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On the omnipresent background gamma radiation of the continuous spectrum

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ABSTRACT

The background spectrum of a germanium detector, shielded from the radiations arriving from the lower and open for the radiations arriving from the upper hemisphere, is studied by means of absorption measurements, both in a ground level and in an underground laboratory. The low-energy continuous portion of this background spectrum that peaks at around 100 keV, which is its most intense component, is found to be of very similar shape at the two locations. It is established that it is mostly due to the radiations of the real continuous spectrum, which is quite similar to the instrumental one. The intensity of this radiation is in our cases estimated to about 8000 photons/($m^2 s \cdot 2\pi \cdot$ srad) in the ground level laboratory, and to about 5000 photons/($m^2 s \cdot 2\pi \cdot$ srad) in the underground laboratory, at the depth of 25 m.w.e. Simulations by GEANT4 and CORSIKA demonstrate that this radiation is predominantly of terrestrial origin, due to environmental gamma radiations scattered off the materials that surround the detector (the “skyshine radiation”), and to a far less extent to cosmic rays of degraded energy.

1. Introduction

After many comprehensive studies of background spectra of germanium detectors [1,2], it has become common knowledge that the main contributors to these spectra are the gamma radiations of discrete spectrum, that originate from naturally occurring radioactive isotopes dispersed in the environment and in the materials that surround the detector, as well as the complex radiations of mixed composition whose origin can be traced to cosmic rays. Gamma radiations of discrete energies produce the line spectrum but are also partially responsible for the continuum, composed of the Compton distributions of discrete energies that escape total detection. Due to the intrinsically high peak-to-Compton ratio, this continuum is in germanium detectors much lower than in other types of detectors. Vicinity of significant quantities of new lead may be also contributing to the continuum due to the presence of ^{210}Pb [3].

Cosmic-ray muons by direct interactions produce the continuous spectrum of energy losses that, for all detector sizes but for the thinnest ones, peaks at high energies, well beyond the region where the spectrum is usually of interest. The muon secondaries, however, contain significant quantity of low-energy radiations that contribute to the continuum in its portion relevant to spectroscopy. The soft, electromagnetic component of cosmic rays by its scattered and degraded radiations also contributes to the continuous part of the background spectrum, mostly at lower energies, within the region of interest to practical spectroscopy. Neutrons, mostly of cosmic-ray origin, contribute the continuous spectrum of recoils that diverges at lowest energies, though usually of very low intensity. The only spectral line that is attributed to cosmic rays is the annihilation line.

All these results in the instrumental background spectrum that is characteristic of the detector size, shape and the dead layers. The prominent feature common to all instrumental background spectra, however, is that the greatest part of the spectral intensity lies in the low-energy continuum that, depending primarily on the detector size, peaks at around 100 keV. It is an empirical fact that in the background spectra of unshielded High Purity Germanium (HPGe) detectors, depending on their size, the total intensity in the lines makes only some 10–20% of the total intensity in this low-energy continuum. The cause for the particular shape of the continuum is usually found in the similarly shaped energy dependence of detection efficiency curves on germanium detectors. The intensity of the continuum is already by an educated guess well over the expected intensity of all the Compton distributions taken together, what suggests that at least some part of the continuum must be of some other origin, unaccounted for by conventional considerations. To check this, in this work we

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study by means of absorption measurements the background radiations that arrive from the upper hemisphere, which may be suspected responsible for the part of this continuum, with the aim of determining its intensity and origin. This assumption is justified by the fact that majority of germanium detectors are vertically oriented and are by virtue of their construction already of very low detection efficiency for low-energy radiations arriving from the lower hemisphere, e.g. Ref. [4].

2. The experiment

The measurements were performed with a vertically oriented 35% efficiency coaxial type radio-pure HPGe detector mounted in the 1.5 mm thick magnesium housing (of the ORTEC GEM30 type). It was shielded from the radiations coming from the lower hemisphere by the lower half of a heavy lead castle and completely open to those arriving from the upper hemisphere. The cylindrical shield around the detector has the thickness of 12 cm, while that of the layer of lead bricks on which the Dewar vessel sits is 10 cm (Fig. 1).

The same setup was used in both the ground level and in the underground laboratory situated at the depth of 25 m of water equivalent (m.w.e.). The detector is usually used in coincidence/anticoincidence with the 1 m^2 plastic scintillator, and is dedicated to the study of the features that cosmic rays contribute to the background spectra of heavily shielded detectors. The laboratories where the current measurements are performed are described in some detail in Ref. [5]. A set of measurements is performed with lead absorbers of increasing thickness positioned so as to block the way to the radiations coming from above (Fig. 1). The background spectra from such measurements are presented in Fig. 2. Absorber thicknesses range from 0.04 mm (45 mg/cm^2) to 4.5 mm (5 g/cm^2), and are marked in the figures. The figures are presented in two different scales; in the figures on the left to show the general change of spectra upon absorption, and in the figures on the right to emphasize the particularly indicative details around the X-rays of lead.

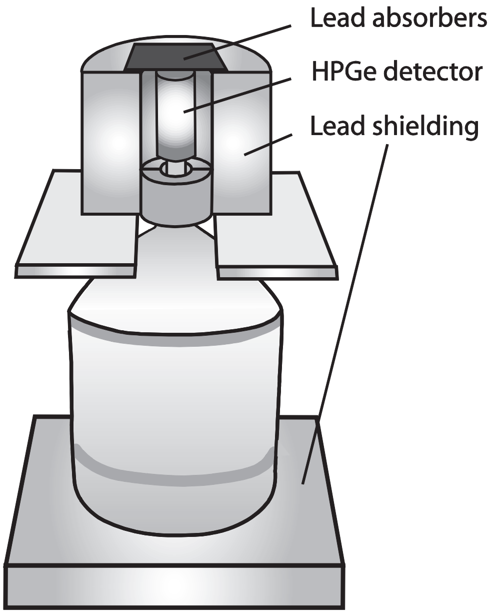

Fig. 1. Detector assembly used in this study.

3. The results and discussion

Visual inspection of the absorption spectra presented in Fig. 2 leads to a number of interesting qualitative conclusions:

1. The spectra taken on the ground level and in the underground exhibit great similarity, the integral intensity of the continuum in the underground being about 1.75 times smaller. At the same time the intensity of cosmic-ray muons in the underground is about 3.5 times smaller [6].
2. The energy, which carries maximum intensity in the continuum, increases with absorber thickness, what is typical of continuous spectra, and is known as the “hardening of the spectrum”.
3. The discontinuity in the absorption spectra on the energy of K_β X-rays of lead (K-absorption edge) reflects the fact that the instrumental continuous spectrum is mostly due to the radiations of the same continuous spectrum, and not due to incomplete detection of radiations of higher discrete energies. If it were due to the distributions of Compton scattered gamma rays of higher energies that have escaped detection, the incoming gamma rays would have been absorbed only weakly by Compton scattering in the absorbers, what would not produce the discontinuity in the spectrum of radiations that reach the detector.
4. Initial increase of the intensity of fluorescent X-rays of lead with absorber thickness again witnesses that the incoming radiation is absorbed by the photoelectric effect. This suggests that the real spectrum of this radiation is similar to the instrumental one, at least up to the energies of about 200 keV, where the photoelectric effect in lead dominates over the Compton effect.
5. Some apparent differences in absorption character of the spectra taken on the ground level and in the underground are to be expected on account of necessarily different composition of the radiations and their different angular distributions at the two locations. The detector in the ground level laboratory virtually has no overhead material, except 1 mm of iron that constitutes the roof of the container, while in the underground laboratory it is surrounded by 30 cm of concrete, that constitutes the walls, the floor and the ceiling of the cavern.

These qualitative conclusions are supported by quantitative analyses of absorption curves at different energies of the continuum. As an illustration, Fig. 3 presents the absorption curves for the count in the channel in the continuum that corresponds to the energy of 89 keV, close to the K-absorption edge in lead. The two well-defined components of very different absorption properties are found. On the surface, the much more intense and less penetrating one by its absorption coefficient corresponds within the errors to the energy close to 90 keV, while the same component in the underground appears of slightly different absorption properties, due to necessarily different composition of the radiations and their different angular distributions. The much less intense and much more penetrating component, both on the surface and in the underground, roughly corresponds to the energy of about 500 keV. The first component thus represents the radiation of the same energy at which it appears in the spectrum, which belongs to the continuum, while the second one represents the sum of Compton distributions of all radiations of higher energies that escape full detection. This last component thus manifests absorption properties of the radiation of an average energy that in our case appears to be around 500 keV.

Since the low-energy component is practically fully absorbed by 1 mm of lead, subtracting the spectrum that corresponds to the absorber of that thickness from the spectrum of the open detector