Detector calibration and shielding design for the background suppression for DM search experiment at JUSL

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Introduction

Dark matter (DM) is a hypothetical matter of unknown composition that constitutes about 85% of the matter content of the Universe. The galaxy rotation curve, gravitational lensing, anisotropy in the cosmic microwave background of the universe etc. indicates the existence of DM. The Weakly interacting massive particles (WIMPs) are one of the most favoured candidates of DM which is considered electrically neutral, interacts with ordinary matter only through gravitational interaction with a very tiny interaction cross-section. Therefore, detection of DM signal is possible either with a highly sensitive detector in a background free environment or by suppressing the background as much as possible. In India, at Jaduguda Underground Science Laboratory, JUSL at 555m deep underground, the dark matter direct search experiment has been initiated [1,2]. A small-scale experiment has recently been carried out with a superheated liquid detector (SLD) of active liquid $C_2H_2F_4$ at a threshold of 5.87 keV. The background measurement and the simulation at JUSL confirm the presence of gamma rays, neutrons and muons in the laboratory cavern [3]. The latest experimental event rate (~10^{-6}/s/gm) of the detector is of the order of the expected event rate (~10^{-6}/s/gm) for background neutrons at JUSL. In order to increase the sensitivity of the detector, it is essential to reduce the background neutron flux incident on the detector. In the present work, detector calibration at SINP surface lab with neutrons and shielding design using the FLUKA simulation toolkit for background neutrons for the above mentioned DM experiment has been carried out.

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Detector calibration

The calibration experiment was carried out with the 100 ml SLD fabricated at the SINP lab. The active liquid of the detector is $C_2H_2F_4$ (b.p. -26.3ºC). The detector is coupled with the acoustic sensor in the intermediate frequency range of 10Hz-90 kHz. The earlier measurements were carried out with acoustic sensors in low frequency (20Hz 20 kHz) and higher frequency (10 kHz-1MHz) range. The measurements were carried out at the operating temperatures of 30ºC, 35ºC, 40ºC, 45ºC and 50ºC using the ^{241}AmBe (10mCi) neutron source. The variation in operating temperature essentially represents the variation in the threshold energy of the detector, e.g., 35ºC corresponds to 1.92 keV threshold. The block diagram of the experimental setup for the detector calibration experiment at the SINP-lab is shown in Fig.1. The detector is immersed in a water bath and the bath is surrounded by a heating coil which is connected to a temperature controller. The acoustic pulse released during the bubble nucleation was collected by the acoustic sensor which was amplified and collected in a LabView based data acquisition system.

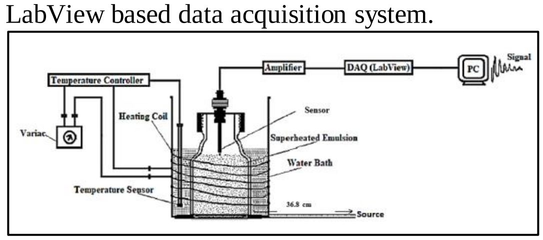

Fig.1. The block diagram of the Experimental setup at SINP lab.

Simulation for shielding design

The $C_2H_2F_4$ SLD is sensitive to the fast neutrons only and the fast neutron flux at JUSL is $(9.93\pm0.22\pm0.10)$ $x10^{-5}$ $cm^{-2}s^{-1}$ [3]. The fast neutrons can be slowed down and absorbed by a material containing light atoms (e.g., hydrogen atoms). In the present work, polyethylene (PE), water and high-density polyethylene (HDPE) have been chosen as the shielding materials. For neutron background, only radiogenic neutron flux is considered as cosmogenic neutron contribution is very less in laboratory cavern [3]. The FLUKA simulation toolkit [4] has been used. For different thicknesses of the shielding materials, the flux reduction after shielding has been simulated.

Results and discussion

The background subtracted event rate of the detector as observed during measurement with Am-Be source at different operating temperatures is shown in Fig.2.

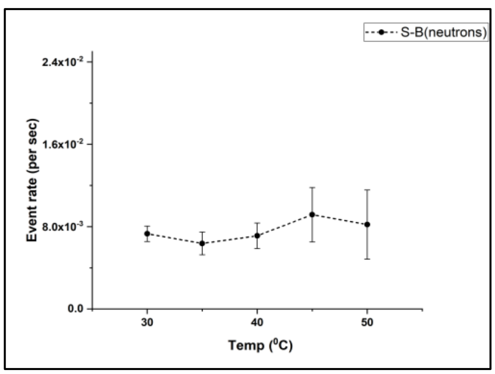

Fig.2. Detector event rate for Am-Be neutron source.

It is observed from Fig.2 that the event rate for neutrons is almost flat over the operating temperature region as varied in the measurement. Future measurements on DM search experiments will be carried out at these temperatures. The neutron is the main background of the DM experiments running at present at JUSL. The detailed analysis of the collected signals has also been performed and few characteristic parameters have been found out from the calibration measurement. The result from the simulation is given in Fig.3 for different types of shielding materials. Fig.3 shows that the maximum reduction of the fluence rate occurs for HDPE and minimum for the water. Therefore, HDPE shielding is most suitable for fast neutron background at JUSL. The estimated neutron flux after 20 cm thick shielding of HDPE, PE and water is $3.81x10^{-8}$ $cm^{-2}s^{-1}$, $6.14x10^{-7}$ $cm^{-2}s^{-1}$ and $1.148x10^{-6}$ $cm^{-2}s^{-1}$ respectively.

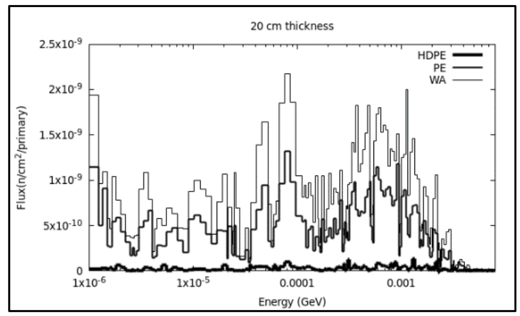

Fig.3. Fast neutron flux distribution after shielding.

Conclusion

The calibration experiment of the SLD fabricated at the laboratory for the DM search experiment has been carried out at different thresholds with a new sensor in the intermediate frequency region. Simulation work has been performed for the shielding of neutrons for different shielding materials. It is observed that the flux reduction is two orders of magnitude higher in HDPE than water. In the future run of the experiment with more sensitive detectors for the realistic shielding a combination of different shielding materials can be used.

References

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