SABRE Shielding Studies

Current Simulation Setup

- SUPL vessel and shielding implemented in GEANT4
  - All shields tested have thickness **totalling 20 cm**
  - Vessel is cylindrical with spherical cap, **height and diameter of 2 m**
- **1 million particles** are generated **on surface of 2.2 m radius sphere which is centred on the crystal of the SABRE detector** for each shield test
- Particle energies originally generated from uniform energy spectrum between 0 and 10 MeV
- **Then weighted by LNGS neutron energy spectrum and SUPL photon energy spectrum**
- Particles are focused towards the centre of the sphere

Summary Data of Shield Tests

Percentage of Detected Background of Worst Performing Shield			
Shield Material (outside to inside)	Lead Thickness (cm)	Neutrons	Photons
5cm Lead, 5cm PE, 5cm Lead, 5 cm PE	10	71.01%	3.74%
10cm Lead, 10cm PE	10	85.23%	3.98%
3cm PE, 7cm Lead, 3cm PE, 7cm Lead	14	98.31%	0.50%
7cm Lead, 3cm PE, 7cm Lead, 3cm PE	14	100.00%	0.65%
5cm PE, 3cm Lead, 8.25cm PE, 3.75cm Lead	6.75	24.45%	55.51%
7cm PE, 3cm Lead, 3cm PE, 7cm Lead	10	20.38%	100.00%
3cm PE, 7cm Lead, 7cm PE, 3cm Lead	10	31.09%	8.84%
5cm PE, 5cm Lead, 5cm PE, 5cm Lead	10	63.56%	3.52%
5cm PE, 3cm Lead, 6cm PE-Bi, 2.25cm PE-Li, 3.75cm Lead	6.75	21.42%	9.79%
3cm PE, 5cm Lead, 6cm PE-Bi, 2.25cm PE-Li, 3.75cm Lead	8.75	26.84%	3.82%

Summary Data of Shield Tests

Percentage of Particles Depositing < 200 keV in Scintillator & > 0 keV in Crystal of Worst Performing Shield			
Shield Material (outside to inside)	Lead Thickness (cm)	Neutrons	Photons
5cm Lead, 5cm PE, 5cm Lead, 5 cm PE	10	74.62%	6.07%
10cm Lead, 10cm PE	10	106.71%	1.95%
3cm PE, 7cm Lead, 3cm PE, 7cm Lead	14	64.41%	0.65%
7cm Lead, 3cm PE, 7cm Lead, 3cm PE	14	100.00%	0.44%
5cm PE, 3cm Lead, 8.25cm PE, 3.75cm Lead	6.75	30.77%	57.82%
7cm PE, 3cm Lead, 3cm PE, 7cm Lead	10	24.70%	100.00%
3cm PE, 7cm Lead, 7cm PE, 3cm Lead	10	44.90%	11.71%
5cm PE, 5cm Lead, 5cm PE, 5cm Lead	10	61.40%	5.10%
5cm PE, 3cm Lead, 6cm PE-Bi, 2.25cm PE-Li, 3.75cm Lead	6.75	14.27%	11.11%
3cm PE, 5cm Lead, 6cm PE-Bi, 2.25cm PE-Li, 3.75cm Lead	8.75	17.13%	1.25%

Key Points

- Best shield configuration **without specialized PE materials and total 10cm thickness of lead**, are alternating layers of PE and Lead, of 3:7:7:3 cm and 5:5:5:5 cm layers

- 3:7:7:3 arrangement better for neutron and 5:5:5:5 arrangement better for gamma

- If PE-Bi and PE-Li can be utilized, then better shielding with less total lead thickness

Summary Data of Shield Tests

Shield Material (outside to inside)	# Neutron in Scintillator	#Photons in Scintillator
5cm Lead, 5cm PE, 5cm Lead, 5 cm PE	187854	8642
10cm Lead, 10cm PE	204717	8621
3cm PE, 7cm Lead, 3cm PE, 7cm Lead	235868	1636
7cm Lead, 3cm PE, 7cm Lead, 3cm PE	220153	1562
5cm PE, 5cm Lead, 5cm PE, 5cm Lead	191250	8882
5cm PE, 3cm Lead, 6cm PE-Bi, 2.25cm PE-Li, 3.75cm Lead	106482	21575
5cm PE, 3cm Lead, 8.25cm PE, 3.75cm Lead	105215	85777
3cm PE, 7cm Lead, 7cm PE, 3cm Lead	114321	17299
7cm PE, 3cm Lead, 3cm PE, 7cm Lead	103099	132610
3cm PE, 5cm Lead, 6cm PE-Bi, 2.25cm PE-Li, 3.75cm Lead	111542	9027

Summary Data of Shield Tests

Shield Material (outside to inside)	# Edec > 0, Escint < 200 keV	# Edec > 0, Escint < 200 keV
5cm Lead, 5cm PE, 5cm Lead, 5 cm PE	186	86
10cm Lead, 10cm PE	268	91
3cm PE, 7cm Lead, 3cm PE, 7cm Lead	182	16
7cm Lead, 3cm PE, 7cm Lead, 3cm PE	222	11
5cm PE, 5cm Lead, 5cm PE, 5cm Lead	176	102
5cm PE, 3cm Lead, 6cm PE-Bi, 2.25cm PE-Li, 3.75cm Lead	67	233
5cm PE, 3cm Lead, 8.25cm PE, 3.75cm Lead	124	1217
3cm PE, 7cm Lead, 7cm PE, 3cm Lead	131	205
7cm PE, 3cm Lead, 3cm PE, 7cm Lead	80	2032
3cm PE, 5cm Lead, 6cm PE-Bi, 2.25cm PE-Li, 3.75cm Lead	64	86

Analysis

- Alternating 5cm lead and PE layers performs better than layering 10cm of lead and PE for neutron shielding, and performed similarly for photons

- Stewart et al. (2008) finds that 3 cm of PE and 7 cm of Lead is sufficient in self-shielding (shielding photons from internal interactions)
  - Using 7 cm lead layers, 14 cm total, greatly decreases photon count, as expected
  - However this leaves 6 cm total of PE, increasing neutron count

- When constrained to 10cm total thickness of PE and lead:
  - Using combinations of 3cm and 7cm layers leads to greater neutron reduction than 5cm layers
  - However, this leads to greater photon count
  - Arrangement of 3cm and 7cm layers has large effect on photon shielding effectiveness

Analysis

- Stewart et al. (2008) tested 80cm shields using layers of PE-Li and PE-Bi
- Their best shield, ML1, was scaled down to 20cm, and was best at neutron shielding, but poor in photon shielding, relative to previous shields
- Testing a version of ML1 with PE-Li and PE-Bi replaced with PE resulted in worse photon shielding, but comparable neutron shielding
- Testing an altered version of ML1 with the outer PE and lead layered swapped more than halved the photon count, and has comparable neutron shielding

Next Steps

- Continue adjusting shield configurations for optimal attenuation of neutrons and photons

- Repeat studies for well performing shields using LNGS neutron spectrum, and SUPL photon spectrum