Nuclear Assessment of a Flibe/SiC Blanket with Magnetic Intervension

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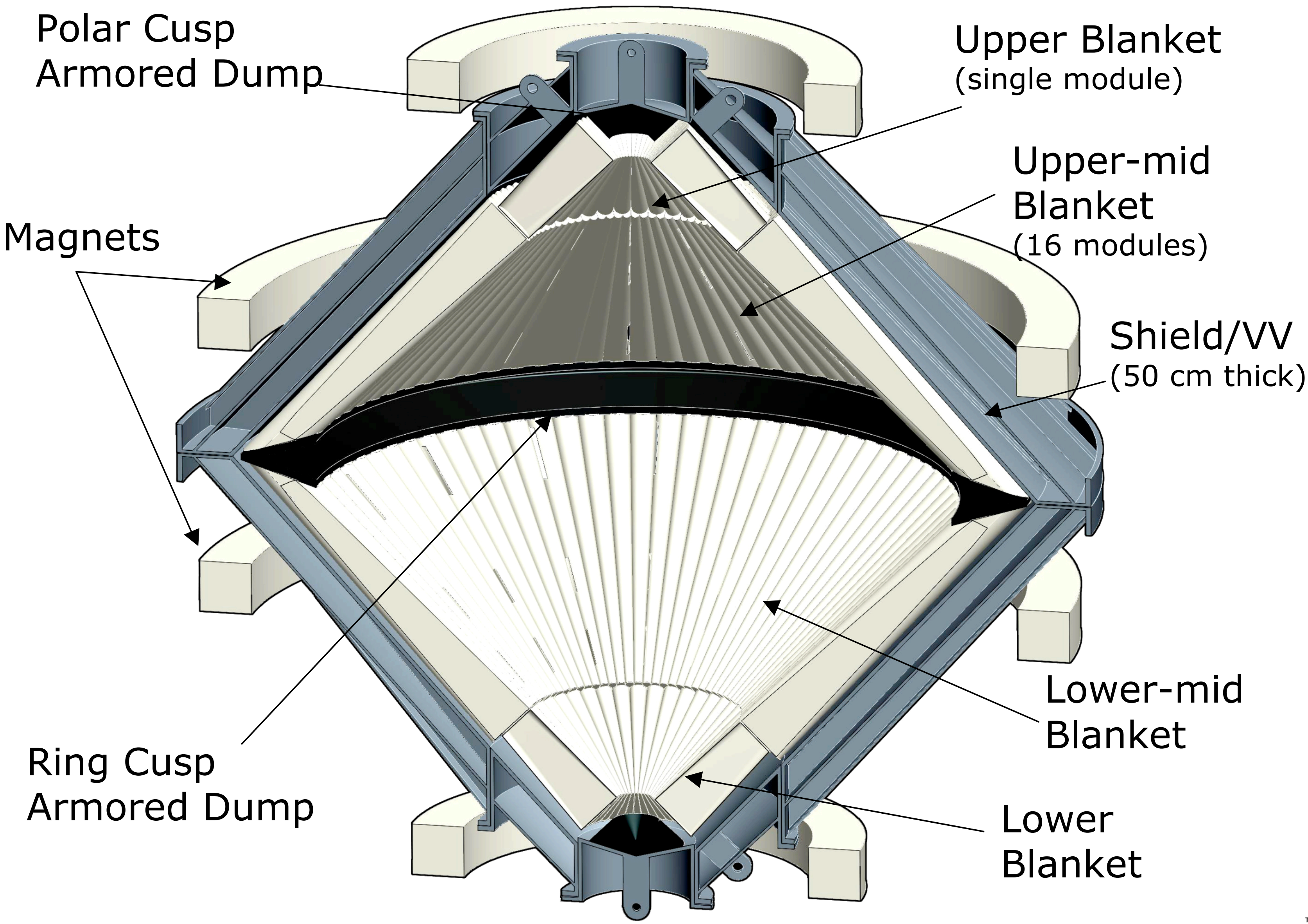
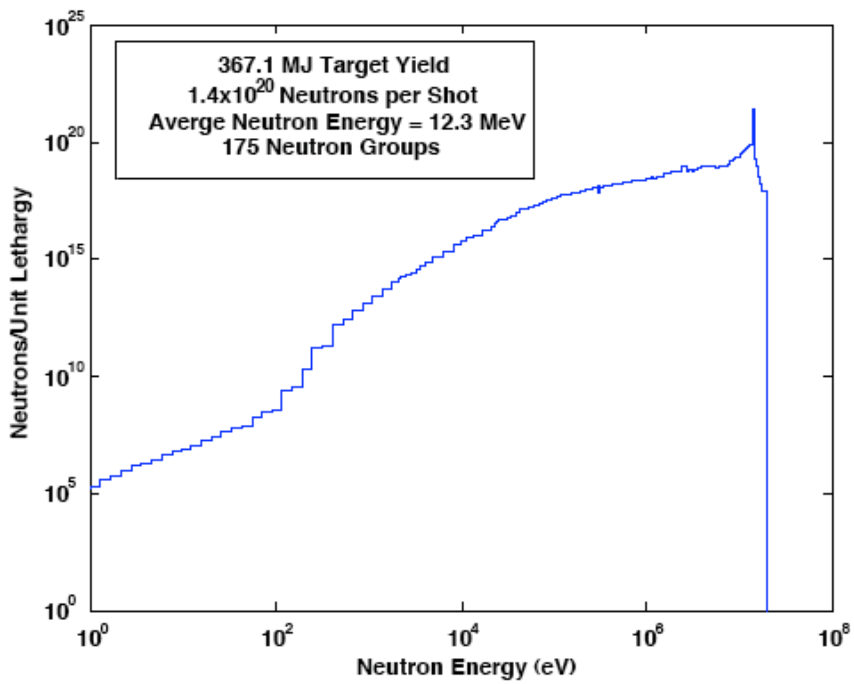
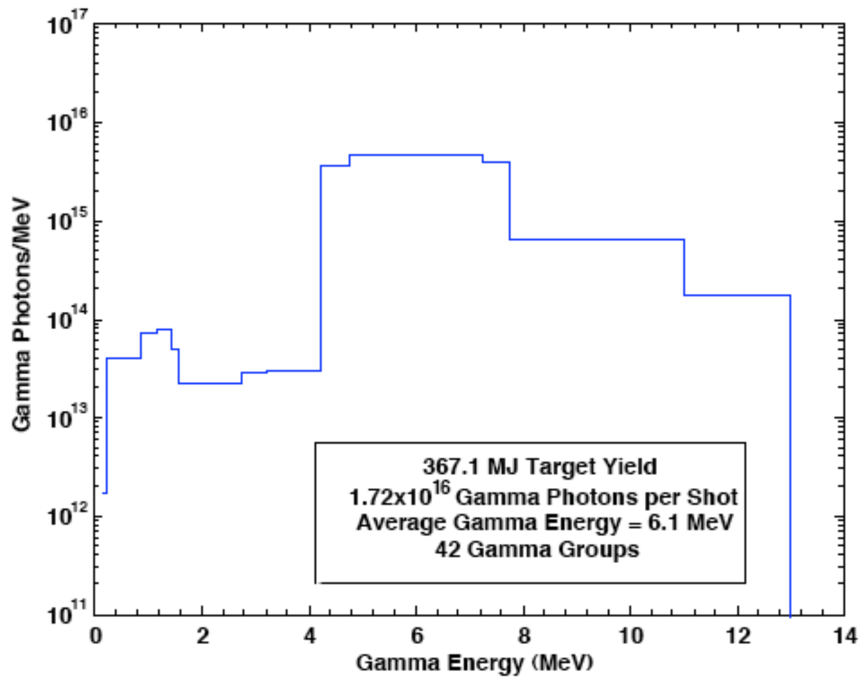
Chamber Configuration



Energy Spectra of Source Neutrons and Gammas Used in Neutronics Calculations

Used target spectrum from LASNEX results (Perkins)





Target yield	367.1 MJ
Rep Rate	5 Hz
Fusion power	1836 MW

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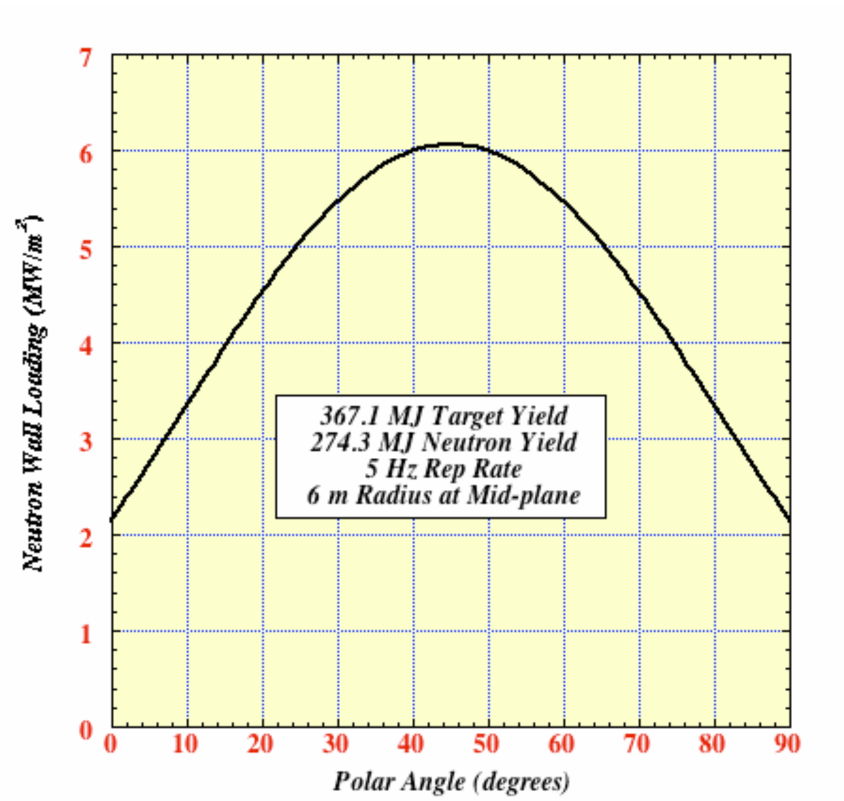
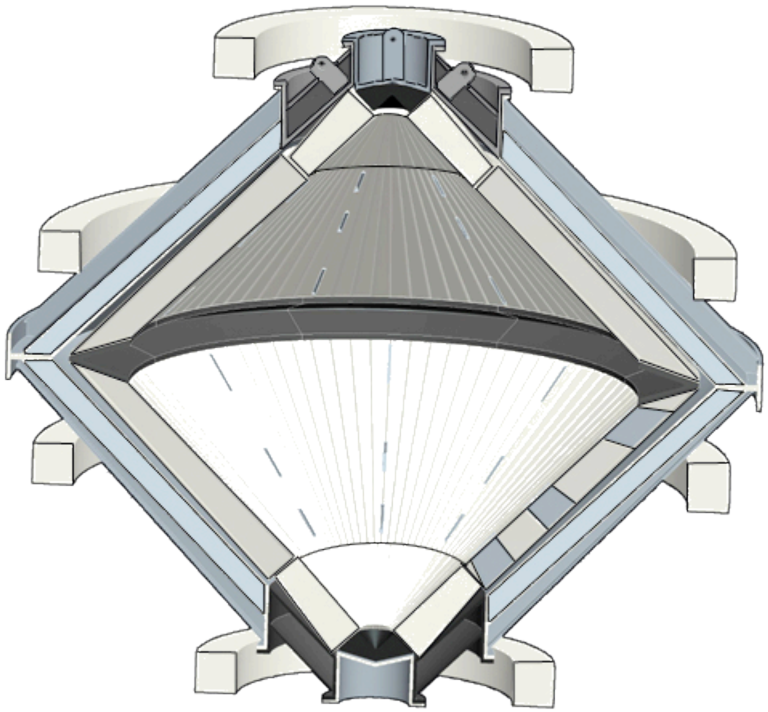
Neutron Wall Loading Distribution





- 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

Design Requirements

- Overall TBR >1.1 taking into account lost breeding blanket coverage
- End-of-life (40 FPY) peak dpa in shield <200 dpa for shield/VV to be lifetime component
- End-of-life (40 FPY) peak He production at back of shield/VV <1 He appm to allow for rewelding
- Peak fast neutron fluence in magnets is limited to 10^{19} n/cm^2 (E>0.1 MeV) due to degradation in J_c of superconductor
- Peak dose in magnet insulator is limited to 10^{10} Rads due to degradation of mechanical properties

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Tritium Breeding Requirement with Magnetic Intervension

- Tritium breeding affected by space taken by ring cusp, 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%***
- Breeding behind the cusp dumps with their cooling system will be reduced significantly by attenuation in these dumps and coolant channels (by more than a factor of 2) as in tokamak divertor plates. In addition, maintenance scheme for these dumps with frequent replacement might not allow using breeding blankets behind them
- For an overall TBR of 1.1 required for tritium self-sufficiency, ***the local TBR should be 1.2*** if we do not count on breeding behind the dumps and >1.16 with partial breeding behind dumps

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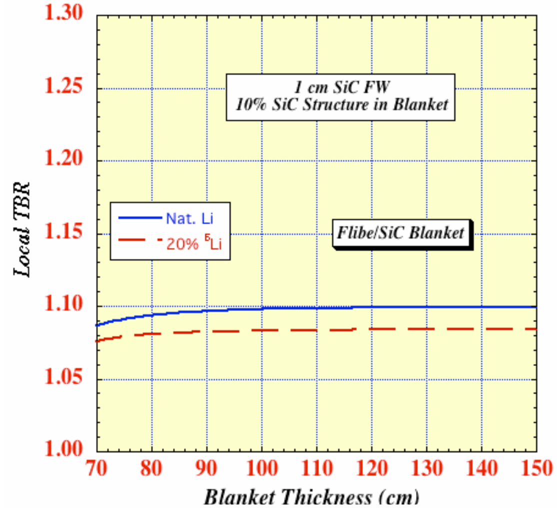
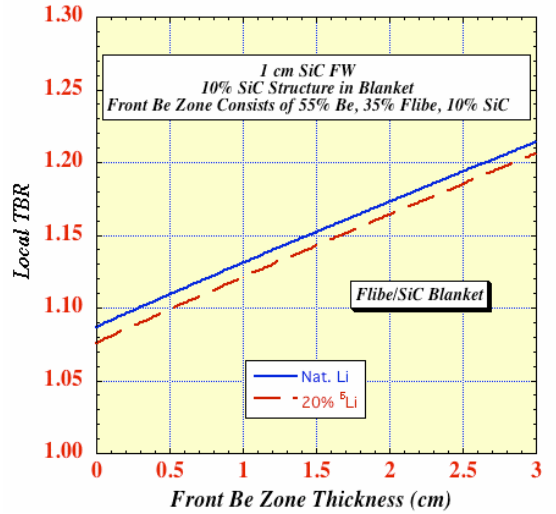
Beryllium is Required with Flibe/SiC Blanket

- **Flibe** has advantage over LiPb of lighter weight to support, and low conductivity. However, it lacks of data on compatibility with SiC structure, requires careful chemistry control, has high melting point, and has lower breeder potential

Local TBR for 70 cm blanket
with 10% structure content

FW thickness (cm)	Local TBR
0	1.135
1	1.087
2	1.043
3	1.028





- Increasing blanket thickness beyond 70 cm has minimal effect on TBR
- Enriching Li does not help breeding
- Front Be zone is needed
- Using Be in contact with Flibe helps with chemistry control of corrosive free fluorine and TF (REDOX process)

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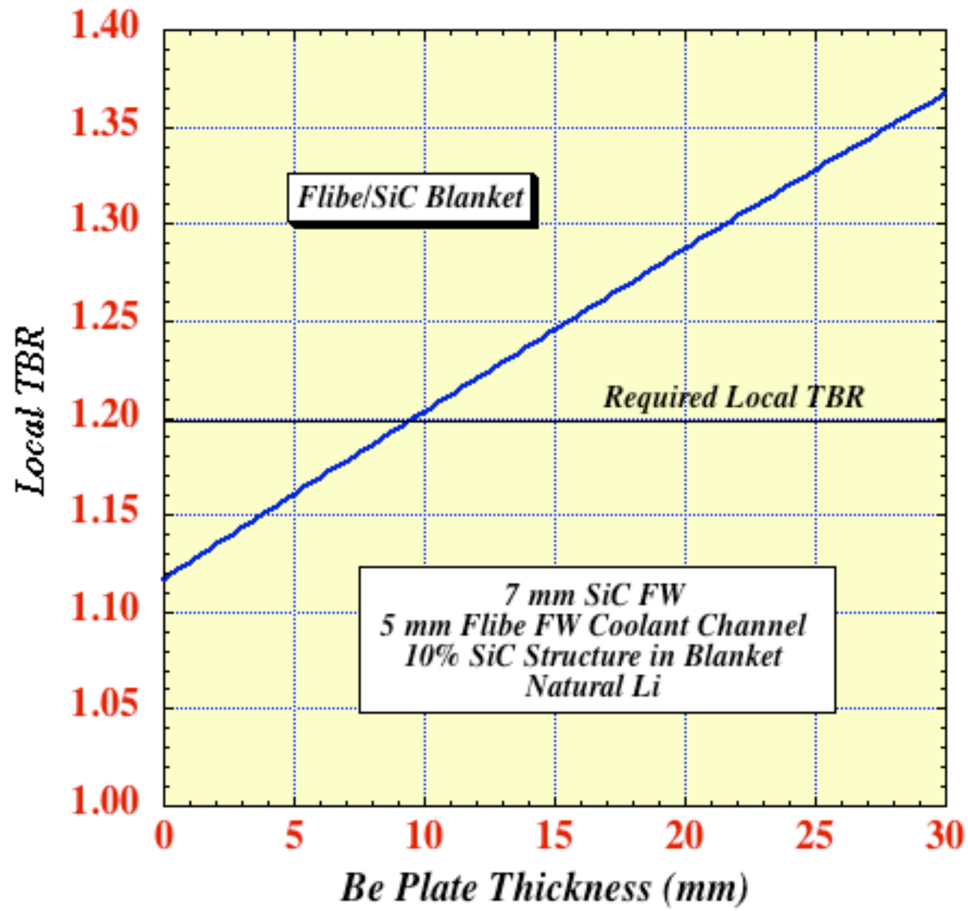
Amount of Beryllium Required in Flibe/SiC Blanket

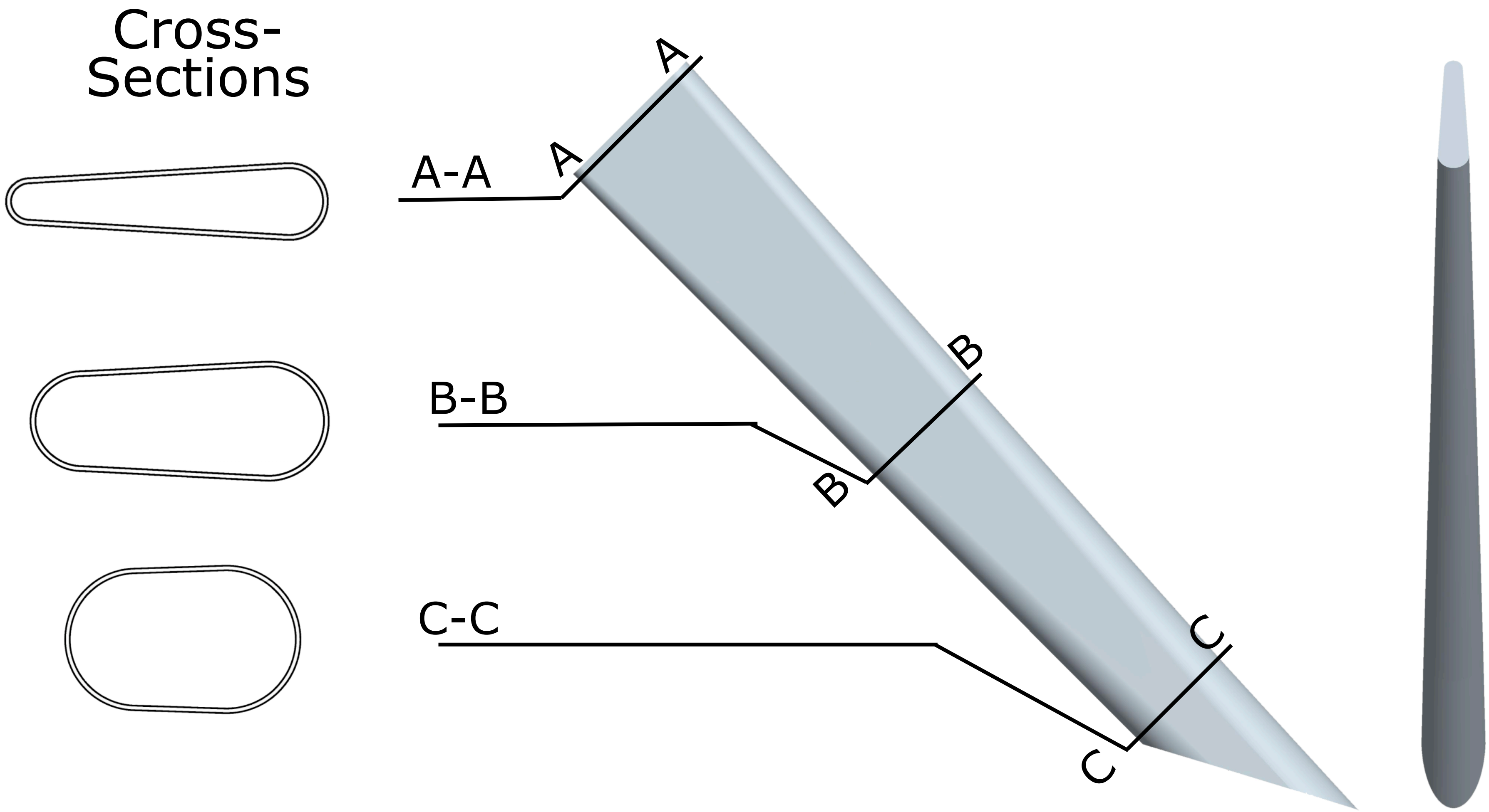


- With 7 mm SiC FW, 5 mm Flibe FW coolant channel, a 10 mm thick Be plate needs to be inserted in the FW channel

Flibe/SiC Blanket Design Features

- Self-cooled Flibe (F_4Li_2Be) with natural Li
- SiC/SiC composite structure
- Utilize concentric channel approach
- 0.7 cm FW (reduced for thermal stress considerations)
- 0.5 cm Flibe FW coolant channel
- 1 cm Be plate attached to back wall of FW coolant channel
- 10% SiC structure in blanket
- Self-draining blanket modules
- Maintenance access is via removable shield modules at each pole
- Blanket thickness is 70 cm at midplane and increases towards top and bottom of chamber
- Each mid blanket consists of 16 modules, which in turn, consist of five sub-modules

Blanket Sub-Module



➢**47 cm wide and 70 cm deep at mid-plane**

➢**19.6 cm wide and 106 cm deep at the ends**

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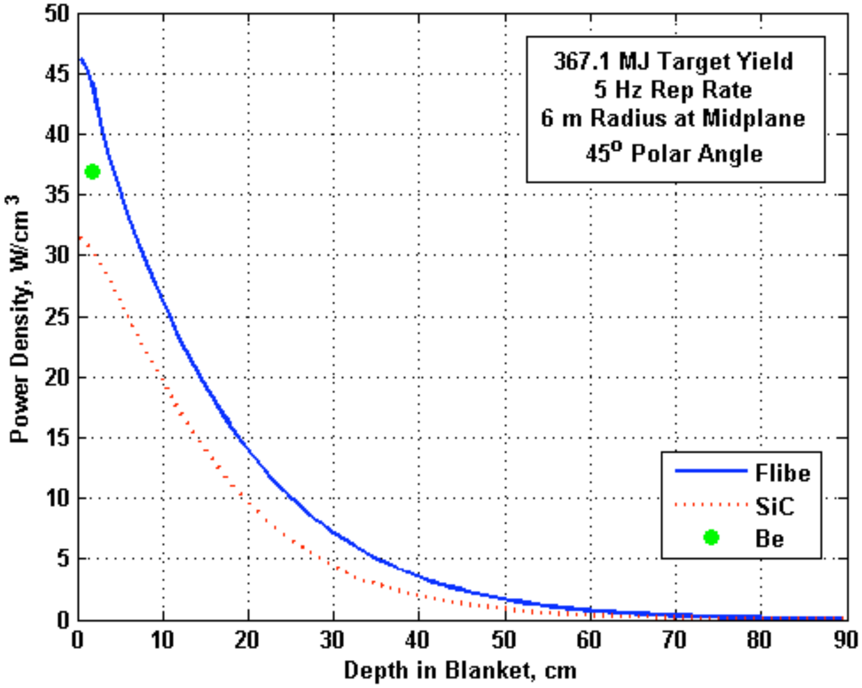
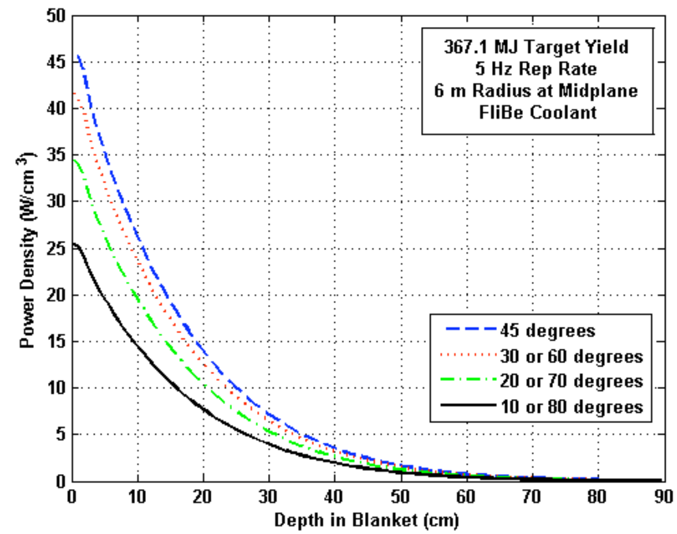
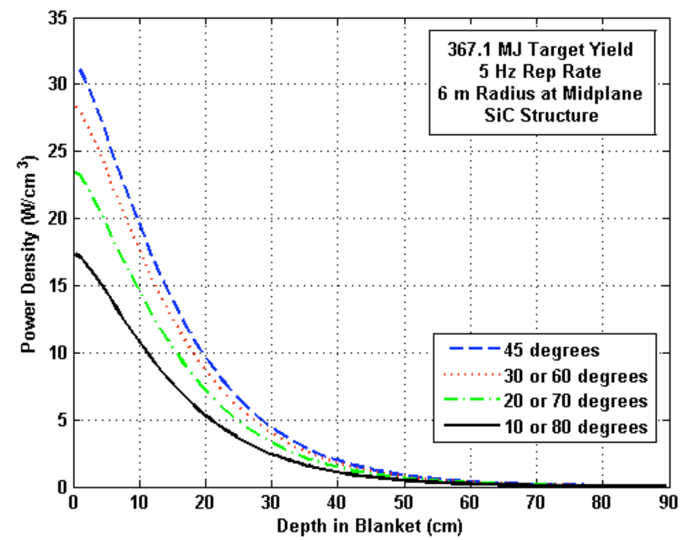
Blanket Nuclear Heating Profiles







- Peak power density in Flibe is 46 W/cm^3
- Peak power density in SiC is 31 W/cm^3
- Peak power density in Be is 37 W/cm^3
- Blanket nuclear energy multiplication is 1.232
- Power density in SiC FW is similar to that with LiPb. Peak heating in Flibe is half that in LiPb. Energy multiplication is ~4% higher than with LiPb

Blanket Thermal Power for 1836 MW Fusion Power

- Blanket coverage 91.6%
- Target yield 367.1 MJ (274.3 n, 0.017 γ, 4.94 x-ray, 87.84 ions)
- 70% of ion energy dissipated resistively in blanket

Volumetric Nuclear Heating
1548 MW

Volumetric Ion Energy Dissipation
307 MW

X-rays Surface Heating
23 MW

Total Thermal Power
1878 MW

- Thermal power in water-cooled 50 cm thick **shield** is only **3 MW**

Power Deposited in Dumps for 1836 MW Fusion Power

- Cusp coverage 7.7%
- Target yield 367.1 MJ (274.3 n, 0.017 γ, 4.94 x-ray, 87.84 ions)
- 30% of ion energy dissipated at dump surfaces

Volumetric Nuclear Heating
106 MW

Ion Surface Heating
132 MW

X-rays Surface Heating
2 MW

Total Dump Thermal Power 240 MW

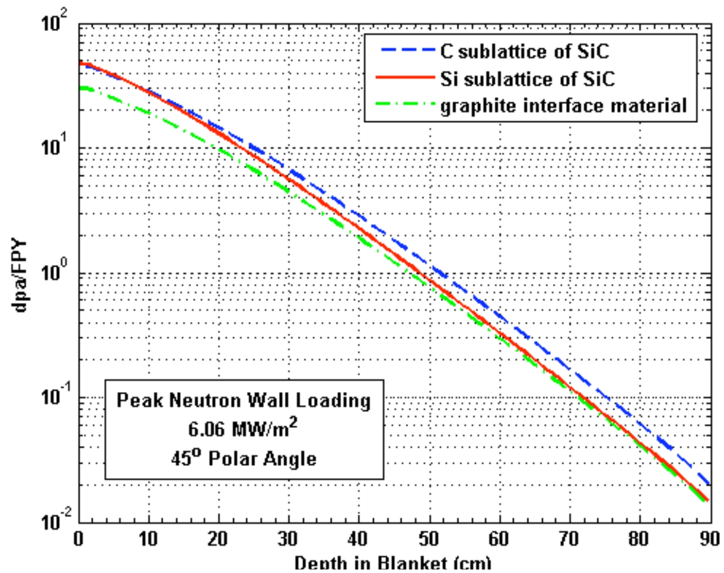
Total plant thermal power is ***2121 MW***
(~2.5% higher than with LiPb)
if energy in dumps and shield is included in power cycle

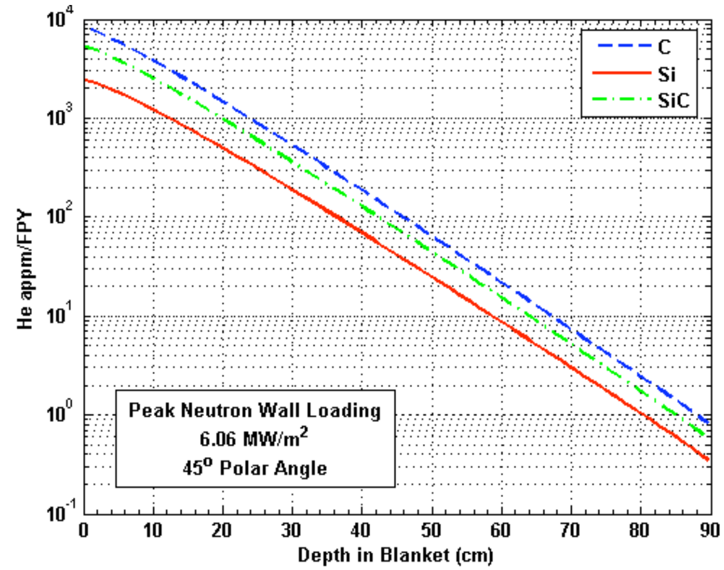
Peak Damage Parameters at Front of FW for Flibe/SiC FW/Blanket

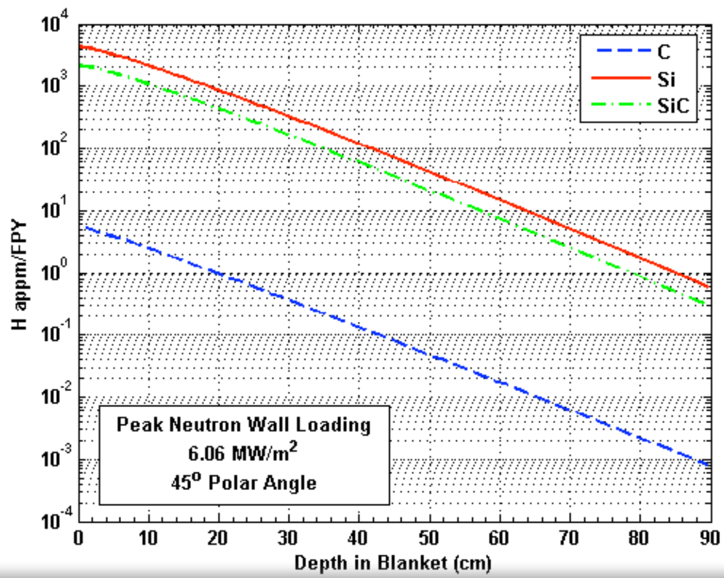
	C Sublattice	Si Sublattice	SiC	Graphite Interface
dpa/FPY	45	47	46	30
He appm/FPY	8,127	2,413	5,270	8,127
H appm/FPY	5	4,291	2,148	5
% Burnup/FPY	0.35%	0.67%	1.02	0.35%

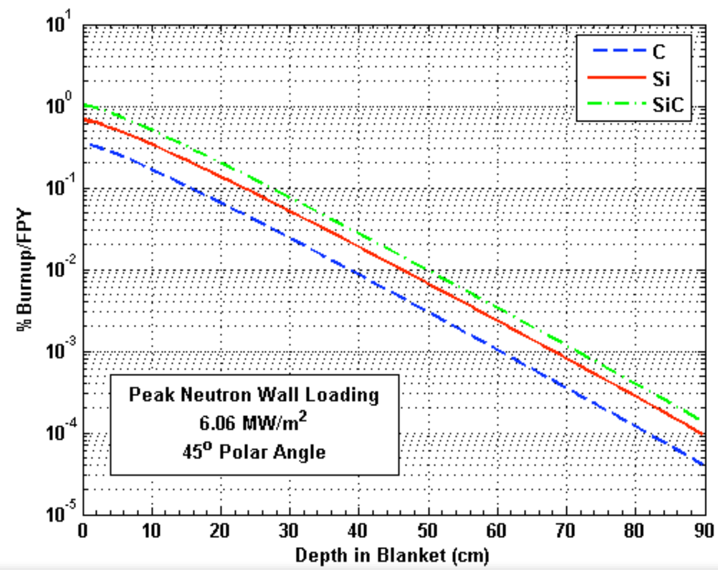
- Comparable atomic displacement damage rates occur in C and Si sublattices
- He production in C is about a factor of 4 larger than in Si due to the (n,n´3α) reaction
- Significant H production occurs in Si with negligible amount in C
- Burnup of Si is about twice that of C
- He production rate in graphite interface is 60% higher than He production rate in SiC
- ***dpa values are about half those with LiPb***
- ***Gas production and burnup rates are ~10% higher than with LiPb***
- Flibe more effective attenuating intermediate and low energy neutrons while LiPb is more effective attenuating high energy neutrons

Radial Variation of Damage Parameters in SiC/SiC Composite









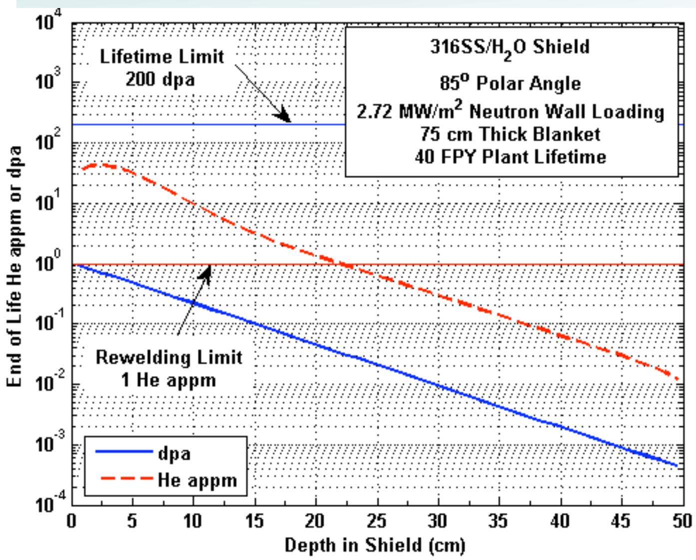
- ***dpa values have steeper radial drop compared to LiPb blanket***
- ***Gas production and burnup rates have less steep radial drop than in LiPb blanket***

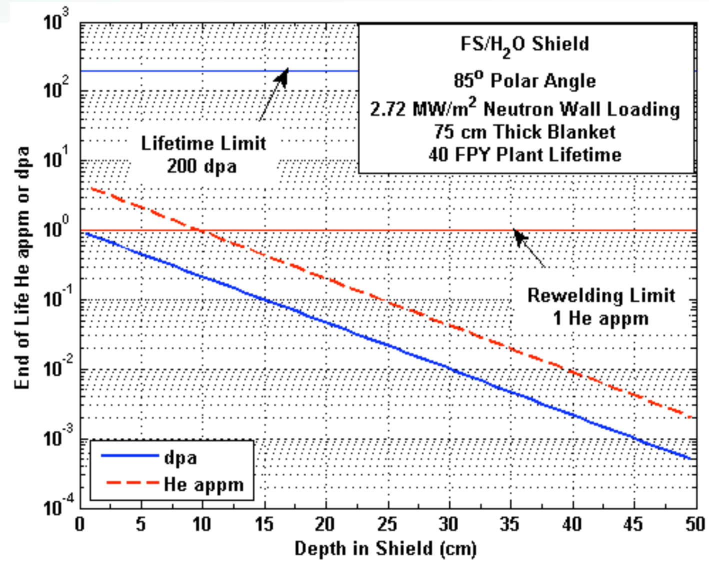
Blanket Lifetime

- Lifetime of SiC/SiC composites in fusion neutron environment ***can only now be speculated***
- Lifetime depends primarily on effect of He and metallic transmutants such as Al, Be, and Mg
- For a 3% burnup limit (corresponding to 135 dpa, 15,500 He appm, and 6,320 H appm), blanket lifetime is 2.94 FPY
- Life time is slightly shorter (by ~10%) than for LiPb blanket due to larger transmutation rate
- Determination of transmutations effect on thermomechanical properties of SiC required for better assessment of SiC lifetime in the HAPL chamber

Radiation Damage in Shield

- A 50 cm thick steel (316SS or FS) shield that doubles as VV is used with 25% water cooling
- Largest damage occurs at location with thinnest blanket





- Peak end-of-life radiation damage in shield is only ~1 dpa ⇒ lifetime component
- He production in 316SS shield is ~ an order of magnitude higher than in FS
- Back of the shield/VV is reweldable
- If FS is used rewelding is possible at locations at least 10 cm deep in shield. If 316SS is used rewelding is possible at locations at least 20 cm deep in shield
- dpa values are lower compared to case with LiPb blanket
- He is lower in 316SS but higher in FS compared to case with LiPb blanket

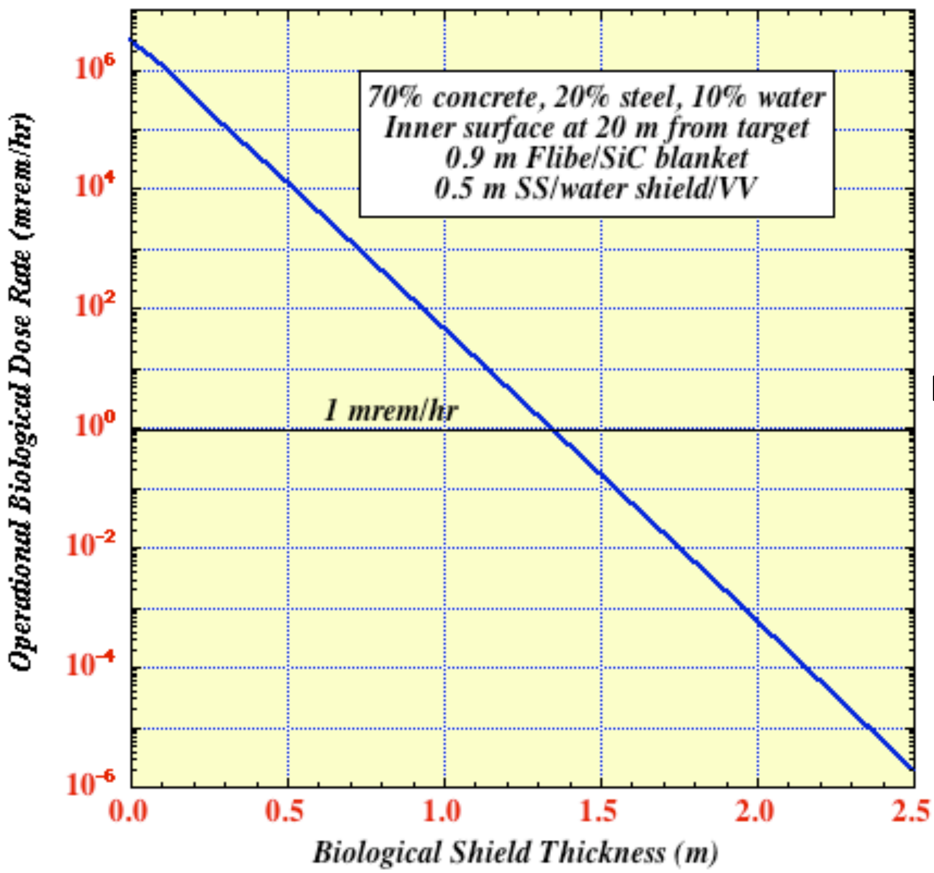
Peak Damage Parameters in Superconducting Cusp Coils

	45° polar angle FS shield	45° polar angle 316SS shield	85° polar angle FS shield	85° polar angle 316SS shield	**Radiation limit**
End of life fast neutron fluence (n/cm^2)	3.63×10^{17}	2.82×10^{17}	**7.93×10^{17}**	6.20×10^{17}	**10^{19}**
End of life insulator dose (Rads)	6.77×10^{8}	5.44×10^{8}	**1.14×10^{9}**	1.14×10^{9}	**10^{10}**
Peak power density (mW/cm^3)	0.027	0.022	**0.054**	0.044	**1**

- 316SS shield provides slightly better magnet shielding
- The cusp coils are well protected with the 50 cm shield (either FS or 316SS)
- No restriction on location of the coils
- A factor of ~2 lower insulator dose compared to case with LiPb blanket

Required Biological Shield

- Biological dose rate during operation behind the shield/VV 1.5x10^7 mrem/hr
- A biological shield is required to allow personnel access
- A biological shield (containment building) made of 70% concrete, 20% carbon steel C1020, 10% water used with inner surface at 20 m from target



- ~1.5 thick biological shield is required behind the blanket and shield/VV to allow personnel access outside containment building during operation
- ~2.5 m thick concrete is required behind the beam ports to shield personnel from streaming neutrons

Summary

- All neutronics requirements can be satisfied for a SiC/Flibe blanket in HAPL with magnetic intervention
- The blanket with a 1 cm thick Be plate in the FW coolant channel has potential for achieving tritium self-sufficiency with an overall TBR of ~1.1
- Peak power density is 46 W/cm^3 in Flibe (half that in LiPb) and 31 W/cm^3 in SiC (similar to LiPb blanket)
- Total plant thermal power is ***2121 MW*** (2.5% higher than LiPb blanket)
- Determination of transmutations effect on thermomechanical properties of SiC required for better assessment of SiC lifetime in HAPL
- For a 3% burnup limit (135 dpa, 15,500 He appm, and 6,320 H appm), blanket lifetime is 2.94 FPY (~10% shorter than LiPb blanket)
- Shield/VV is lifetime component (dpa a factor of 5 lower than with LiPb blanket)
- Back of shield/VV is reweldable
- The cusp coils are well protected with the 50 cm shield (insulator dose a factor of 2 lower than with LiPb blanket)
- 1.5-2.5 m thick concrete bio-shield (containment building) is required for operational personnel access