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Neutron and alpha backgrounds in the LSBB

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Abstract. We describe studies of the existing neutron and alpha radiation fields in the GESA site of the LSBB, effected as part of the SIMPLE dark matter search, to include the impact of various shieldings in their suppression, and the results of their measurement using SIMPLE detectors.

1. INTRODUCTION

The SIMPLE dark matter search [1] is sited in the GESA facility of the LSBB [2]. All direct searches are based on the detection of nuclear recoil events induced by elastic WIMP scattering. Because these are intrinsically rare event searches, all generally strive for a maximum of radio-background reduction and/or elimination, with target goals of $\sim 2.7 \times 10^{-6}$ events per kg of detector per day of measurement (evt/kgd) [3].

Achieving this level is not straightforward. Underground siting is *a priori* to all such endeavors in order to reduce backgrounds associated with cosmic ray (μ, n) reactions. Although this background decreases exponentially with increasing depth, the background neutron field becomes essentially constant owing to the presence of natural radionuclides of the uranium (^{238}U) and thorium (^{232}Th) series, and potassium ^{40}K in the surrounding rock itself, which is shielded to some extent by the concrete used to reinforce the underground site, but which contains its own U/Th contaminants.

The U/Th decay moreover results in radon production in the rock, which readily transports through porous material via diffusion and convection, and to which the concrete shielding is only slightly impervious depending on its thickness and quality. Radon buildup permits its permeation of the experimental site, and is problematic either via (α, n) reactions [4] with the surrounding materials, or simply via an increased α density. It is also of concern from a health point of view, as it and its short-lived decay products can be inhaled.

We here describe studies of the background expected from the ambient neutron- and α-fields in the GESA facility, involving both MCNP simulations based on chemical and radio-assays of the surrounding rock, concrete and shielding materials, and measurements using the SIMPLE detectors. Comparison of the two provides a verification of the estimated/measured unshielded field intensities, and confirms the α-field as a source of concern for general LSBB operation.

2. SITE DESCRIPTION

GESA is a 60 m^3 cavern in the LSBB complex with 505 m calcite rock overburden, equivalent to 1500 meters water equivalent (mwe). The cavern is shielded from the surrounding rock by a 30–100 cm thickness of low grade concrete, which is internally sheathed by 1 cm of steel to form a Faraday cage, as shown schematically in Figure 1. The cavern air is circulated through a ventilation duct ($83 \times 45\,cm^2$) at $0.2\,m^3/s$, equivalent to a complete replacement $\sim 300\times$ per day; the air is however circulated from the adjacent $1250\,m^3$ Capsule and radon-laden, so that the measured level varies between 20–1000 Bq/m^3 as a result of groundwater circulation in the mountain.

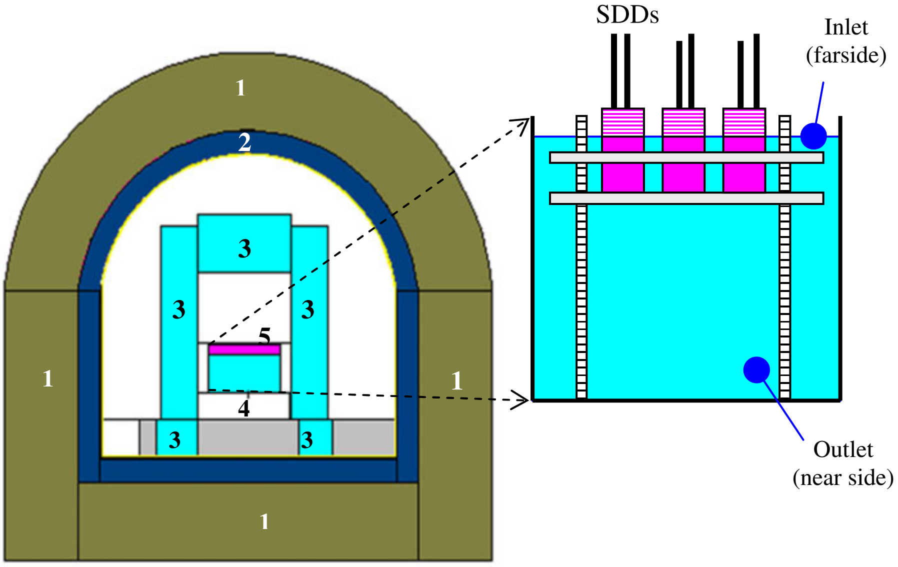

Figure 1. Schematic of the SIMPLE SDDS in the GESA site: **1**-concrete, **2**-steel sheath, **3**-water, **4**-wood platform, **5**-SDDS. (inset) waterpool configuration, showing water inlet/outlets and single SDD (not to scale); the water level is 6 cm above the active detector mass.

As seen in Figure 2, without the concrete, an upper limit on the anticipated neutron flux of $\sim 4 \times 10^{-1}\,m^{-2}\,s^{-1}$ [5] resulting from the rock might be expected, or an on-detector rate of 3.7×10^5 evt/kgd for SIMPLE.

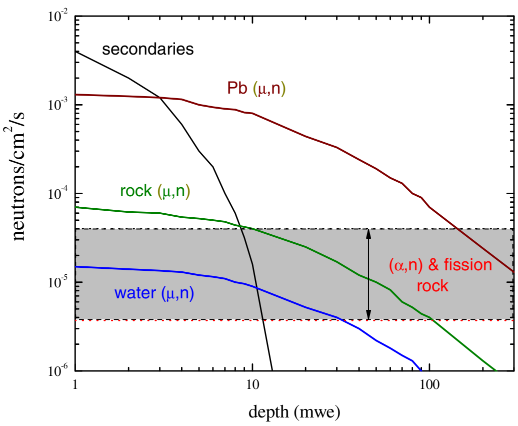

Figure 2. Falloff of cosmogenically-induced neutron field vs. the ambiental field arising from the U/Th content of the rock. For depths below $\sim$100 mwe, the principle background derives from the rock U/Th contaminants.

Table 1. Estimated background neutron contributions to the measurement with various shieldings.

	sp fission (evt/kgd)	(α, n) ^{238}U (evt/kgd)	(α, n) ^{232}Th (evt/kgd)
concrete	1203	972	816
+20 cm wood only	371	310	263
+50 cm water only	2.51	2.11	1.78
+20 cm wood, 50 cm water	0.405	0.342	0.342

Variation of the concrete thickness in the MCNP simulations suggest no significant differences for thicknesses >20 cm, i.e. that the primary neutron background in GESA originates from the concrete. Radio-assays of the GESA concrete and steel [6] yield levels of 1.90 ± 0.05 ppm ^{232}Th and 0.850 ± 0.081 ppm ^{238}U (concrete); 3.20 ± 0.25 ppb ^{232}Th and 2.9 ± 0.2 ppb ^{238}U (steel), respectively, yielding an unshielded, on-detector rate of $\sim 3 \times 10^3$ evt/kgd for the current 15 detector array.

3. MEASUREMENTS

3.1 Setup & sensitivities

The SIMPLE detectors (SDDs) are based on dispersions of micrometric droplets of superheated liquid C_2ClF_5 [1]: at their operating temperature (9 °C) and pressure (2 bar), these are insensitive [7] to backgrounds from electrons, γ's and minimum ionizing radiations common to other dark matter experiments as a result of their intrinsic insensitivity to low linear energy transfer (<150 keV/μm^3) radiations; they remain sensitive to neutrons for $E_{recoil} \geq 8$ keV, and α radiation with $E_{recoil} > 200$ keV. Neutron calibration measurements yield a detection efficiency of 98 ± 3%, and otherwise confirm the detector response.

The SDDs are fabricated in the clean room (SG facility) of the LSBB at 210 mwe, transported to GESA and submerged within a 700 liter water tank, which itself is surrounded by a water shield of 50–75 cm thickness to further reduce the neutron background from the concrete as shown in Fig. 1. The water serves as a neutron moderator with a reduction factor of ∼5 per 10 cm of water thickness [8].

MCNP simulations which include the above shieldings indicate the majority of the on-detector neutrons to originate from the concrete floor directly beneath the water tank. A 20 cm thick wood platform below the waterpool was installed, with about half the moderating power of an equal water thickness, and the detector depths adjusted to 50 cm above the tank base. Table 1 displays the MCNP-estimated effect of these additions, which yield an expected rate of 1.09 ± 0.02 (stat) ± 0.07 (syst) evt/kgd.

Background α's are extremely short-range: they must be inside the detectors in order to produce a signal. All detector construction materials have been radio-assayed [9], yielding U/Th concentrations below 10^{-6} Bq/g and an α-contribution <0.7 evt/kgd.

Diffusion of the atmospheric radon into a detector is limited by the surrounding waterpool, which covers the detectors to ∼6 cm above their sensitive volumes. Radon is readily soluble in water [10]; with a diffusion length of 2.2 cm, the equilibrium radon concentration is reduced by a factor 60 at 9 cm below the water surface. The upper water layer is however prevented from reaching equilibrium concentration [11] by the top-input circulation of the tank water through a filtered, closed-cycle, temperature-regulating cryothermostat at 25 liter/min (equivalent to replacing the top 1 cm water layer each minute). The level is further reduced a factor 300 further because of the short (<0.7 mm) radon diffusion lengths of the SDD construction materials (glass, plastic, metal). The research grade N_2 over-pressuring of the device inhibits the advective influx of radon-bearing water through the detector cappings, as well as diffusion of radon from the walls of the glass container into the gel (via stiffening of the gel); a glycerin layer covering the gel further inhibits radon diffusion into the gel matrix via the cap and teflon pressure line. Combined, simulations suggest an on-detector rate of 4×10^{-3} Bq/m^3, or 3.26 ± 0.08 (stat) ± 0.76 (syst) evt/kgd.

3.2 Results

Data was taken from a run of a 15 detector (0.208 kg) array over 67 days of measurement between 27 October 2009 and 5 February 2010. The total exposure was 14.10 ± 0.01 kgd, with losses resulting from the detectors being introduced at one device per day over the three week installation period, and from weather-induced power failures during the run. The radon levels monitored in GESA during this period varied 50–80 Bq/m^3.

An initial data set (4056 events) was formed by passing the data files through a pulse validation routine [12] which tagged signal events if their amplitude exceeded the noise level of the detector by 2 mV (S/N $\sim$2). The set was then cross-correlated in time between all SDDs, and coincidences rejected as local noise events since a WIMP interacts with no more than one of the in-bath detectors.

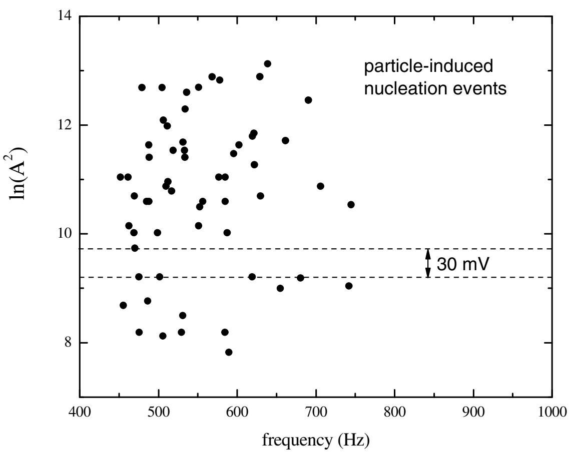

Figure 3. Scatter plot of the squared amplitude of the primary harmonic of each recorded particle induced nucleation event with respect to its frequency (1.3% of the total event record); the dashed lines identify the 30 mV-equivalent gap in the amplitude distribution.

The signal waveform, decay time constant and spectral density structure of the remaining 1828 single events were next inspected individually. A particle-induced nucleation event possesses a characteristic frequency response, which differs significantly from those of gel-associated acoustic backgrounds such as trapped N_2 gas, gas escape, and gel fractures which appear at lower frequencies [12], and local acoustic backgrounds such as water bubbles which differ in power spectra. This event-by-event analysis permits isolation of the true nucleation events with an efficiency of better than 97% at a 95% C.L. The resulting particle-induced events (1.3% of the initial data set) are shown in Figure 3 in terms of their squared amplitudes (proportional to the sound intensity): two amplitude populations are clearly observed, separated by the equivalent of $\sim$30 mV, or 100$\times$ the system resolution.

At 9 °C and 2 bar, the reduced superheat of the SDDs is 0.3 and the probability of events from electrons, γ's and minimum ionizing particles negligible [1] over the exposure. The detectors were offline calibrated in the SG facility using, separately, a weak Am/Be neutron source with 15 cm water shielding, and U_3O_8 diluted into the gels during fabrications; the instrumentation and signal analysis were the same as in the data run described above. Figure 4 shows a histogram of the squared amplitudes of the calibration data, which also manifests two distinct amplitude populations, with the lower amplitudes associated with the neutron events.

Identifying the 46 particle-induced events with amplitudes $\geq$130 mV in Figure 3 with the α-field yields a rate of 3.32 ± 0.27 (stat) evts/kgd, consistent with its estimate to within experimental certainties. The remaining 14 particle-induced events, consistent with the smaller amplitude events of Figure 4, are associated with the neutron field and yield an efficiency-corrected rate of 1.01 ± 0.28 (stat) evt/kgd, consistent with the MCNP estimate of the neutron field.

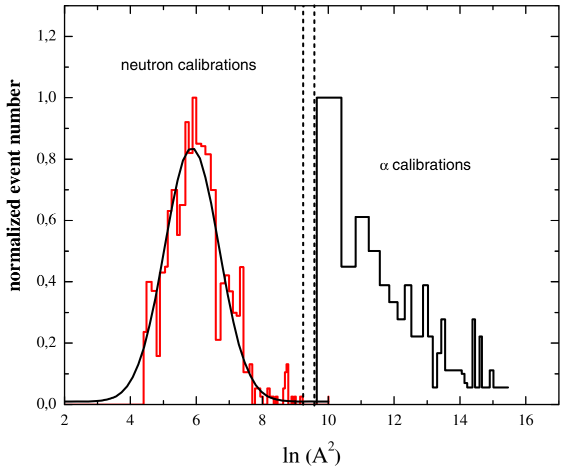

Figure 4. Combined amplitude histogram of separate offline neutron and α calibration events; the dashed vertical line correspond to those in Fig. 3, and identify the amplitude division of the two particle-induced populations.

4. DISCUSSION

The α measurement is in good agreement with its simulation estimate, and provides an indirect confirmation of the radon measurements effected during the run, both in- and outside the water shielding. For the experiment, this is also further reducible via various techniques, including improved site ventilation with fresh air and encapsulating the experiment with a N_2 flow at ~1 liter per hour.

Neither the environmental neutron nor muon fields in GESA have yet been directly measured. The simulations require as input the material radio-assays, which in the case of the wood and water are currently being performed in Portugal. These were estimated from available information [13], with uncertainties of up to 100% incorporated in the reported results. Nevertheless, the difference between the measured neutron field and its simulation is 0.5σ, confirming both the concrete as the primary source of neutron backgrounds, and the effect of various shielding materials in reducing the concrete contribution. This level can be further reduced by additional water or polyethylene shielding.

5. CONCLUSIONS

Measurement of the heavy radiation fields in the shielded GESA environment yields a neutron event rate of ~1 evt/kgd, or ~1.3 neutrons/m^{3}d, and an α-field is ~3 evt/kgd.

The neutron field is consistent to within experimental uncertainties with MCNP estimates of the on-detector neutron field in the present shielded environment, which derive primarily from the U/Th content of the GESA concrete. Unshielded, this implies a rate of $\sim 3 \times 10^3$ evt/kgd. The α-field is consistent with its origin in the 70 Bq/m^3 radon-bearing atmosphere above the detector waterpool during the measurements, which principally derives from the radon influx into GESA. Together, these unshielded fields reasonably represent the general radiation fields extant in the LSBB. Further verification is to be provided by in-progress measurements of the neutron field (see V. Lacoste, these Proceedings).

The unshielded neutron field is well below levels of concern for "normal" experimental activity (but above those desired in rare event searches). The unshielded α-field is however of some concern, given its seasonal variation which reaches levels 10–20 times higher during the Summer months, and has impact on the health aspects of prolonged research activities in the LSBB in general [14]. Increased fresh air ventilation is currently being effected [15] within the tunnel complex towards reducing this level to well below 100 Bq/m^3 throughout the year.

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