Neutronics Analysis of A Self-Cooled Blanket for A Laser Fusion Plant with Magnetic Diversion

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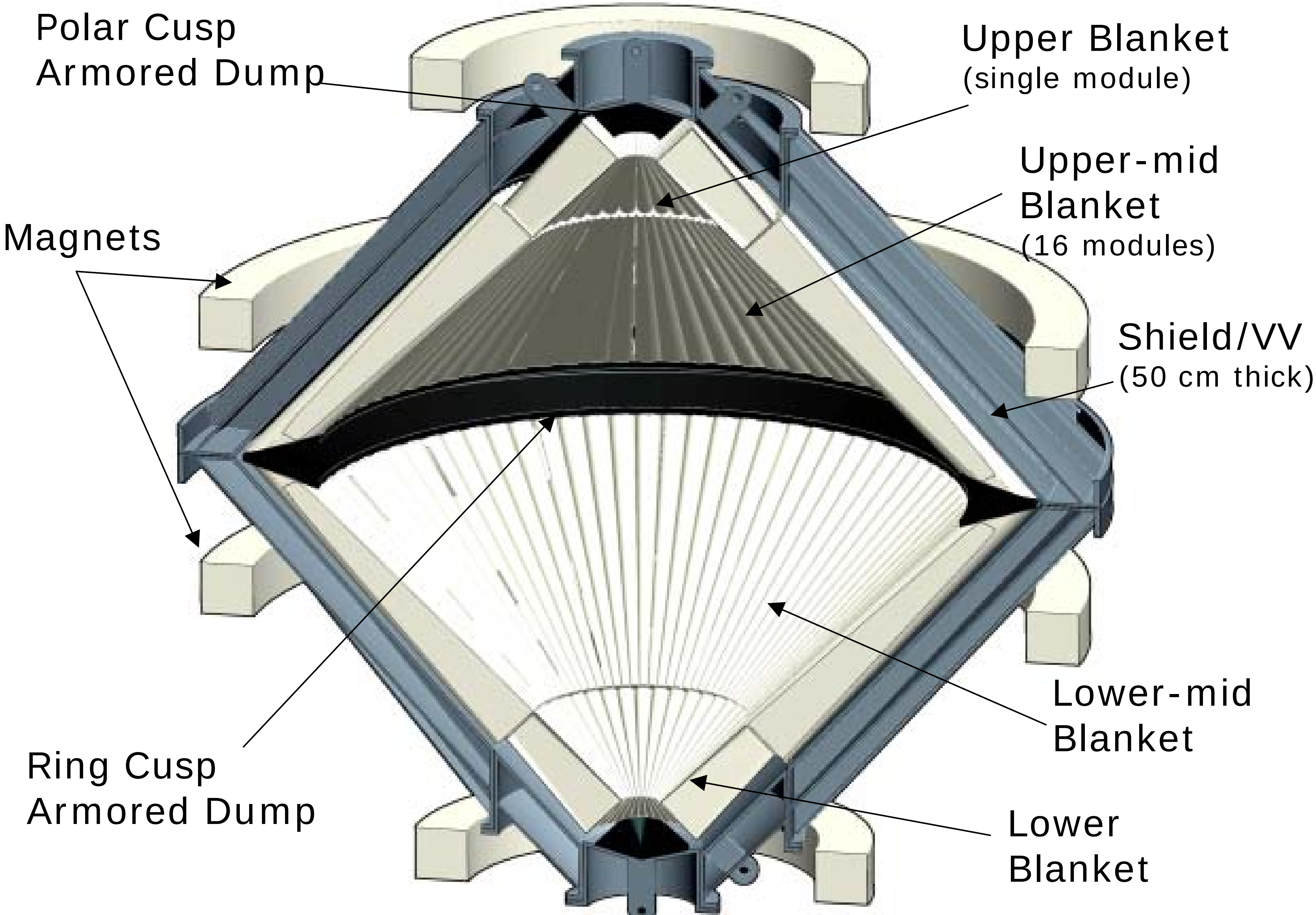
Background

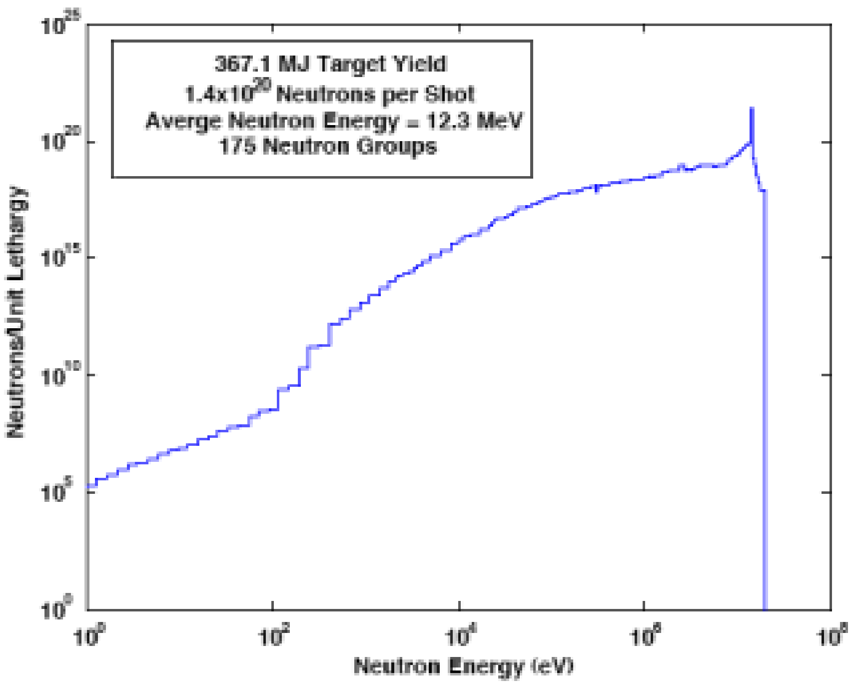
- HAPL program is developing laser inertial fusion energy (IFE) based on direct drive targets and a dry wall chamber
- Dry wall must accommodate ion and photon threat spectra from target
- Current HAPL strategy assumes chamber without protective gas and tungsten and ferritic steel as armor and structural materials resulting in a large chamber (~10.5 m radius)
- Parallel effort explores using magnetic diversion to steer ions away from chamber wall
- Neutronics issues for blanket designs in the HAPL chamber with magnetic diversion are investigated

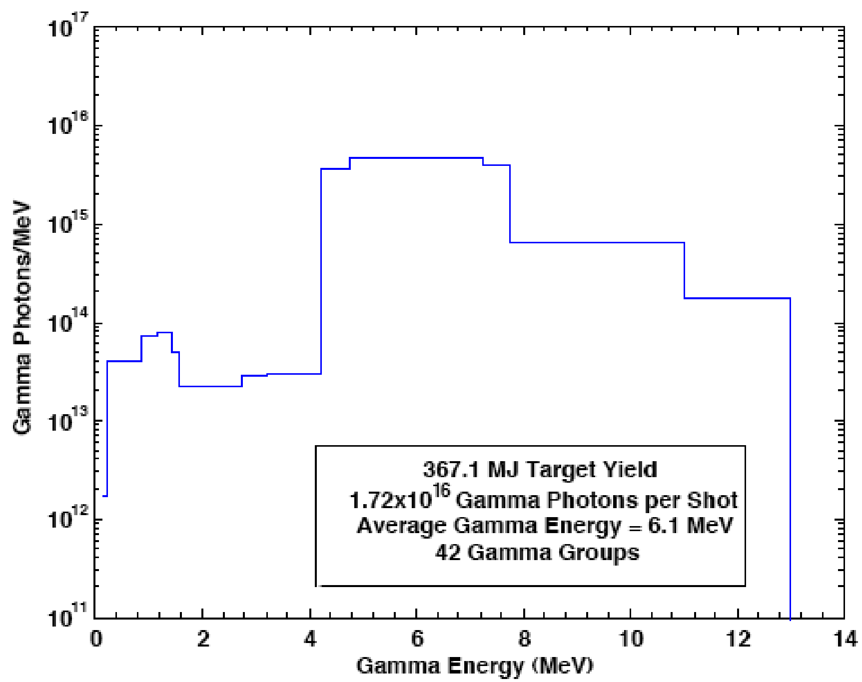
Chamber Configuration



Energy Spectra of Source Neutrons and Gammas Used in Neutronics Calculations

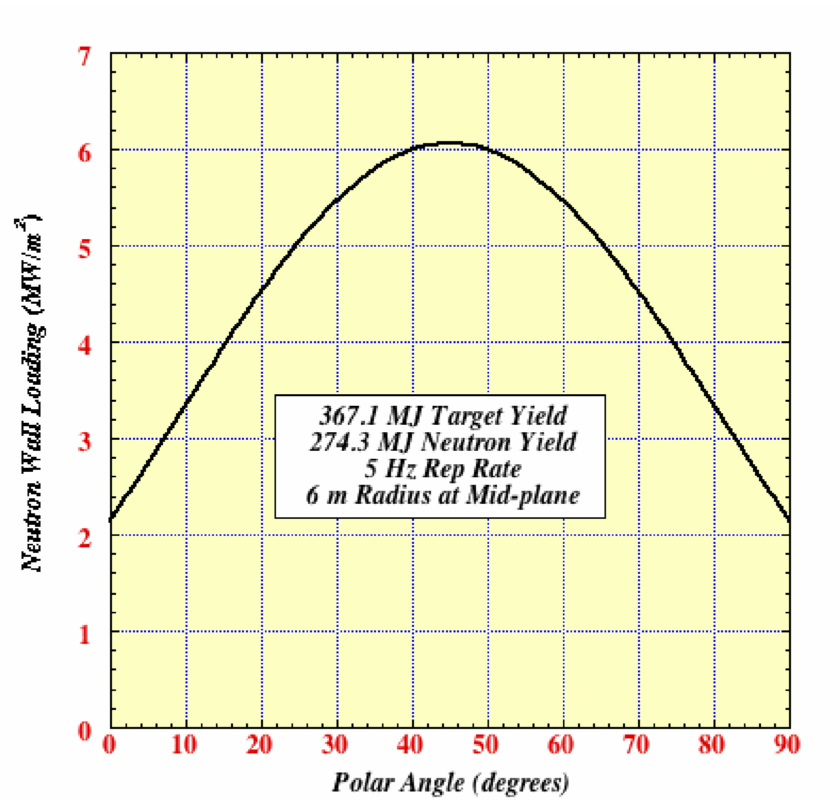
Used target spectrum from LASNEX results (Perkins)

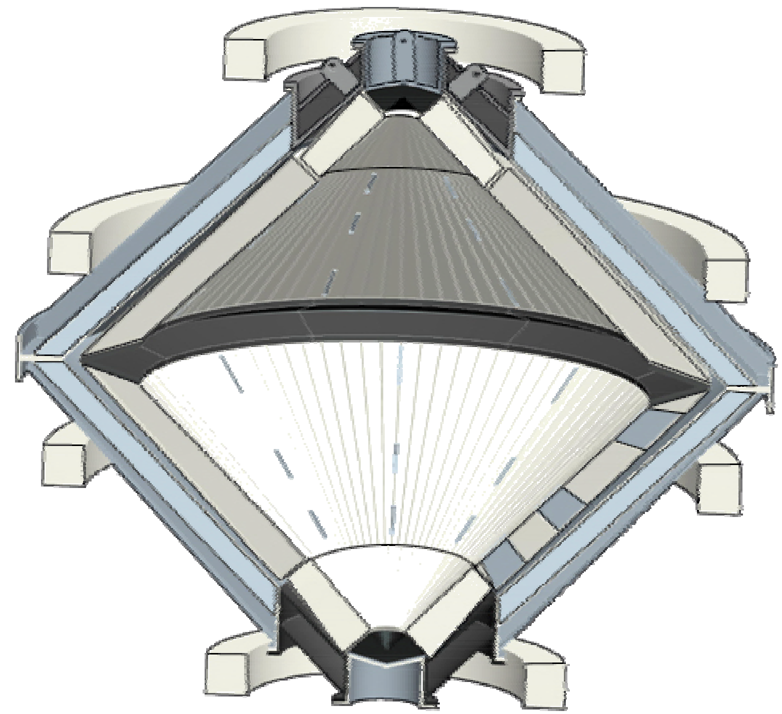




Target yield	367.1 MJ
Rep Rate	5 Hz
Fusion power	1836 MW

Neutron Wall Loading Distribution



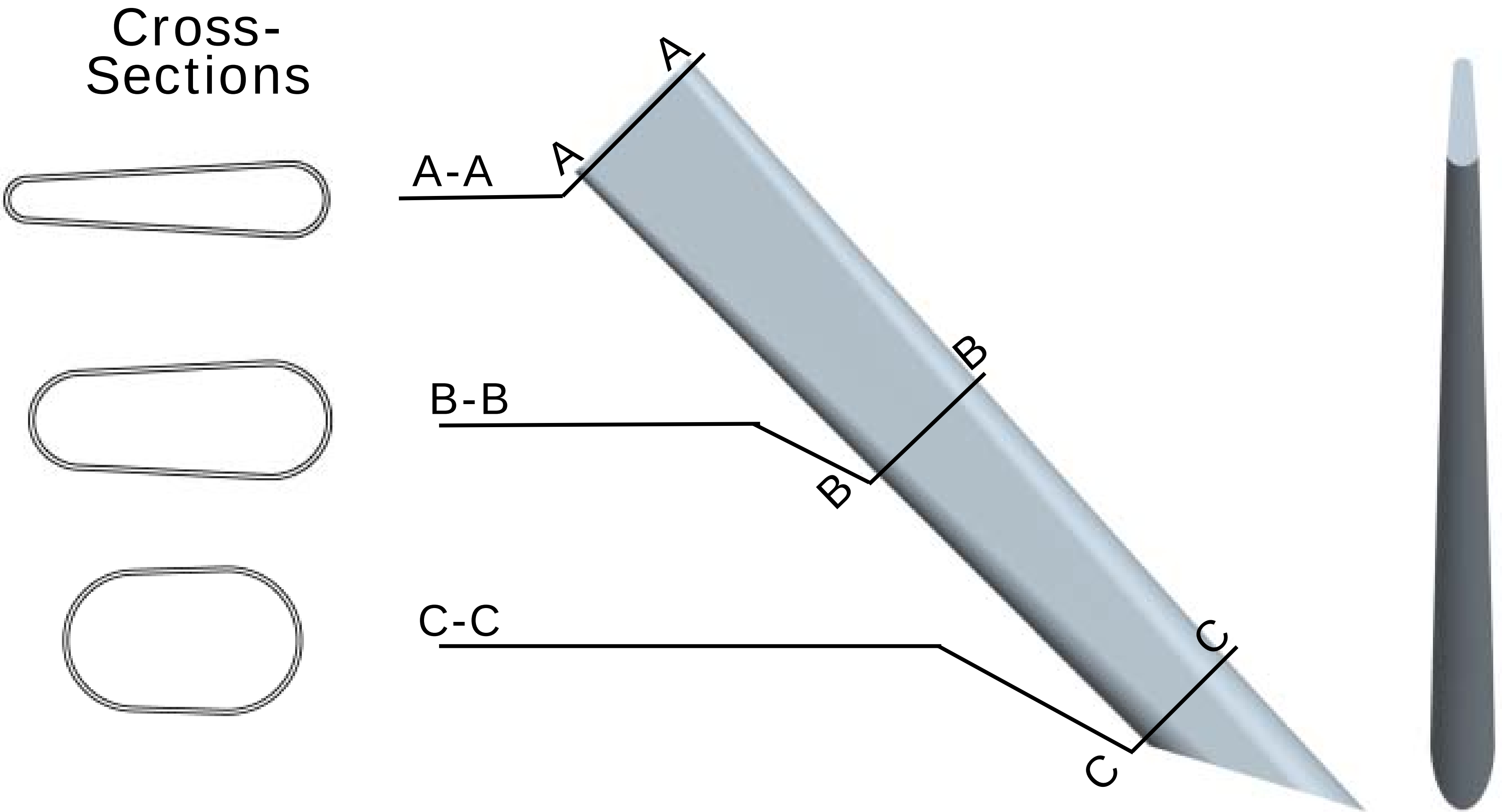


- NWL peaks at 45° polar angle where FW is closest to target and source neutrons impinge perpendicular to it
- Peak NWL is 6 MW/m^2
- Average chamber NWL is 4.3 MW/m^2

Blanket Design Features

- Self-cooled $Li_{17}Pb_{83}$ with 90% ^{6}Li
- Silicon Carbide composite structure
- Utilize concentric channel approach
- FW, annular channel and inner wall thicknesses are each of the order of ~1 cm
- 20% SiC structure in blanket
- Self-draining blanket modules
- Maintenance access is via removable shield modules at each pole
- Blanket thickness is 70 cm at mid-plane and increases towards top and bottom of chamber
- Each mid blanket consists of 16 modules, which in turn, consist of five sub-modules

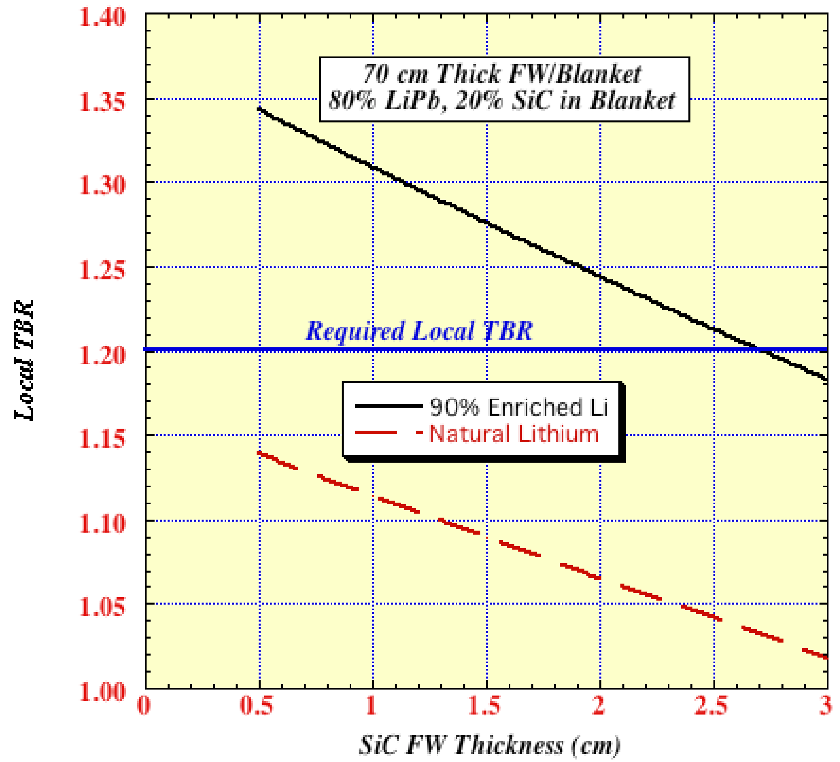
Blanket Sub-Module



- ➢47 cm wide and 70 cm deep at mid-plane
- ➢19.6 cm wide and 106 cm deep at the ends

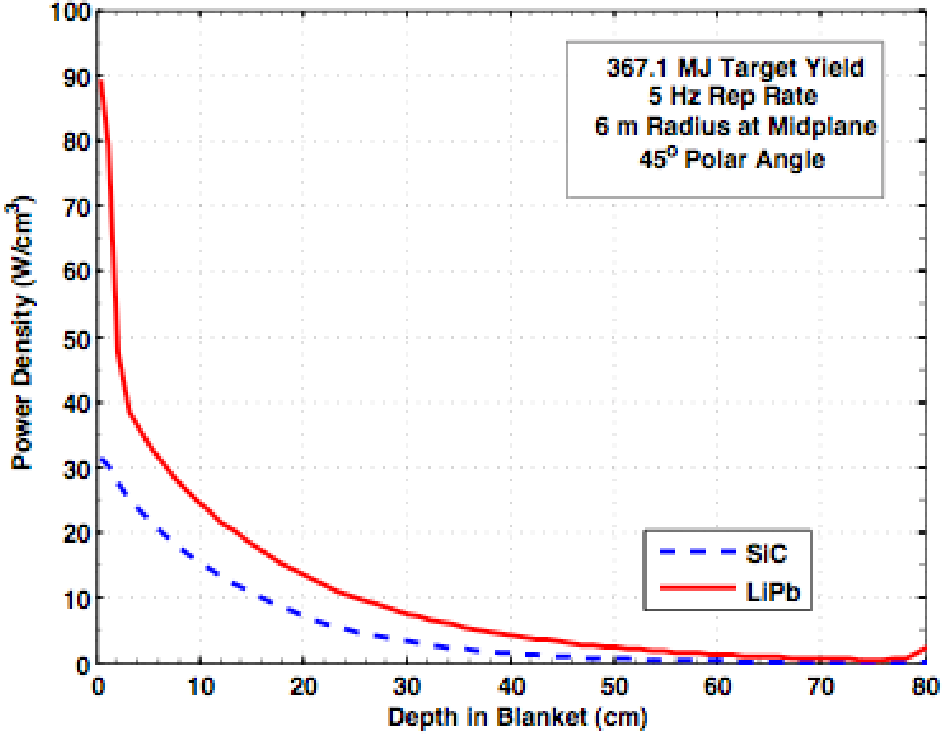
Tritium Breeding

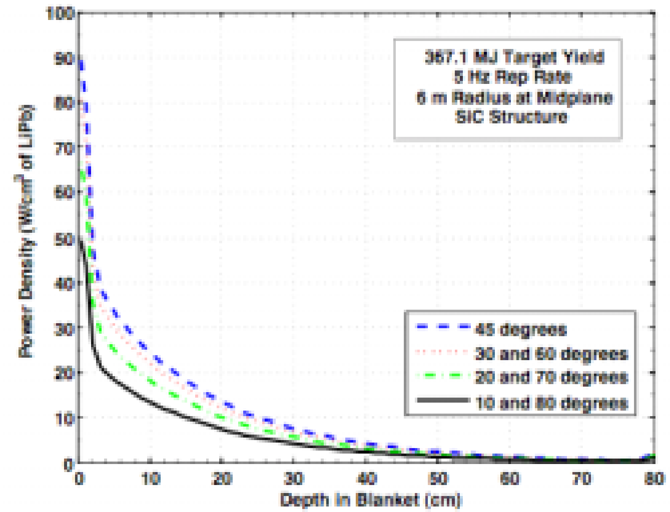
- Tritium breeding affected by space taken by ring cusp, point cusps, and beam ports
- Total breeding blanket coverage lost is ***8.4%***
- For an overall TBR of 1.1 required for tritium self-sufficiency, ***the local TBR should be 1.2***

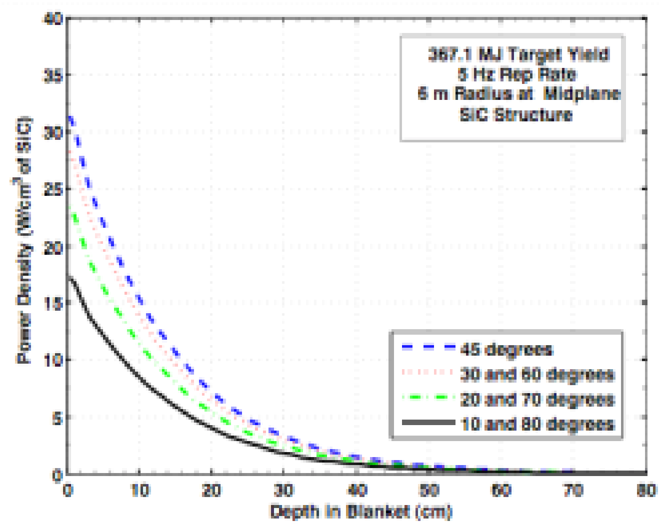


- With 90% ^{6}Li and ~1 cm thick SiC FW overall TBR is estimated to be ~1.25
- Li enrichment can be used as a knob to control TBR as needed

Blanket Nuclear Heating Profiles



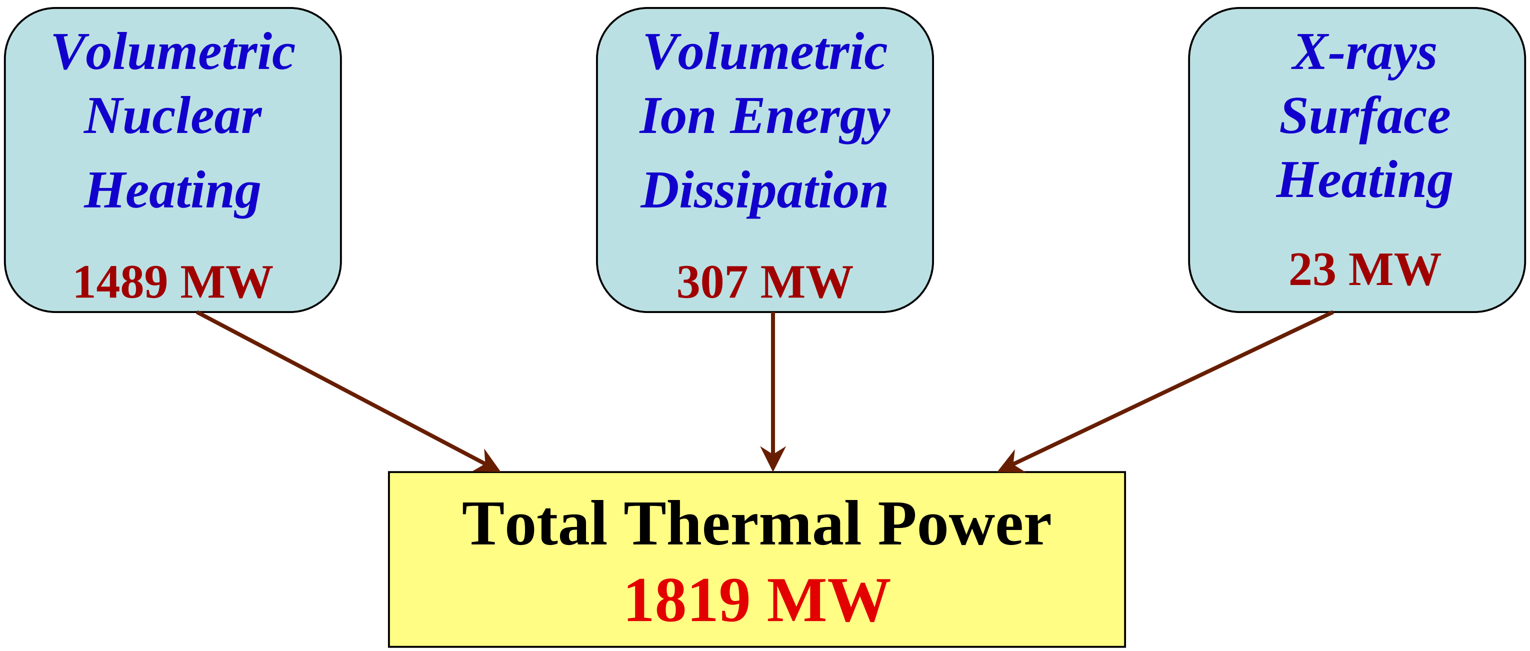




- Peak power density in LiPb is 89 W/cm^3
- Peak power density in SiC is 31 W/cm^3
- Blanket nuclear energy multiplication is 1.185

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



- 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

SiC/SiC Composite Lifetime Assessment

- 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
- 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 Sublattice	Si Sublattice	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
% Burnup/FPY	0.32%	0.60%	0.92	0.32%

- dpa

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
- For a 3% burnup limit (corresponding to 260 dpa, 16,300 He appm, and 6,370 H appm), blanket lifetime is 3.26 FPY
- Determination of effect of transmutations 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
- Damage determined at location with highest NWL and at location with thinnest blanket

QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

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- Peak end-of-life radiation damage in shield is only ~5 dpa $\Rightarrow$ 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

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**

- 316SS shield provides slightly better magnet shielding
- The cusp coils are well protected with the 50 cm shield
- No restriction on location of the coils

Summary

- All neutronics requirements can be satisfied for a SiC/LiPb blanket in HAPL with magnetic diversion
- Blanket has potential for achieving tritium self-sufficiency with an overall TBR of ~1.25
- 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***
- Lifetime of SiC$_f$/SiC composites in fusion neutron environment can only now be speculated
- For a 3% burnup limit (260 dpa, 16,300 He appm, and 6,370 H appm), blanket lifetime is 3.26 FPY
- Shield/VV is lifetime component with reweldable back
- The cusp coils are well protected with the 50 cm shield