Nuclear Assessment of HAPL Chamber with Magnetic Intervention

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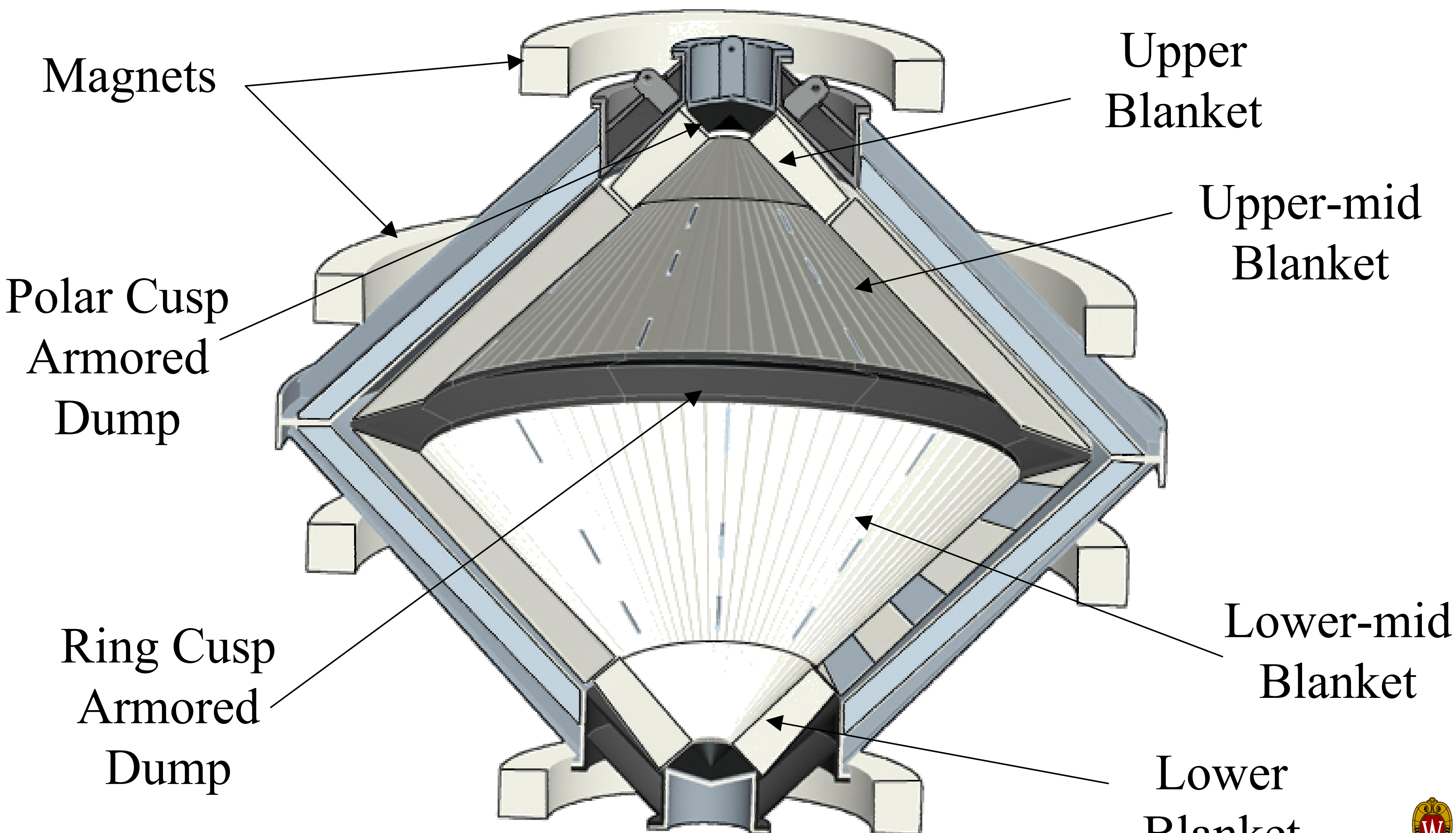
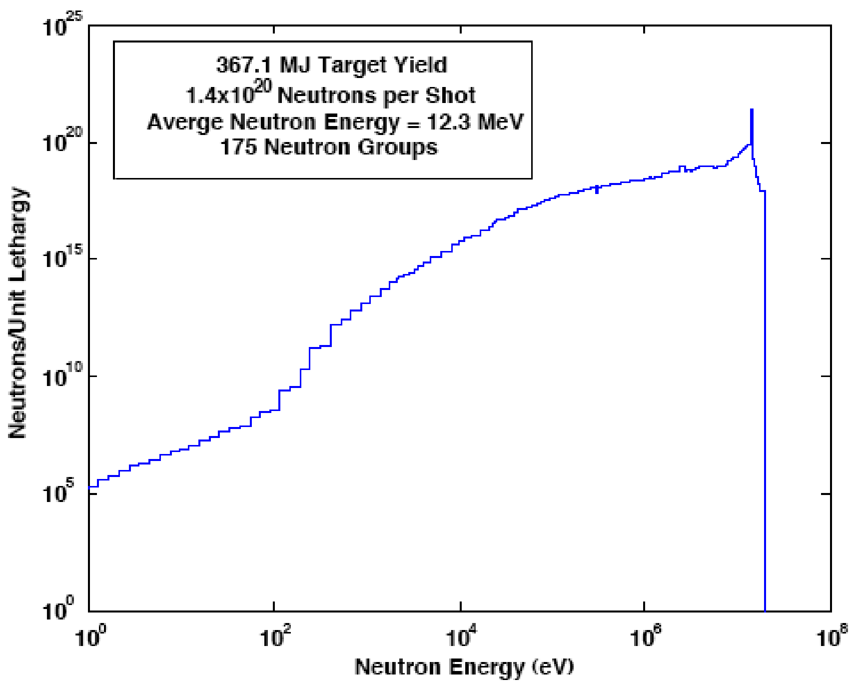
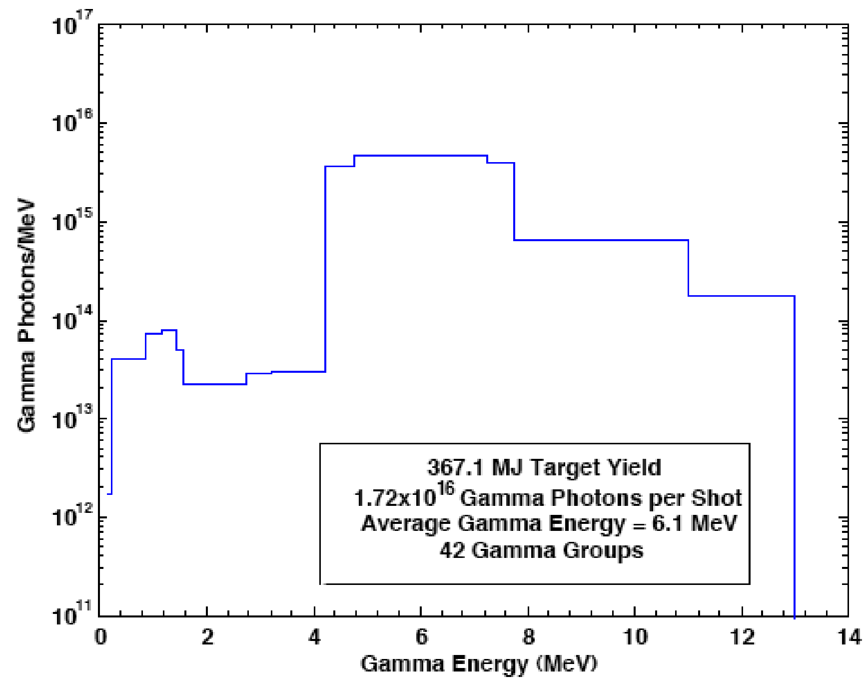
Chamber Configuration



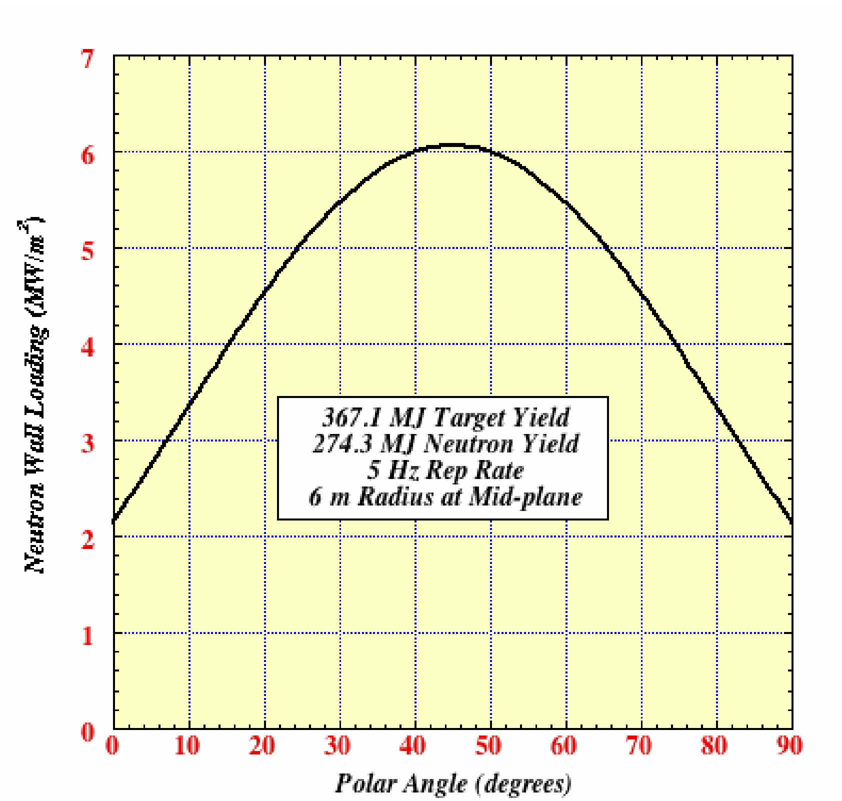
Energy Spectra of Source Neutrons and Gammas Used in Neutronics Calculations

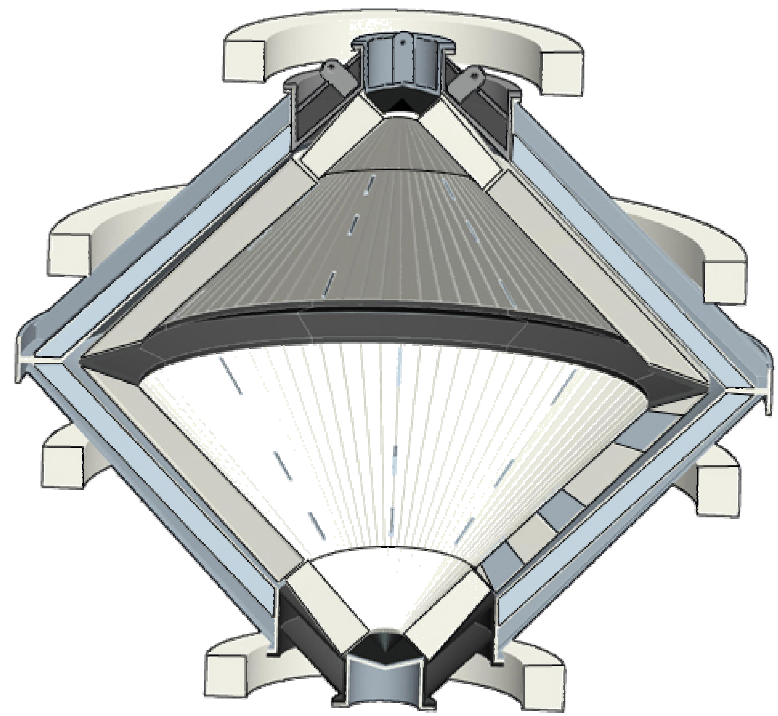
Used target spectrum from LASNEX results (Perkins)





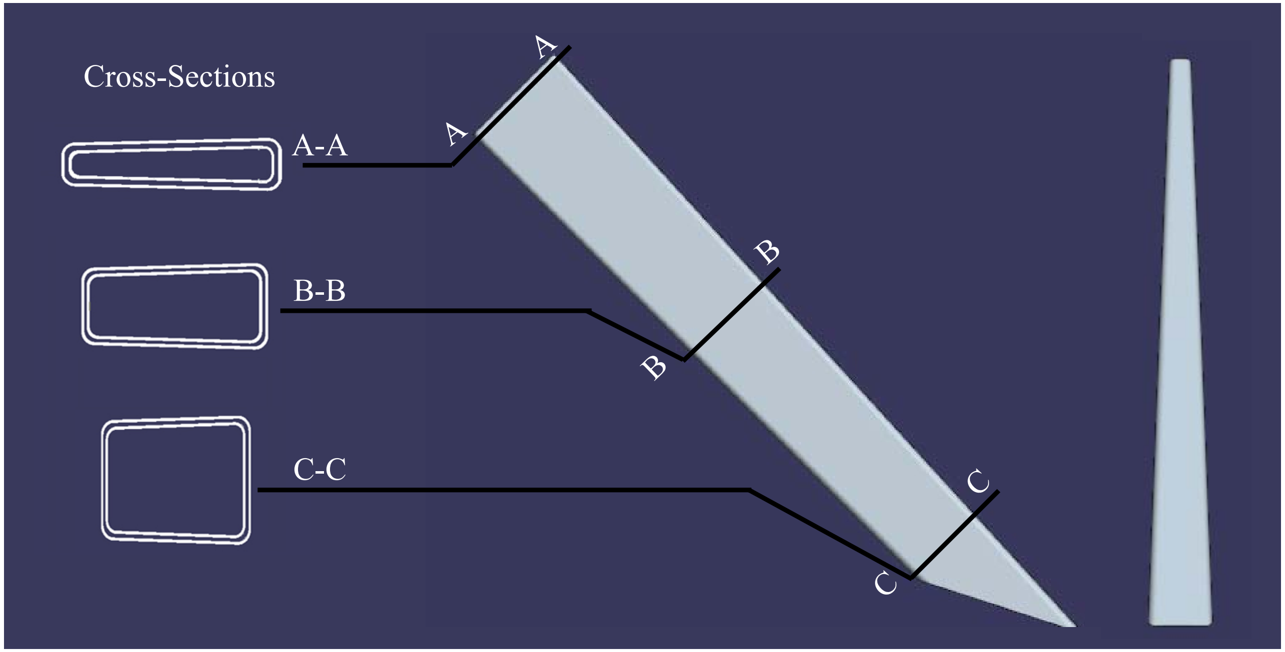
Target yield	367.1 MJ
Rep Rate	5 Hz
Fusion power	1836 MW





- 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

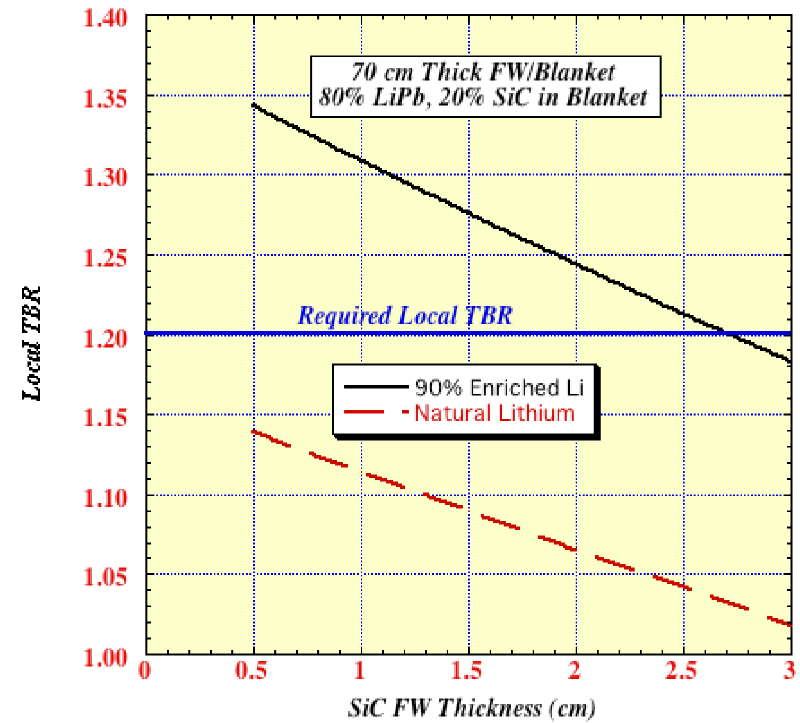
- Self-cooled $Li_{17}Pb_{83}$ with 90% ^6Li
- Silicon Carbide composite structure
- Utilize concentric channel approach
- 1.5 cm FW
- 20% SiC structure in blanket
- Blanket thickness is 70 cm at midplane and increases towards top and bottom of chamber



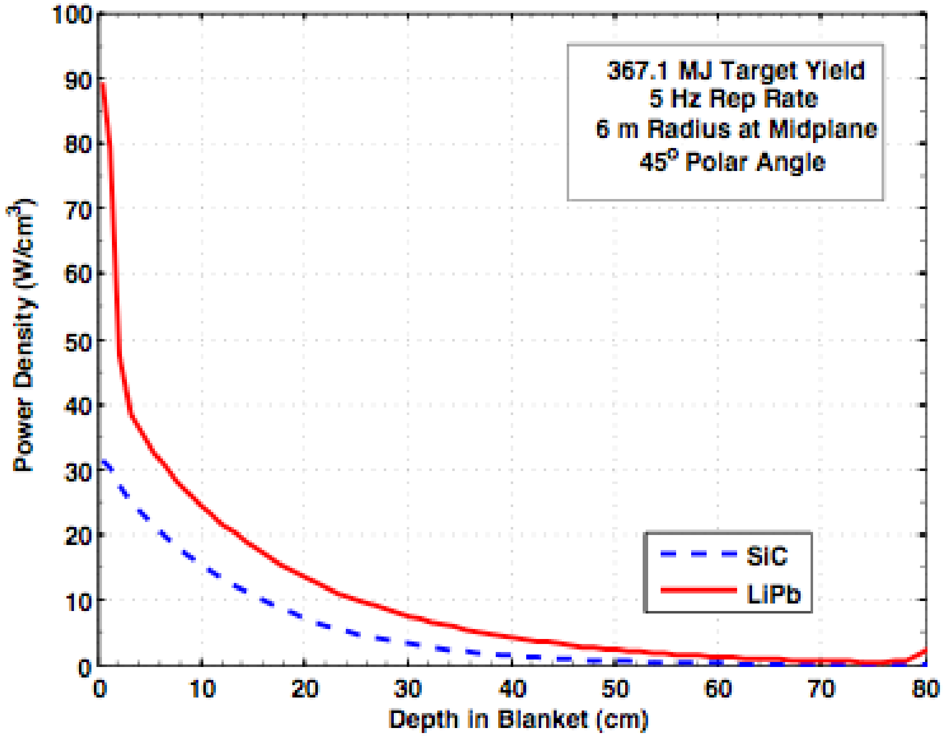
- Overall TBR >1.1 taking into account lost breeding blanket coverage
- End-of-life (40 FPY) peak dpa in shield <200 dpa for shield/VV to be lifetime component
- End-of-life (40 FPY) peak He production at back of shield/VV <1 He appm to allow for rewelding
- Peak fast neutron fluence in magnets is limited 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

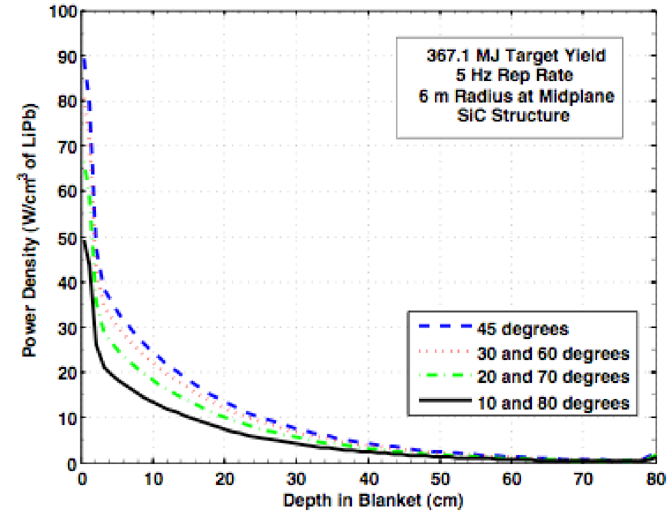
Tritium Breeding

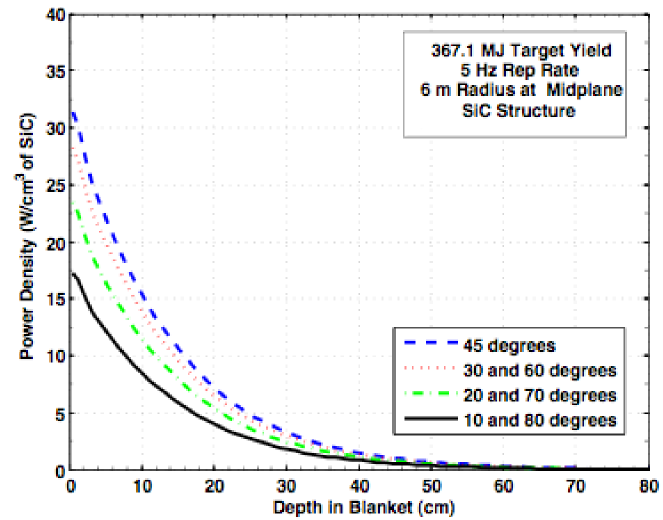
- Tritium breeding affected by space taken by ring cusp, point cusps, and beam ports
- Full angle subtended by the ring cusp and each of the point cusps is ~8.5°
  - Breeding blanket coverage lost by the ring cusp is *7.4%*
  - Breeding blanket coverage lost by the two point cusps is *0.3%*
- Breeding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



- With 90% ^{6}Li and 1.5 cm thick SiC FW overall TBR is estimated to be ~1.2
- Li enrichment can be used as a knob to control TBR as needed







- Peak power density in LiPb is 89 W/cm^3
- Peak power density in SiC is 31 W/cm^3
- Blanket nuclear energy multiplication is 1.185

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
1489 MW

Volumetric Ion Energy Dissipation
307 MW

X-rays Surface Heating
23 MW

Total Thermal Power
1819 MW

- Thermal power in water-cooled 50 cm thick **shield** is only **11 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 ***2070 MW***
if energy in dumps and shield is included in power cycle

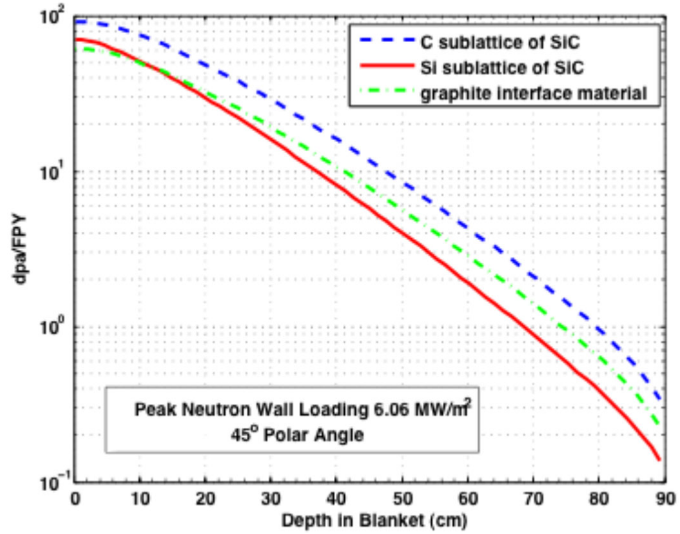
- Lifetime of SiC/SiC composites in fusion radiation environment is a major critical issue
- Radiation effects in fiber, matrix, and interface components represent important input for lifetime assessment
- Rates of dpa, He production, H production, and % burnup calculated for both sublattices of SiC fiber/matrix and interface material
- Used recommended displacement energies for SiC, namely 20 and 40 eV for the C and Si sublattices, respectively
- Leading interface material candidates are:
  - Graphite for near-term applications
  - Multilayer or porous SiC for longer-range applications

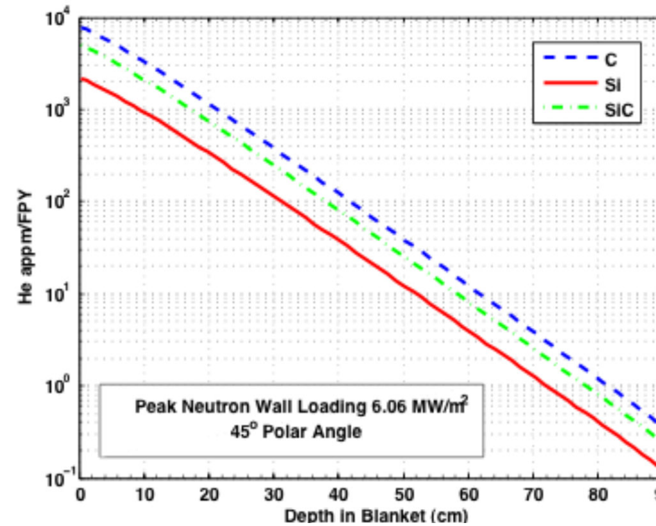
Peak Damage Parameters at Front of FW for LiPb/SiC FW/Blanket

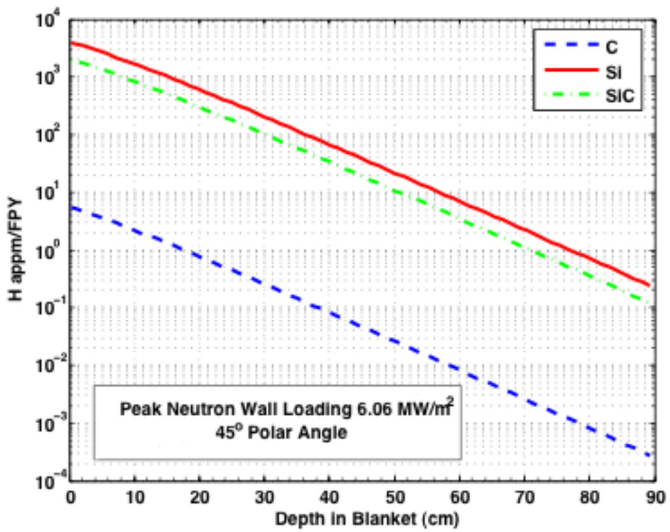
	C Subla ttice	Si Subla ttice	SiC	Graphite Interface
dpa /FPY	92	70	81	61
He appm/FPY	7,844	2,174	5,009	7,844
H appm/ FPY	5	3,900	1,953	5
% Burn up/FPY	0.32%	0.60%	0.92	0.32%

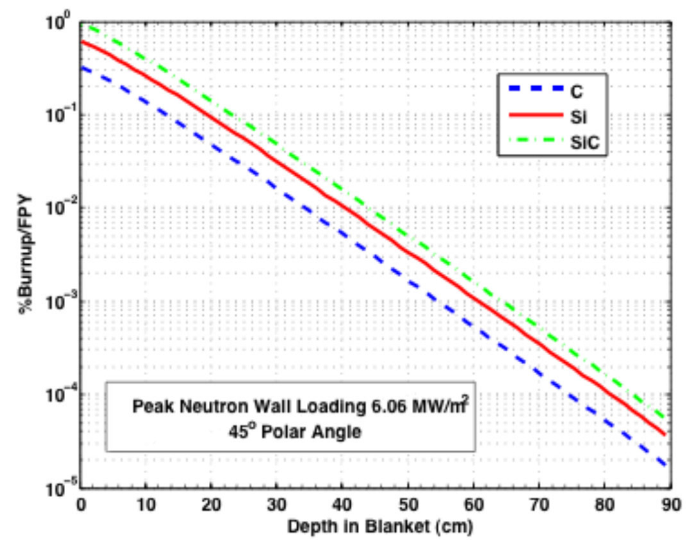
- dpa value are ~10% lower than in MFE with same NWL and gas production and burnup are lower by a factor of 2 due to softer spectrum and perpendicular incidence on FW
- Higher atomic displacement damage rates occur in C sublattice
- He production in C is about a factor of 4 larger than in Si due to the (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

Radial Variation of Damage Parameters in SiC/SiC Composite









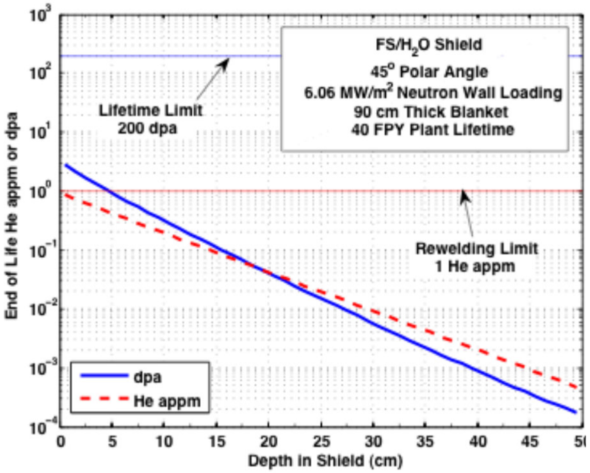
Lifetime Considerations

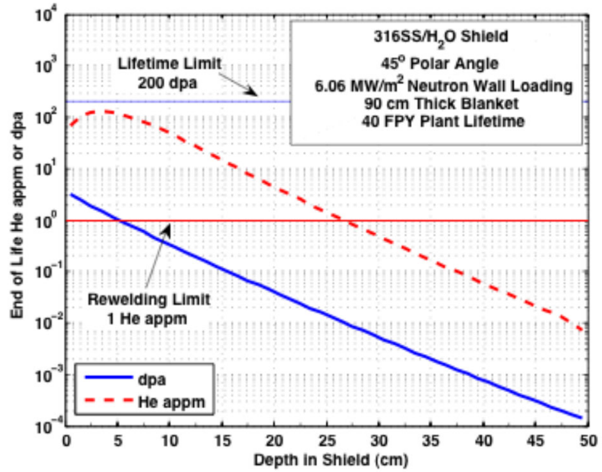
- The issue was addressed in a recent paper:

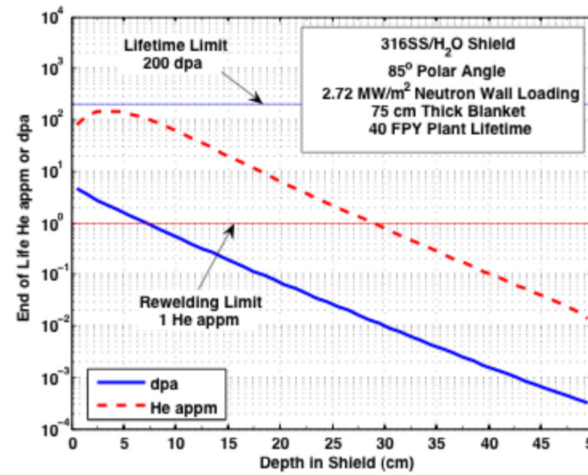
  M. Sawan, L. Snead, and S. Zinkle, "Radiation Damage Parameters for SiC/SiC Composite Structure in Fusion Nuclear Environment," Fusion Science & Technology, vol. 44, pp 150 – 154 (2003).
- Lifetime of SiC/SiC composites in fusion neutron environment can only now be speculated
- Lifetime depends primarily on effect of He and metallic transmutants such as Al, Be, and Mg
- Presence of free silicon degrades strength and enhances creep at high temperatures.Calculations indicated that transmutation of Si occurs at twice the rate of C producing excess C in the crystal. Unlike free silicon, carbon is not expected to segregate to grain boundaries and degrade properties
- He is the likely life-limiting factor for SiC. It is clear that bubble formation due to production of He in presence of neutron damage will produce swelling in SiC. Magnitude of swelling is not known, though it will certainly scale with burnup. Until this is known, an actual estimate of lifetime can only be a guess
- For a 3% burnup limit (corresponding to 260 dpa, 16,300 He appm, and 6,370 H appm), blanket lifetime is 3.26 FPY

Radiation Damage in Shield

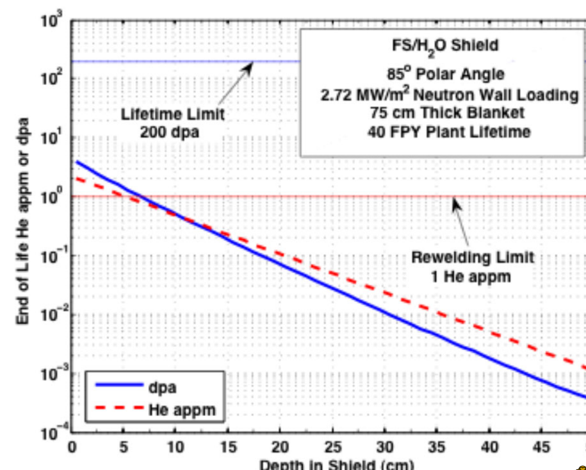
- ➢ A 50 cm thick steel (316SS or FS) shield that doubles as VV is used with 25% water cooling
- ➢ Damage determined at location with highest NWL and at location with thinnest blanket







- ➢ Peak end-of-life radiation damage in shield is only ~5 dpa implying that it will be lifetime component
- ➢ He production in 316SS shield is ~2 orders of magnitude higher than in FS
- ➢ Back of the shield/VV is reweldable
- ➢ If FS is used rewelding is possible at locations at least 5 cm deep in shield. If 316SS is used rewelding is possible at locations at least 30 cm deep in shield



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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)	3.48×10^{17}	2.47×10^{17}	**7.04×10^{17}**	5.14×10^{17}	**10^{19}**
End of life insulator dose (Rads)	1.41×10^{9}	1.07×10^{9}	**2.30×10^{9}**	1.76×10^{9}	**10^{10}**
Peak power density (mW/cm^3)	0.067	0.051	**0.105**	0.082	**1**

- FS is 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

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Tritium Breeding Issue with Flibe/SiC Blanket

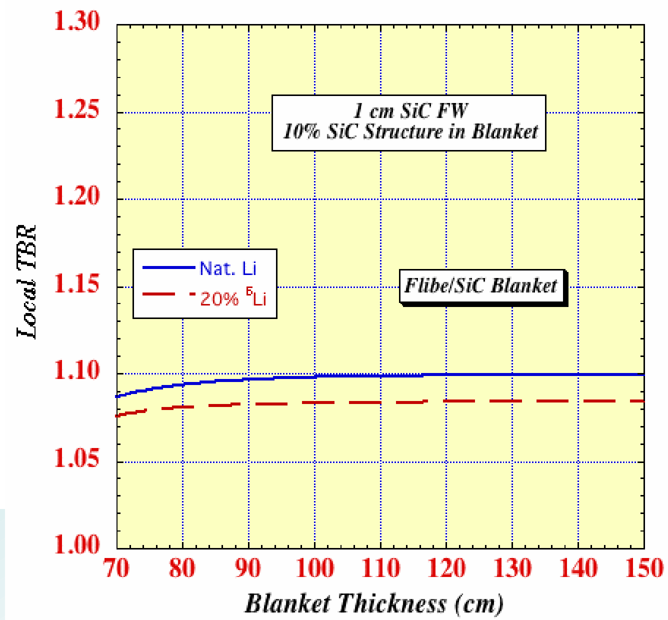
- **Flibe** has advantage over LiPb of lighter weight to support, and low conductivity. However, it lacks of data on compatibility with SiC structure, requires careful chemistry control, has high melting point, and has lower breeder potential
- Breeding behind the cusp dumps with their cooling system 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
- Required local TBR is >1.2 is we do not count on breeding behind the dumps and >1.16 with partial breeding behind dumps

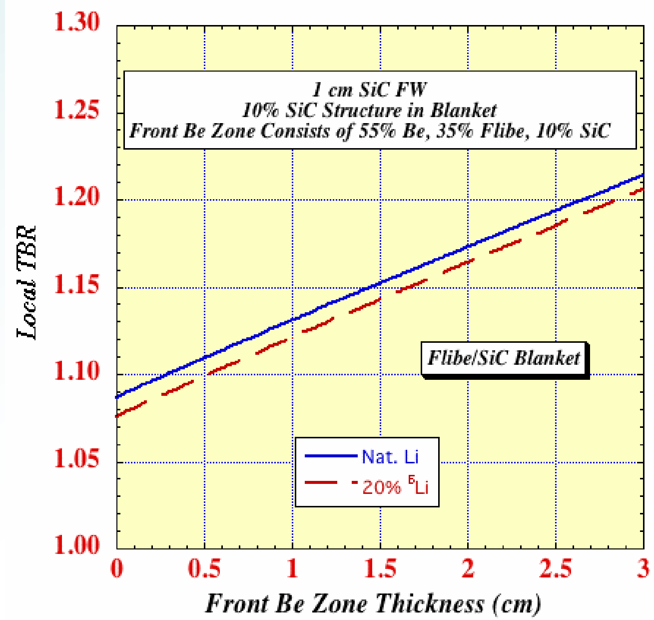
Beryllium is required with Flibe/SiC Blanket

Local TBR for 70 cm blanket
with 10% structure content
(half that with LiPb)

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 tritium breeding
- 3 cm thick front Be zone is needed
- Li enrichment can be used as a knob to reduce TBR if needed





- With 90% ^{6}Li in LiPb and 1.5 cm thick SiC FW overall TBR is estimated to be ~1.2
- Li enrichment can be used as a knob to reduce TBR if needed
- At the 6 MW/m^2 peak NWL, peak power density is 89 W/cm^3 in LiPb and 31 W/cm^3 in SiC
- Total plant thermal power is ***2070 MW*** if energy in dumps and shield is included in power cycle
- Lifetime of SiC/SiC composites in fusion neutron environment can only now be speculated
- For a 3% burnup limit (corresponding to 260 dpa, 16,300 He appm, and 6,370 H appm), blanket lifetime is 3.26 FPY
- Peak end-of-life radiation damage in shield is only ~5 dpa implying that it will be lifetime component
- If FS shield is used rewelding is possible at locations at least 5 cm deep in shield. With 316SS rewelding is possible at locations at least 30 cm deep in shield
- The cusp coils are well protected with the 50 cm shield (either FS or 316SS)
- With Flibe breeder/coolant 3 cm thick front Be zone is needed. Li enrichment can be used as a knob to reduce TBR if needed