Abstract

The Thesis was worked-out within the project APVV-15-576 *Rare nuclear processes and development of methods for their investigations*. Interactions of neutrons with a high-purity germanium detector were studied experimentally and by simulations using the GEANT4 tool. Elastic and inelastic scattering of fast neutrons as well as neutron capture on Ge nuclei were observed. Peaks induced by inelastic scattering of neutrons on ^{70}Ge, ^{72}Ge, ^{73}Ge, ^{74}Ge and ^{76}Ge were well visible in the γ-ray spectra. In addition, peaks due to inelastic scattering of neutrons on copper and lead nuclei, including the well-known peak of ^{208}Pb at 2614.51 keV, were detected. The GEANT4 simulations showed that the simulated spectrum was in a good agreement with the experimental one. Differences between the simulated and the measured spectra were due to the high γ-ray intensity of the used neutron source, the physics implemented in GEANT4 and contamination of the ^{241}Am-Be neutron source.

Next, investigation of neutron-induced background was carried out by studying interactions of cosmic ray neutrons with an HPGe detector inside its shield placed on a ground floor of a 3-storey building. The study was conducted experimentally and by Monte Carlo simulations using GEANT4 simulation tool. Detailed analysis of measured background γ-ray spectra showed that many γ-lines visible in the spectra were induced by neutrons. The majority of detected γ-rays originated in germanium, copper, lead and tin. Iron and aluminium components were less important background sources. Inelastic scattering and neutron capture were the most often occurring processes of neutron interactions with the detector and its shielding. The contamination by natural radionuclides, particularly by ^{40}K, ^{214}Pb, ^{214}Bi and ^{208}Tl, was also present in the background spectra. Nevertheless, approximately 35% of the frequently observed ^{208}Tl peak at the energy of 2614.51 keV was produced by inelastic scattering of neutrons on ^{208}Pb nuclei. The experimental background was compared with GEANT4 simulations, which were carried out without and with the shielding layer of the building. The final integral count rates for the measured spectrum in the energy range from 50 keV to 2875 keV was 1.26 ± 0.07 s^{-1} and for the simulated one 1.25 ± 0.13 s^{-1}, indicating a good agreement of simulation with the experiment and validating the tool.

Finally, the background of an HPGe detector measured in a deep underground laboratory was investigated analytically and by Monte Carlo simulations using the GEANT4 toolkit. Contributions of different background sources to the experimental γ-ray background were determined. Namely, contribution of radionuclides in the materials of the detector and around the detector, neutrons produced in (α, n) reactions due to presence of radionuclides in concrete and rock, by spontaneous fission of mainly ^{238}U, and finally, cosmic rays with neutron generation. The simulation, including radionuclides in the material, was in a good agreement with the experiment. At the same time, background spectra induced by neutrons and muons were simulated separately. The radiation coming from the presence of members of the ^{238}U, and ^{232}Th decay series, and ^{40}K in the detector parts and the laboratory walls contribute to the continuum of the experimental spectrum at the level of around 94%. According to simulations, the contribution of muon events to the experimental energy spectrum was below 1% and it was confirmed that muon induced spectra are about three orders of magnitude lower than the experimental one. The comparison of integral count rates of the experimental spectrum with the simulated spectrum induced by neutrons showed that about 6% of the measured background continuum originated from neutron reactions. Fast neutrons contributed more to the background (at around 65%) than thermal neutrons. Despite only a 6% share of neutron contributions in the total γ-ray background, they contributed mainly to the lower continuum of the spectrum up to 250 keV, which is a region of interest for potential low mass weakly interacting massive particle (WIMP) dark matter interactions. In addition, they interact with the detector and the shield by inelastic scattering and induce unwanted γ-rays. Neutron capture,

elastic and inelastic scattering were simulated separately as well. It was found that inelastic scattering is the major contributor to the spectrum induced by neutrons. The effect of neutrons on the background of the HPGe detector operating underground, such as Obelix, is manifested mainly by their contribution to the continuum up to 1 MeV, especially in the lower part up to 500 keV. Thus, neutrons are an important background component in deep underground laboratories, too. Possible detector optimization is also discussed.

In order to build an underground laboratory in Slovakia for astrophysical and environmental radioactivity studies, calculations of the muon vertical energy spectrum in 1000 m w.e. and 50 m w.e. were carried out. The muon-induced backgrounds of a HPGe detector with a relative efficiency of 100% were simulated in both depths. The complete geometry of the HPGe detector was coded in GEANT4 including the low-level shield. Gamma lines coming from neutron interactions with the detector and its shield seen in the simulated background spectra were analysed and evaluated. It was found that in the background spectrum simulated in the 50 m w.e. shallow laboratory, the copper peaks are prevailing. In the background spectrum simulated in the 1000 m w.e. deep laboratory, the germanium peaks are prevailing up to 1500 keV, but above 1500 keV the copper peaks dominate. The simulated background spectra were compared and it was found that a depth of 1000 m w.e. is sufficient to reduce the cosmic-ray induced background by five orders of magnitude. The number of visible peaks coming from neutron interactions in the background spectrum simulated for the shallow laboratory in the depth of 50 m w.e. is higher than in the 1000 m w.e. deep laboratory, as expected. Comparison of count rates of individual peaks for both spectra were carried out as well. Use of copper in the detector shield for HPGe detectors located in underground laboratories is not recommended as far as background induction by cosmic rays is concerned. The effect of natural radioactivity in planned Slovak laboratory was estimated. The contribution of natural radionuclides to the total background continuum would be about 40% at the depth of 1000 m w.e. and 10% at 50 m w.e. using HPGe detector with relative efficiency of 100%. Selection of ultra-high purity materials for the detector and shield construction was recommended with the aim to minimize the contribution of γ-rays from natural radionuclides to the background spectrum. The detection limits for ^{137}Cs in a hypothetical sample was determined in both depths. It would be 7.3 mBq and 0.54 mBq in the 50 m w.e. and 1000 m w.e. laboratory, respectively. The detection limit would decrease by one order of magnitude at most if the laboratory would be built in the 1000 m w.e. depth compared to the depth of 50 m w.e.