Required Dimensions of HAPL Core System with Magnetic Intervention

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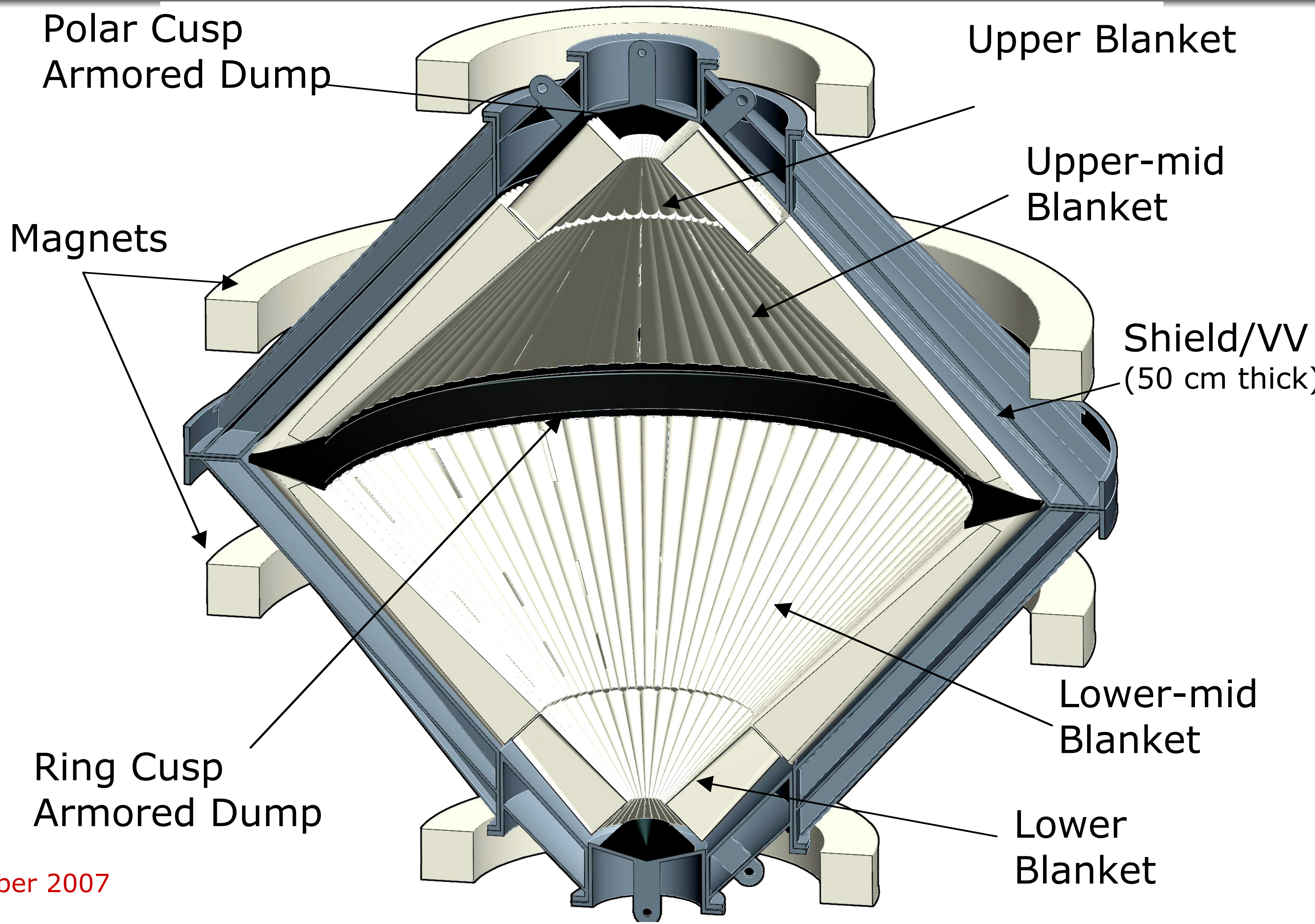
Background

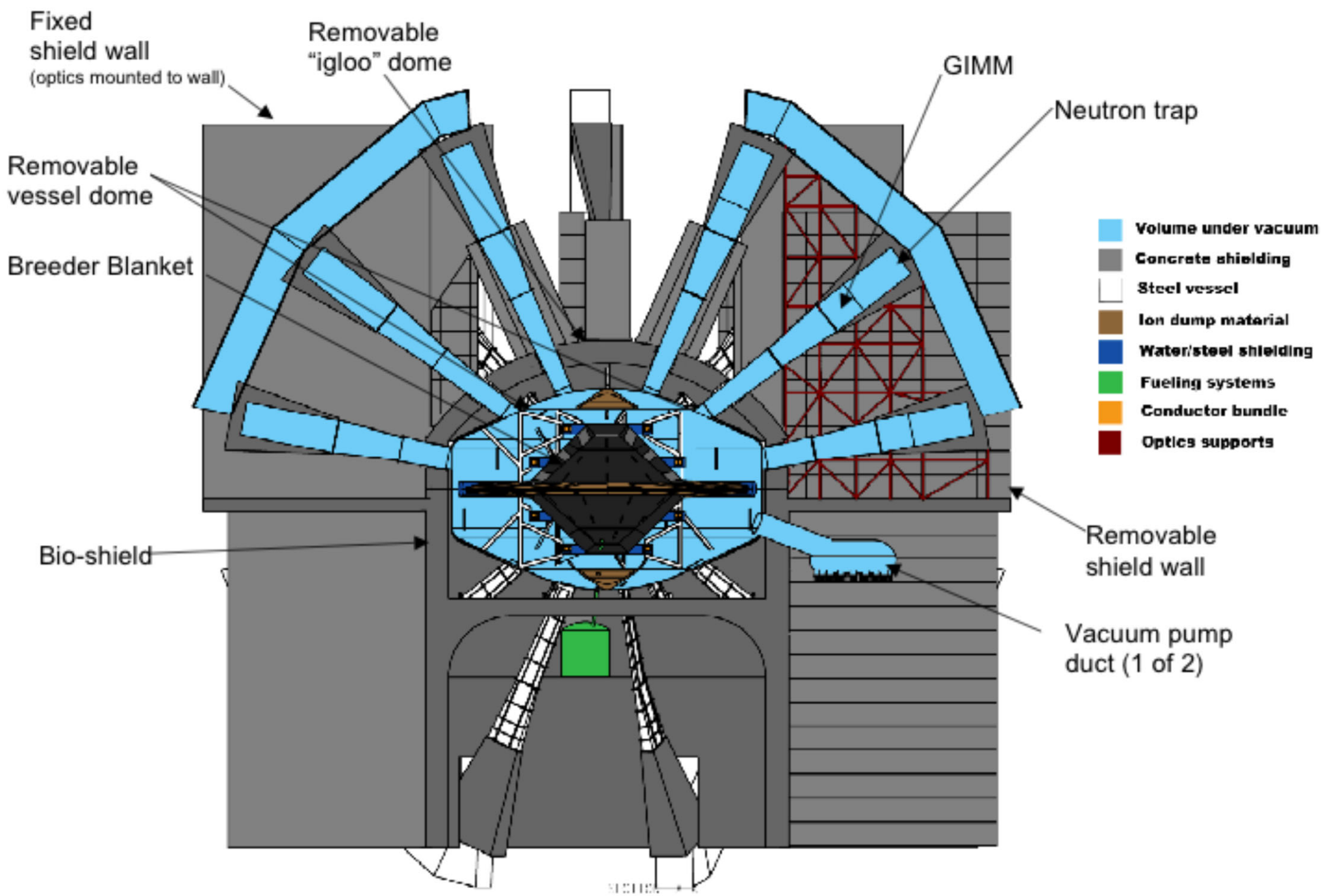
- Two HAPL core system configurations considered with magnetic intervention
  - Small VV between chamber and magnets
  - Large VV enclosing chamber and magnets
- Two blanket design options considered with low electrical conductivity SiC_f/SiC composite structure (required for dissipating the magnetic energy resistively)
  - LiPb/SiC
  - Flibe/Be/SiC
- Required dimensions of HAPL core components that satisfy nuclear design requirements were determined for the two blanket concepts and the two core system configurations

Chamber Configuration

(Magnets outside Shield/VV)

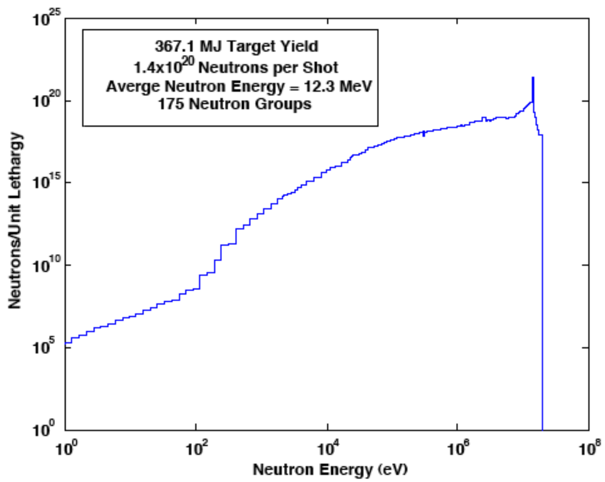


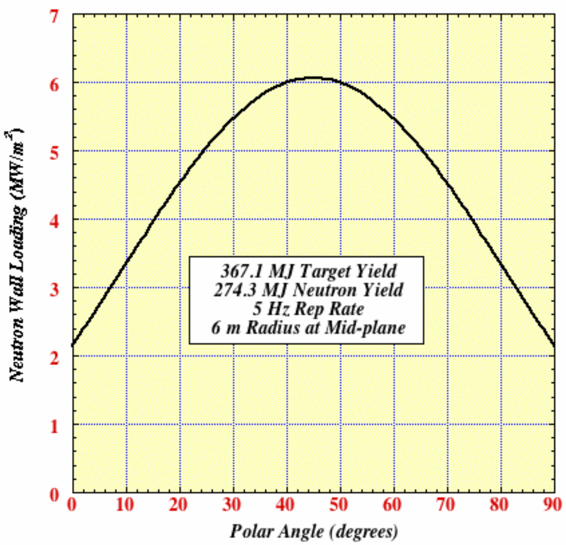
Chamber Configuration
(Magnets inside VV)

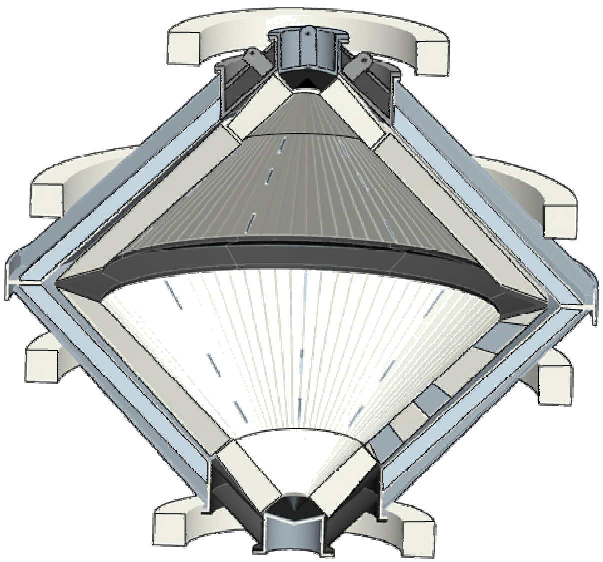


- Local SS/water shield surrounds magnets
- Blanket and magnets with their associated shields are ***inside*** VV
- Bio-shield is outside VV

Neutron Wall Loading Distribution

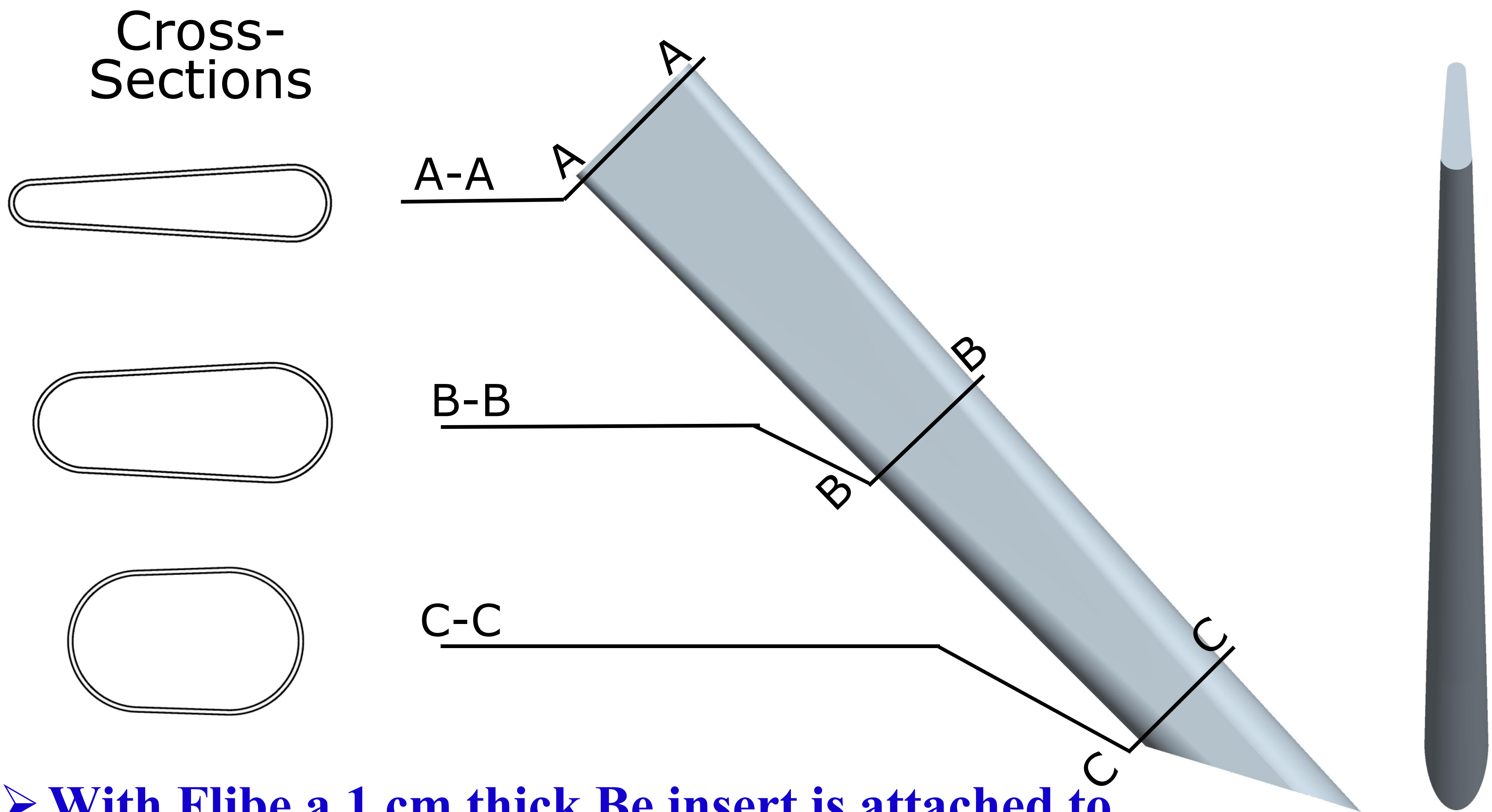






- NWL peaks at 45° polar angle where FW is closest to target and source neutrons impinge perpendicular to it
- Peak NWL is 6 MW/m^2
- Average chamber NWL is 4.3 MW/m^2

Blanket Sub-Module



➢ **With Flibe a 1 cm thick Be insert is attached to back wall of FW coolant channel**

Nuclear Design Requirements

- Tritium self-sufficiency
  - Overall TBR >1.1
- Shield and VV are lifetime components
  - Peak end-of-life radiation damage <200 dpa
- Magnet is lifetime component
  - Peak fast neutron fluence $<10^{19}$ n/cm^2 (E>0.1 MeV)
  - Peak insulator dose $<10^{10}$ Rads
- Vacuum vessel is reweldable
  - Peak end-of-life He production <1 He appm
- Personnel access allowed during operation outside biological shield
  - Operational dose rate <1 mrem/h

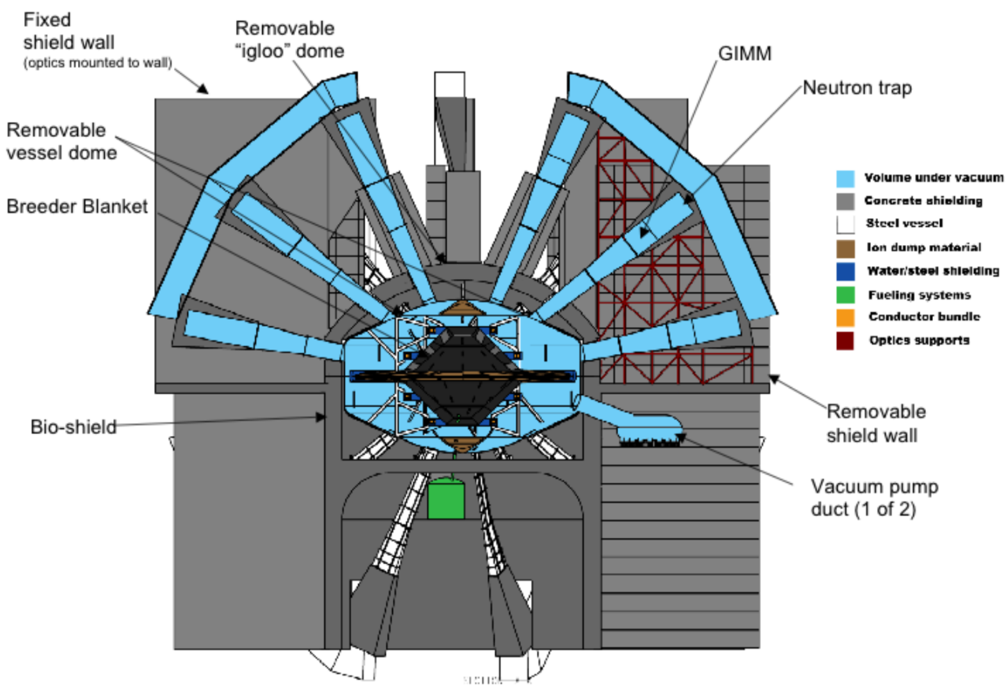
Tritium Breeding Requirement

- Tritium breeding affected by space taken by ring and point cusps and beam ports
- Full angle subtended by the ring cusp and each of the point cusps is ~8.5°
  - Breeding blanket coverage lost by the ring cusp is *7.4%*
  - Breeding blanket coverage lost by the two point cusps is *0.3%*
- Breeding blanket coverage lost by 40 beam ports is *0.7%*
- Total breeding blanket coverage lost is ***8.4%***
- For an overall TBR of 1.1 required for tritium self-sufficiency, ***the local TBR should be 1.2***

Dimensions for Configuration with Small VV

- Blanket thickness is 70 cm at mid-plane and increases to 106 cm at top/bottom of chamber
- A 50 cm thick steel/water shield that doubles as VV is used between blanket and magnets
- ~1.5 thick biological shield is required behind the blanket and shield/VV and increased to ~2.5 m behind beam ports
- All nuclear design requirements satisfied with these dimensions for both LiPb/SiC (with 90% Li-6) and Flibe/SiC (with nat. Li) blankets
- Flibe/SiC gives better performance parameters compared to LiPb/SiC
  - ~3% higher thermal power
  - A factor of 5 lower dpa in shield at end-of-life
  - A factor of 2 lower magnet insulator dose at end-of-life
- Flibe has the advantage of lighter weight to support and lower electric conductivity

Neutronics Assessment for MI Chamber Core Configuration with Outer VV



- Local SS/water shield surrounds magnets
- Blanket and magnets with their associated shields are ***inside*** VV
- Bio-shield is outside VV

- Several iterations carried out for both LiPb and Flibe blankets with conditions at polar angle of 85° to determine dimensions that simultaneously satisfy all nuclear design requirements
  - ✓ Tritium self-sufficiency is achievable
  - ✓ Shield, magnets, VV are lifetime components
  - ✓ VV is reweldable
  - ✓ Operational personnel accessibility outside bio-shield

Dimensions of MI Chamber Core Components (Flibe/SiC Blanket Option)

- Blanket thickness varies from 100 cm at mid-plane to 150 cm at top/bottom of chamber
- Use natural Li in Flibe
- 25 cm thick steel/water (25% water coolant) magnet shield
- 10 cm steel/water (25% water coolant) vacuum vessel
- 1.9 m concrete bio-shield (70% concrete, 20% carbon steel C1020, 10% water)

- Local TBR 1.204
  ⇒ Tritium self-sufficiency can be achieved
- Peak EOL shield damage 0.04 dpa
  ⇒ Magnet shield is lifetime component
- Peak EOL magnet fast neutron fluence 1.14×10^{18} n/cm^2
- Peak EOL magnet insulator dose 3.77×10^{9} Rads
  ⇒ Magnet is lifetime component
- Peak EOL VV He production 0.13 appm (FS), 3.23 appm (SS)
  ⇒ Ferritic steel vacuum vessel is reweldable
- Operational dose rate outside bio-shield 0.27 mrem/h
  ⇒ Personnel access allowed during operation outside bio-shield

Required Dimensions for LiPb/SiC Blanket

- Blanket composition is 90% LiPb (90% Li-6) and 10% SiC structure
- Using same dimensions determined for the Flibe/SiC blanket option does not allow for simultaneously satisfying all design requirements
  - Local TBR 1.47 (excessive breeding)
  - Peak EOL magnet insulator dose 4×10^{10} Rads (magnet not lifetime component)
  - Operational dose rate outside bio-shield 1.1 mrem/h (need thicker bio-shield)
- Reducing enrichment results in less effective shielding
- Using a thicker blanket will make it more difficult to support the weight and excessive tritium will be produced
- More magnet shielding is needed
- Several calculations performed with conditions at polar angle of 85° to determine dimensions that satisfy all design requirements

Dimensions of MI Chamber Core Components (LiPb/SiC Blanket Option)

- Blanket thickness varies from 80 cm at mid-plane to 120 cm at top/bottom of chamber
- Use low Li enrichment in LiPb (10% Li-6)
- 45 cm thick steel/water (25% water coolant) magnet shield
- 10 cm steel/water (25% water coolant) vacuum vessel
- 2.2 m concrete bio-shield (70% concrete, 20% carbon steel C1020, 10% water)

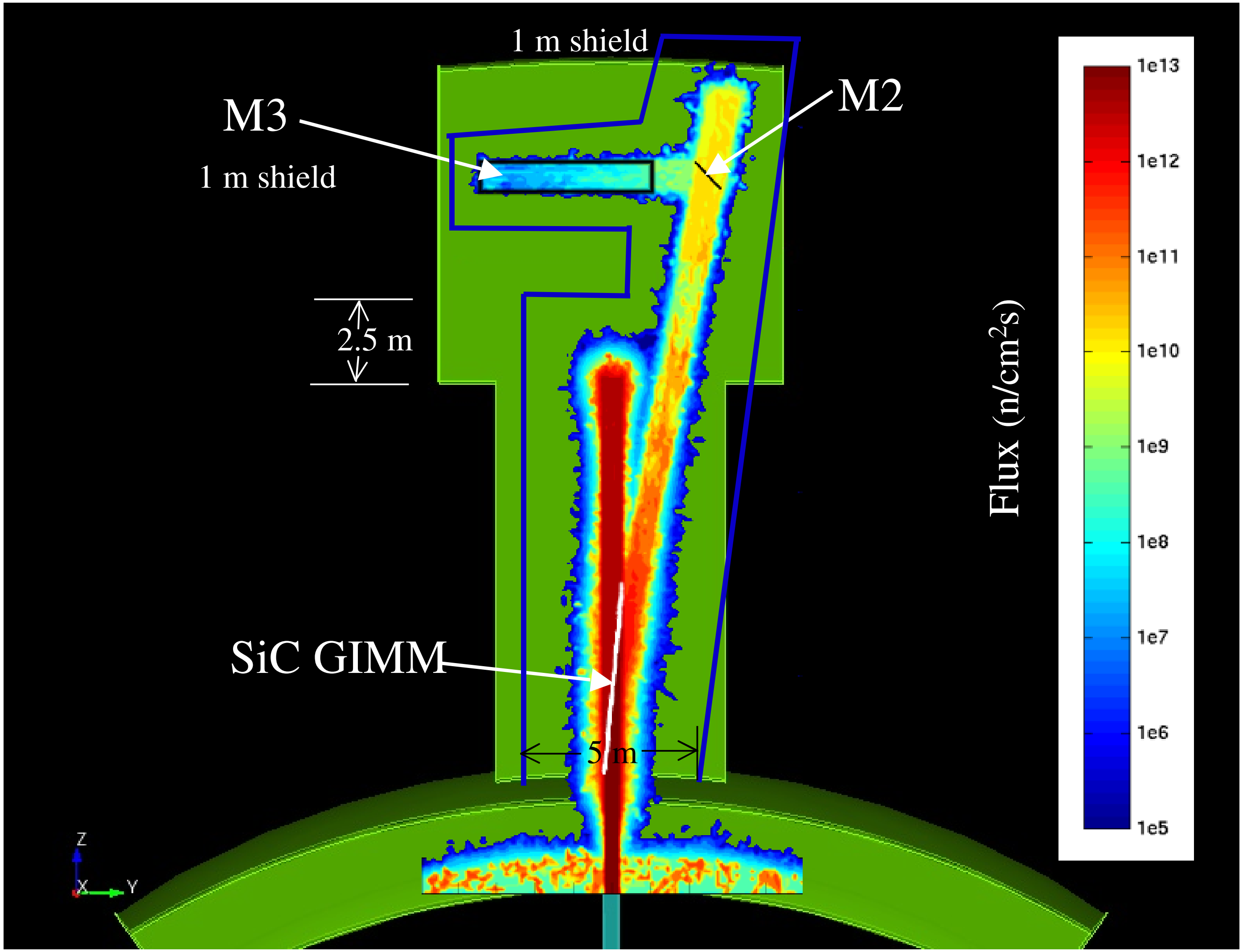
- Local TBR 1.217
  - ⟹ Tritium self-sufficiency can be achieved
- Peak EOL shield damage 4 dpa
  - ⟹ Magnet shield is lifetime component
- Peak EOL magnet fast neutron fluence 3.16×10^{17} n/cm^2
- Peak EOL magnet insulator dose 4.8×10^9 Rads
  - ⟹ Magnet is lifetime component
- Peak EOL VV He production 0.55 appm (FS), 541 appm (SS)
  - ⟹ Ferritic steel vacuum vessel is reweldable
- Operational dose rate outside bio-shield 0.42 mrem/h
  - ⟹ Personnel access allowed during operation outside bio-shield

Comparison of Dimensions that Satisfy All Design Requirements for the Blanket Options

	Flibe Blanket	LiPb Blanket
Blanket Thickness (cm)	**100-150**	**80-120**
Lithium Enrichment	**7.5% Li-6**	**10% Li-6**
Magnet Shield Thickness (cm)	**25**	**45**
Vacuum Vessel Thickness (cm)	**10**	**10**
Bio-shield Thickness (cm)	**190**	**220**

- Although LiPb blanket is thinner, the weight is still larger
- Magnet shield is a factor of ~2 heavier with liPb blanket resulting in more support requirements
- ~0.3 m thicker bio-shield is required with LiPb blanket
- We find the Flibe blanket to be well suited for this configuration based on the above findings and because of its lower electrical conductivity

Bio-shield Dimensions Around Final Optics



Summary and Conclusions

- All neutronics requirements can be satisfied with a Flibe/SiC or a LiPb/SiC blanket in HAPL with magnetic intervention
- A 1 cm thick Be insert plate in the FW coolant channel is required with Flibe to ensure tritium self-sufficiency
- Determined dimensions that simultaneously satisfy all nuclear design requirements
- Flibe blanket is well suited for magnetic intervention due to lighter blanket weight to support, thinner magnet and biological shields, and lower electrical conductivity
- Upon converging on a reference blanket design and configuration option, 3-D neutronics calculations will be performed to confirm that the design satisfies all requirements