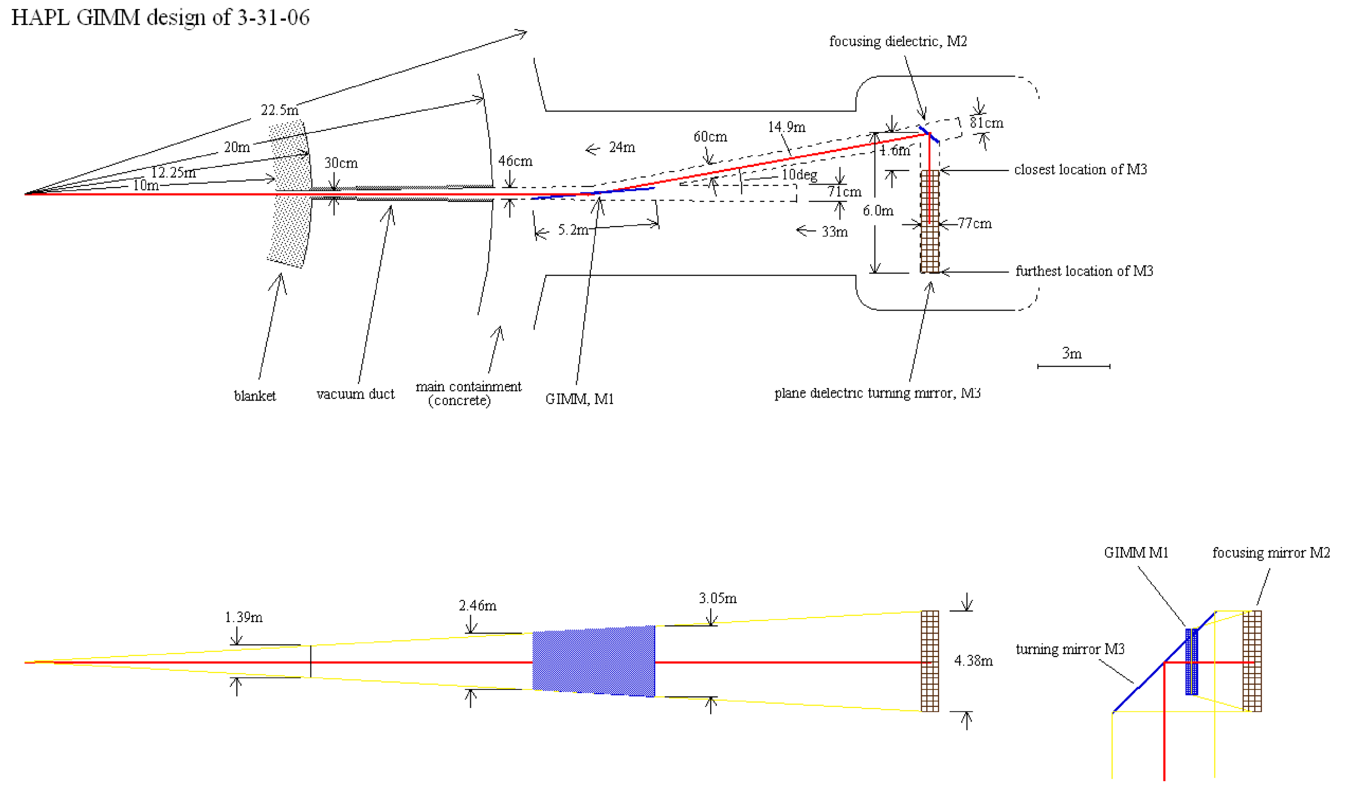
Three-Dimensional Nuclear Analysis for the Final Optics System of HAPL

Mohamed Sawan, Ahmad Ibrahim, Tim Bohm, Paul Wilson

Fusion Technology Institute - University of Wisconsin, Madison, WI

Baseline HAPL Optics Configuration with GIMM



Provided by Malcolm McGeoch

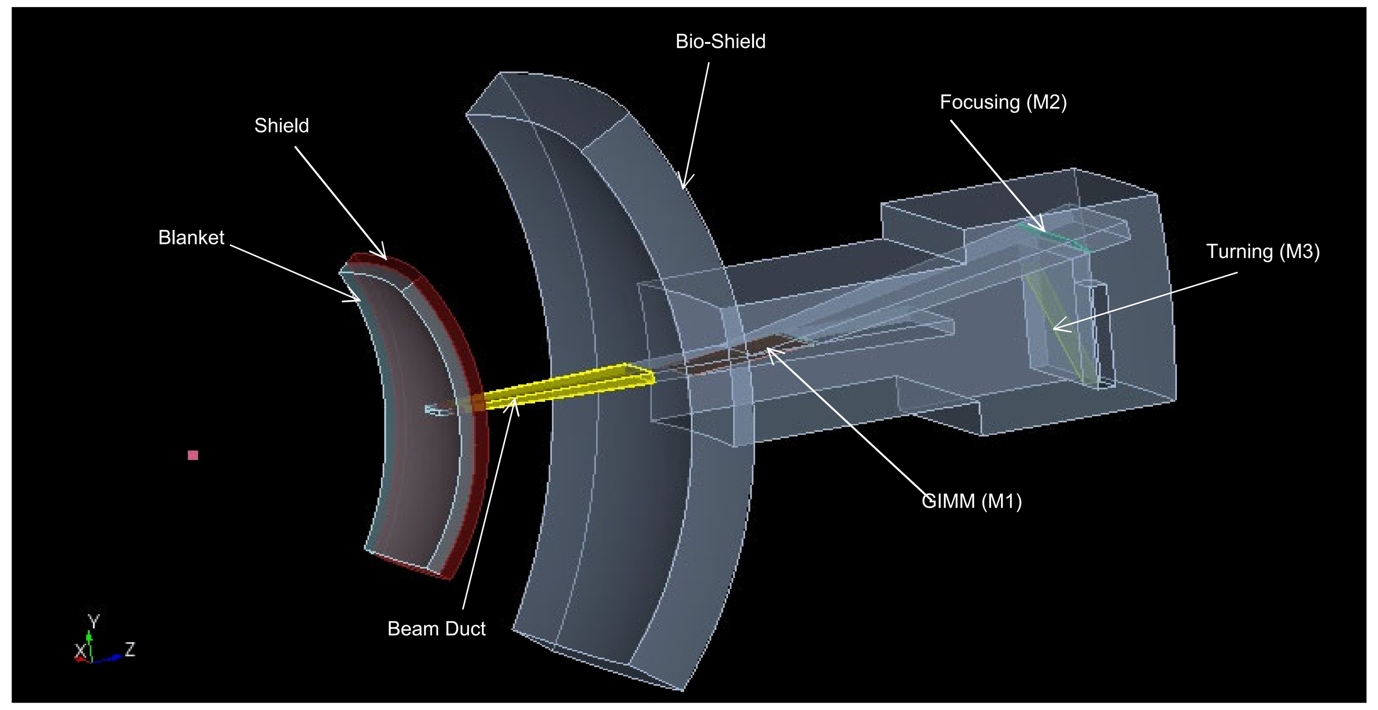
Objectives

- Determine nuclear environment at the GIMM (M1), focusing mirror (M2), and turning mirror (M3) final optics of HAPL
- Assess impact of GIMM design

Approach

- Used Monte Carlo code MCNPX-CGM with direct neutronics calculations in CAD model
- Continuous energy FENDL-2.1 nuclear data
- Modeled one beam with reflecting boundaries
- Neutron traps used behind GIMM and M2
- Two lightweight GIMM design options considered (SiC, AlBeMet)
- 1 cm thick Sapphire M2 and M3 mirrors
- Blanket/shield included in model
- Concrete containment building housing optics

Geometrical Model Used in 3-D Neutronics Analysis



Flux at Front Faceplate of GIMM

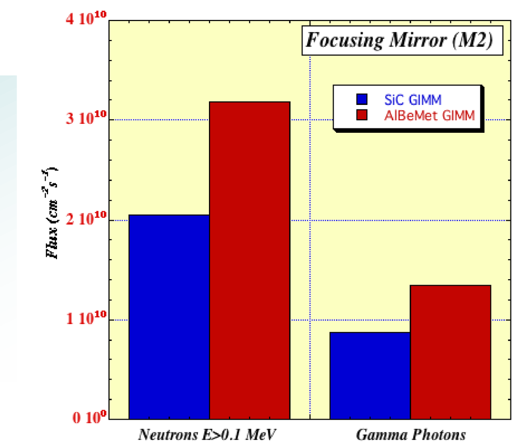
		Flux ($cm^{-2}.s^{-1}$)
SiC GIMM	Neutrons E>0.1 MeV	**1.39×10^{13}** (±2.1%)
	Total Neutrons	1.43×10^{13} (±2.1%)
	Total Gamma	1.57×10^{12} (± 5.5%)
AlBeMet GIMM	Neutrons E>0.1 MeV	1.21×10^{13} (±2.1%)
	Total Neutrons	1.30×10^{13} (±2.1%)
	Total Gamma	1.88×10^{12} (±4.4%)

Material choice and thickness slightly impacts peak flux in GIMM
Neutron spectrum softer for AlBeMet with 93% >0.1 MeV compared to 97% for SiC

Flux at Focusing Dielectric Mirror M2 Located @14.9 m from GIMM

		Flux ($cm^{-2}.s^{-1}$)	Fluence per full power year (cm^{-2})
SiC GIMM	Neutrons E>0.1 MeV	2.05×10^{10} (±4.0%)	6.46×10^{17}
	Total Neutrons	2.27×10^{10} (±4.0%)	7.15×10^{17}
	Total Gamma	0.88×10^{10} (±6.9%)	2.77×10^{17}
AlBeMet GIMM	Neutrons E>0.1 MeV	**3.18×10^{10}** (±3.9%)	**1.00×10^{18}**
	Total Neutrons	3.57×10^{10} (±3.8%)	1.12×10^{18}
	Total Gamma	1.35×10^{10} (±5.9%)	4.25×10^{17}

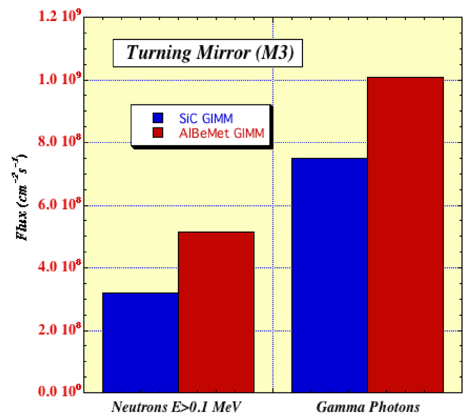
Neutron flux is a factor of ~1.6 higher with AlBeMet GIMM
Total neutron and gamma fluxes are more than two orders of magnitude lower than at GIMM
Neutron spectrum is hard with ~90% of neutrons @ E>0.1 MeV



Peak Flux at Turning Mirror M3 Located @ 1.6-6 m from M2

		Peak Flux ($cm^{-2}.s^{-1}$)	Peak Fluence per full power year (cm^{-2})
SiC GIMM	Neutrons E>0.1 MeV	3.18×10^{8} (±7.3%)	1.00×10^{16}
	Total Neutrons	8.44×10^{8} (±8.2%)	2.66×10^{16}
	Total Gamma	7.51×10^{8} (±8.0%)	2.37×10^{16}
AlBeMet GIMM	Neutrons E>0.1 MeV	**5.14×10^{8}** (±7.6%)	**1.62×10^{16}**
	Total Neutrons	1.31×10^{9} (±8.8%)	4.13×10^{16}
	Total Gamma	1.01×10^{9} (±5.5%)	3.18×10^{16}

Neutron flux is a factor of ~1.6 higher with AlBeMet GIMM
Total neutron flux is about two orders of magnitude lower than at M2 with smaller gamma flux reduction
Neutron spectrum is softer with ~40% of neutrons @ E>0.1 MeV



Peak Fast (E>0.1 MeV) Neutron Fluence per Full Power Year at Mirrors in Final Optics of HAPL

	Peak Fast Neutron Fluence per FPY (n/cm2)	
	SiC GIMM	*AlBeMet GIMM*
GIMM (M1)	*4.38×10^{20}* (±2.1%)	*3.81×10^{20}* (±2.1%)
Focusing Mirror (M2)	*6.46×10^{17}* (±4.0%)	*1.00×10^{18}* (±3.9%)
Turning Mirror (M3)	*1.00×10^{16}* (±7.3%)	*1.62×10^{16}* (±7.6%)

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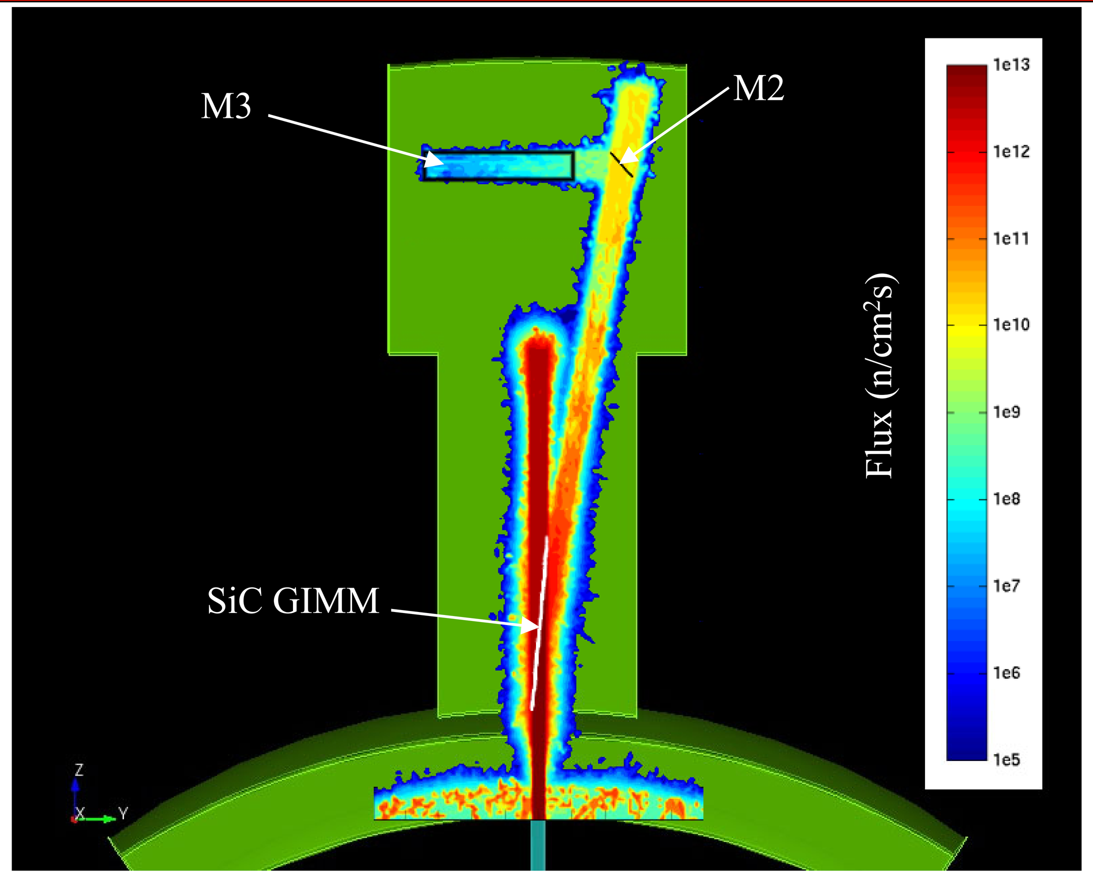
Fast Neutron Flux Distribution in Final Optics of HAPL



Findings and Conclusions

- 3-D neutronics calculation performed to determine nuclear environment in the HAPL final optics and compare impact of possible GIMM design options
- Neutron flux at dielectric mirrors is higher by a factor of ~1.6 with AlBeMet
- Neutron spectrum softens significantly at M3 (~40% >0.1 MeV vs. ~90% at M2)
- Peak fast (E>0.1 MeV) neutron fluence per FPY:
  - ***GIMM*** ***4.4×10^{20} n/cm²***
  - ***M2*** ***1.0×10^{18} n/cm²***
  - ***M3*** ***1.6×10^{16} n/cm²***
- Significant drop in nuclear environment occurs as one moves from the GIMM to dielectric focusing and turning mirrors
- Experimental data on radiation damage to metallic and dielectric mirrors are essential for accurate lifetime prediction
- For fluence limits of 10^{21} n/cm² (GIMM) and 10^{19} n/cm² (dielectric), expected GIMM lifetime is ~2 FPY, expected M2 lifetime is 10 FPY, and M3 is lifetime component