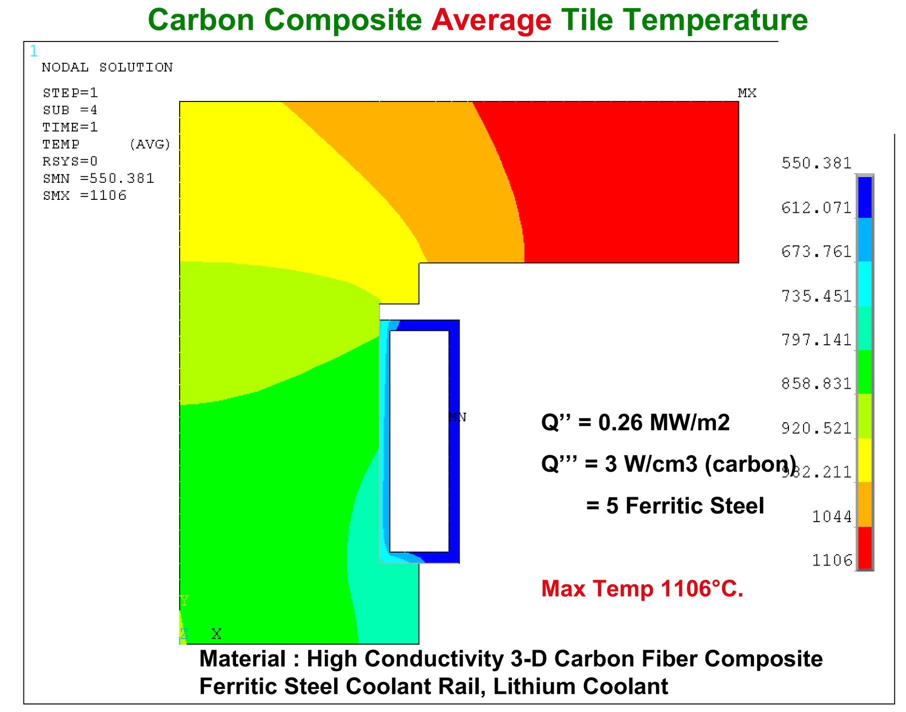
- Peak surface heat flux at midplane =0.37 MW/m²
  - Drops to 0.13 MW/m² at top/bottom with an average value of 0.26 MW/m²
- Peak neutron wall loading at midplane =1.09 MW/m²
  - Drops to 0.39 MW/m² at top/bottom with an average value of 0.77 MW/m²

Carbon Composite Hottest Tile Temperature



Material : High Conductivity 3-D Carbon Fiber Composite
Ferritic Steel Coolant Rail, Lithium Coolant

Carbon Composite Average Tile Temperature



Material : High Conductivity 3-D Carbon Fiber Composite
Ferritic Steel Coolant Rail, Lithium Coolant

Conclusions

- ***Using mobile FW tiles that are periodically removed, annealed, and reinstalled tritium retention and surface erosion may be mitigated***
- **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 need for enrichment**
- **Choice of structural material depends primarily on compatibility with Li**