Development of a shield based on Monte–Carlo studies for the COBRA Experiment

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Goal

- Developement of an efficient radiation shield for a large scale COBRA experiment
- Monte–Carlo based: All simulations were done with geant4 9.4.p01
- Comparing commercially available shielding materials

$\rightarrow$ **Goal**: Identification of the most effective combination of material

External radiation sources

- Most important external radiation sources are muons, neutrons and γ–radiation
- Muonic component of cosmic rays is suppressed and hadronic component is negligible
  - Except **muon–induced neutrons** originating from the rock material or the shielding materials itself
  - Can have energies up to GeV, propagate large distances and lose energy by nucleus recoils
- γ–radiation mainly becomes important when originating from neutron interactions

$\rightarrow$ **Main focus** of interest was neutron radiation from rock material and neutron–induced radiation originating from shielding materials

Measured Neutron Flux at LNGS

Energy Bins	Neutron Flux [1] $[10^{-6}\mathrm{cm}^{-2}\mathrm{s}^{-1}]$	Energy Bins	Neutron Flux [2] $[10^{-6}\mathrm{cm}^{-2}\mathrm{s}^{-1}]$
(0 – 50) meV	1.08 ± 0.02		
50 meV – 1 keV	1.84 ± 0.20		
1 keV – 2.5 MeV	0.54 ± 0.01	(1 – 2.5) MeV	0.14 ± 0.12
(2.5 – 5) MeV	0.27 ± 0.14	(2.5 – 5) MeV	0.13 ± 0.04
(5 – 10) MeV	0.05 ± 0.01	(5 – 10) MeV	0.15 ± 0.04
(10 – 15) MeV	$(0.6 \pm 0.2) \cdot 10^{-3}$	(10 – 15) MeV	$(0.4 \pm 0.4) \cdot 10^{-3}$
(15 – 25) MeV	$(0.5 \pm 3.0) \cdot 10^{-6}$		

[1] P.Belli et al. Deep underground neutron flux measurement with large BF_3 counters

[2] F. Arneodo et al. Measurement of neutron flux produced by cosmic ray muons with LVD at Gran Sasso

Strategy

- Examine each material as a single layer shield for its radiation interaction properties
- Maximize the attenuation for a specific radiation source by combining multiple materials

→ Building a multilayer shield

Single Layer Properties

- Monoenergetic neutrons with 1 keV – 15 MeV were aimed at a 1 m thick slab, subdivided into 1 mm thick slices

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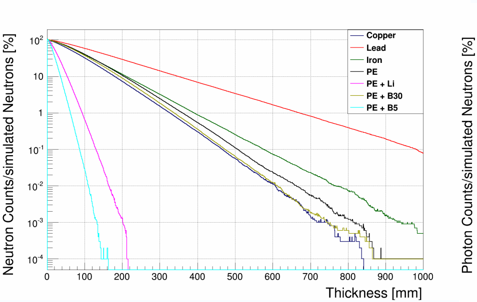
- Considered materials:

Material	Composition [ratio]	Density [g/cm^3]
Copper	nat.	8.96
Lead	nat.	11.35
Iron	nat.	7.824
PE	CH_2 [1:2]	0.92
PE+Li (7.5 %)	CH_2,Li [1:2:0.24]	1.06
PE+B (30 %)	CH_2,B [1:2:0.34]	1.12
PE+B (5 %)	CH_2,B [1:2:0.18]	1.6

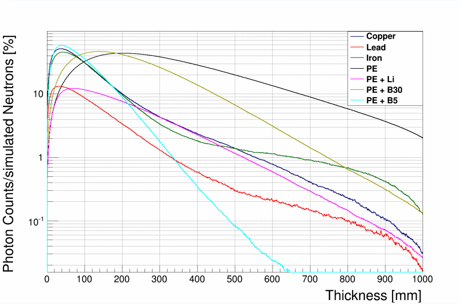
Neutron/Photon Counts: E_n=5 MeV

Neutron Counts
E_n=5 MeV, Cut: E_{kin}>1 MeV



effective neutron attenuation ($<$10%): $<$10 cm

Photon Counts
E_n=5 MeV



(n,γ) self–shielding ($<$10%): $\sim$20 cm

Multilayer Properties

- Standard neutron shield is built out of three layers (metal, moderator, absorber)
- In this study the moderator and the absorber were combined (doped PE)
- In regard to other important background sources (natural radioactivity) copper was used as inner layer

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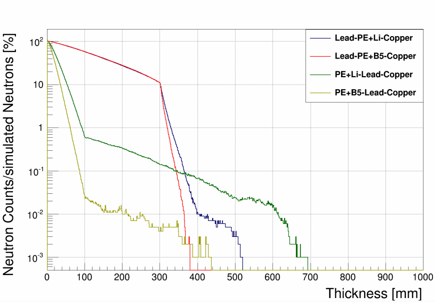
- In regard to other important background sources (natural radioactivity) copper was used as inner layer
- Monoenergetic neutrons with 1 keV – 15 MeV were aimed at a 1 m thick slab, subdivided into 1 mm thick slices, of three materials

Lead (30 cm) – PE+Li/B5 (10 cm) – Copper
PE+Li/B5 (10 cm) – Lead (50/40 cm) – Copper

Neutron/Photon Counts: E_n=5 MeV

Neutron Counts

E_n=5 MeV, Cuts: E_{kin}>1 MeV



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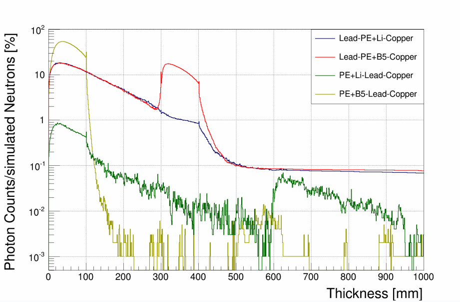

Lead (30 cm) – PE+Li/B5 (10 cm) – Copper

PE+Li/B5 (10 cm) – Lead (50/40 cm) – Copper

Summary

- Multilayer Result:
  - **Lead (30 cm) – PE+Li/B5 (10 cm) – Copper (10 cm)**:
    - Effective neutron (<0.01%) and γ (<0.1%) attenuation after $\sim$ 50 cm
  - **PE+Li (10 cm) – Lead (50 cm) – Copper**:
    - Effective neutron (<0.1%) and γ (<0.1%) attenuation after $\sim$ 60 cm

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  - **PE+B5 (10 cm) – Lead (40 cm) – Copper**:
    - Effective neutron ($<0.001\%$) and γ ($<0.01\%$) attenuation after $\sim$ 50 cm

Summary

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    - Effective neutron (<0.001%) and γ (<0.01%) attenuation after $\sim$ 50 cm

Thank you for your attention!