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Neutron Background Simulations for LEGEND-1000 in a Geant4-based Framework

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The LEGEND (Large Enriched Germanium Experiment for Neutrinoless double-beta Decay) Collaboration will begin the construction of its initial phase, LEGEND-200, using recently repurposed GERDA infrastructure, with a final 1000-kg installation (LEGEND-1000) in planning. A simulation study of the neutron background is underway, using a custom simulation module based on Geant4. Neutron backgrounds have a strong dependence on laboratory depth, shielding material, and cryostat design. This module has been developed to study cosmogenically-induced neutrons, as well as neutrons from (α, n) reactions. The progress and status of this work will be discussed.

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[*] Speaker

1. Neutron simulations

A simulation module using the Geant4[1] software framework was developed primarily for LEGEND-1000[2] simulations, using the "shielding" physics list. It includes custom inputs and a geometry resembling the LEGEND-1000 baseline geometry, shown in Figure 1. The radiogenic neutron flux and energy spectra were calculated using material assay measurements[3] performed for the GERDA experiment as well as the NeuCBOT software package[4]. Cosmogenic muon flux and spectra were based on a parametrization from [5] and detector signal estimates from neutron capture are from [6].

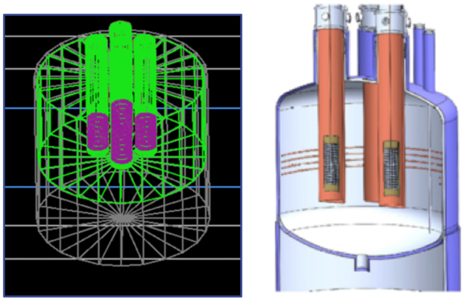

Figure 1: The simulation geometry used in this work (left) and a CAD sketch of the LEGEND-1000 baseline design (right).

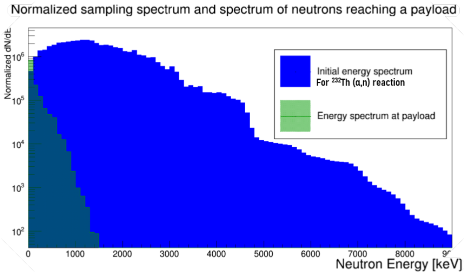

Figure 2: Normalized energy spectra of neutrons from the ^{228}Th (α,n) reaction in the stainless steel cryostat at time of creation (blue) and on contact with a germanium crystal (green overlay).

2. Radiogenic neutrons

In the LEGEND-1000 baseline design, some major contributors of radiogenic neutrons are (α, n) reactions and spontaneous fission from impurities in the stainless steel cryostat. The neutron energy spectra are depicted in Fig. 2. The neutrons must propagate through 2 m of liquid argon at minimum to reach a germanium detector, significantly reducing flux and energy. Neutrons reaching detectors must also be captured in order to generate a signal in the region of interest, decreasing background further. Conservative calculations in this work suggest the background contribution from radiogenic neutrons will be less than 10% of the total LEGEND-1000 background goal.

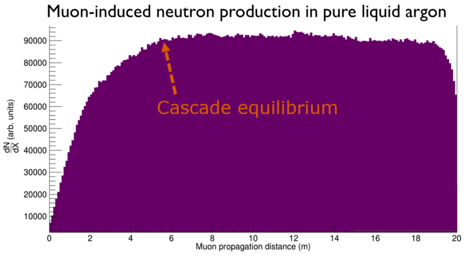

Figure 3: Neutron production rate as a function of muon path length in liquid argon. LEGEND-1000 path lengths are in the region of rapid rate increase before equilibrium is reached.

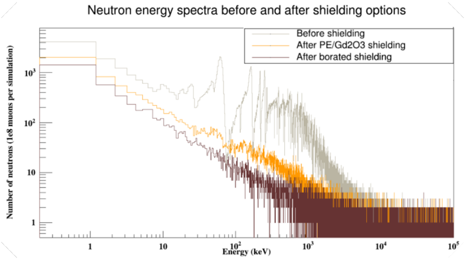

Figure 4: Neutron flux with shielding options described in the text. Shields are 10 cm thick and cylindrical.

3. Cosmogenic neutrons

Cosmogenically induced neutrons are primarily generated during hadronic showers initiated by cosmic ray muons of GeV to TeV energy interacting with nuclei along their trajectories. The resulting particle cascade increases in size until reaching equilibrium. Outside the liquid argon, the water shielding effectively stops muon showers. A key insight of this work was that larger liquid argon shielding could increase cosmogenic neutron flux impinging on the detectors, as shown in Fig. 3. At SNOLab depth and with a minimum argon shielding of 2 meters, the cosmogenic neutron backgrounds are also less than 10% of the total LEGEND-1000 background goal.

4. Mitigation strategies

A solid shield and liquid argon doping are under consideration to mitigate the neutron flux at the detectors. A polyethylene shield with an inner lining of gadolinium oxide and a polyethylene shield doped with a 5% mass fraction of boron were considered. The shield material can reduce neutron flux at the detectors by up to a factor of two, as in Figure 4, but may introduce new sources of background such as (a,n) reactions in the shields. Liquid argon doping studies are ongoing. Preliminary results suggest that ^{131}Xe doping at various concentrations did not significantly affect neutron flux. ^{3}He doping was effective, but cost and supply considerations may limit procurement.

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