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Gamma background characterization on VESUVIO: before and after the moderator upgrade

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Abstract. The VESUVIO spectrometer at the ISIS pulsed neutron and muon source is a unique instrument which makes use of eV neutrons and inverted geometry, allowing deep inelastic neutron scattering experiments with high values of energy and wavevector transfers. The neutron detection techniques on the VESUVIO forward-scattering detector banks is based on (n,γ) conversion, therefore neutrons are indirectly detected and the signals produced by scattered neutrons, accordingly the photons, is recorded using gamma scintillators. The use of γ-sensitive detectors make γ-background one of the main limiting factors affecting the data quality and instrument sensitivity on VESUVIO. This work aims to assess how the sample-independent gamma background has changed after the recent upgrades to the water moderator viewed by the instrument, which resulted in a twofold increase of the thermal neutron flux. Here we show that the gamma background is mainly influenced by the thermal neutron flux and that the recent upgrade results in a fivefold increase in the gamma background in the photon energy range 300 keV-3 MeV. We point out the possibility of providing a thermal-neutron filter along the incident beam in order to suppress this background source.

1. Introduction

Currently, the ISIS pulsed Neutron and Muon Source [1] has over 30 neutron and muon instruments distributed in two main buildings, Target Station 1 (TS1) and Target Station 2 (TS2). Amongst the many techniques available, beamlines at ISIS routinely allow neutron imaging techniques for applications in Engineering or Material Science and Cultural Heritage, neutron diffraction techniques to study crystalline solids or liquids, and tests microchip's response to neutron radiation. Other beamlines at ISIS allow the investigation of atomic and magnetic motions of atoms. The VESUVIO spectrometer installed at TS1, makes use of Deep Inelastic Neutron Scattering (DINS)[2], to measure atomic momentum distributions and nuclear quantum effects in condensed matter systems [3]. A water moderator, decoupled and poisoned, at 295 K serve several beamlines on TS1, providing neutrons with the energy useful for the various fields of application. The "poisoning"of the moderator with gadolinium foils is used to lower the Maxwellian component of the neutron velocity distribution and reduce the intensity of the over-thermalized neutrons in the reflectors system [4]. On February 2016, the TS1 water moderator has undergone an upgrade [5, 6] which consisted in the removal of one of the two gadolinium poisoning foils. As a result, several beamlines on TS1 like MAPS, SXD and, in particular VESUVIO, benefit from an increase factor of up to two in thermal neutron flux. Figure 1 shows the predicted gain in the neutron flux as obtained from MCNPX [7] simulations [5, 6]. The experimental results has shown an even large increase of 10 - 20% , as reported in ref. [6], compared to the simulated results, possible due to simplified moderator model which cannot include all eventual sources of performance deterioration over the years. The benefits of the extra flux for these instruments include the capability to measure smaller samples (SXD), improve the speed and statistical quality of low energy excitations measurements (MAPS) and improve diffraction and transmission data collection done in parallel with spectroscopy experiments (VESUVIO) [8].

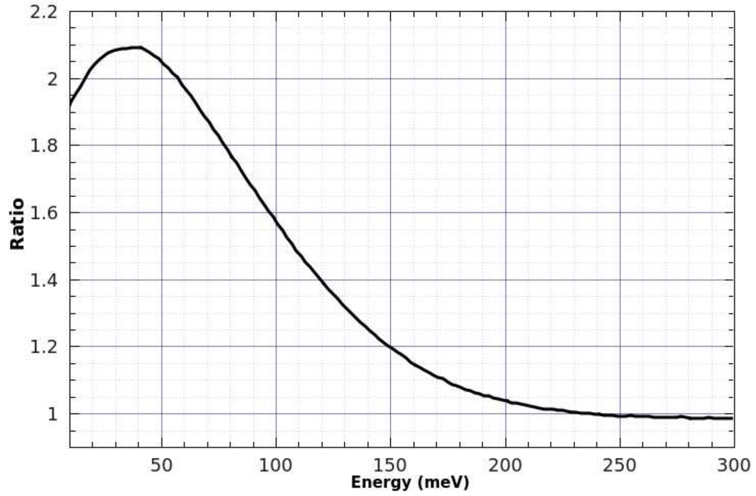

Figure 1. Simulated flux ratio before and after water moderator upgrade as a function of neutron energy [5].

Forward-scattered neutrons on VESUVIO are converted into prompt-gamma radiations through an (n,γ) process in the resonance condition, and the photon cascade, rather than the scattered neutron, is therefore detected. Gold resonant filters select the neutrons final energy at ca. 4.9 eV and the γ-ray emitted following radiative capture process are detected using YAP (Yttrium-Aluminium-Perovskite) scintillators. The use of gamma-sensitive detectors means that the detected signal contains all photons triggered by the neutron scattered from the sample as well as generated in (n,γ) processes by the sample environment and beamline components elements, such as beam stop, moderator, or collimators. This background signal affect DINS data and results as the main component of the raw spectra acquired on VESUVIO. DINS spectra are indeed obtained by the foil cycling technique [9], that envisages the use of two foils of the same neutron absorbing material, one is the analyzer foil itself, fixed in front of the photon detector, the second one is placed between the sample and the analyzer. During the scattering experiments, the latter alternates in and out of the scattered neutron beam. The difference between filter-in and filter-out measurements allows to obtain a subtraction of the background. However, gamma background remains one of the principal factors affecting both the data quality and instrument sensitivity on VESUVIO. Therefore, a characterization of the gamma background is relevant for beamlines that employ gamma-sensitive detectors to identify optimization strategies of signal-to-background ratio.

2. Experimental set-up and data collection

Sample-independent background spectra were collected in February 2017 with an High-Purity Germanium detector (HPGe) designed to be resistant to damage from fast neutrons, whose characteristics are shown in table 1. The detector resolution indicated by the producer is 2.5 keV (FWHM) measured on the ^{60}Co peak at 1.33 MeV and 760 eV on the ^{56}Fe peak at 5.9 keV. This might be dependent on the experimental conditions; Its experimental evaluation was 3.5 keV on the ^{115}In at 1.29 MeV. This variation may be due to many factors including an incomplete polarization of the diode. The high resolution of this kind of detector allows to identify and to assign the gamma peaks to the corresponding chemical elements and isotopes. According to the VESUVIO layout, the neutron beam travels in vacuum from the moderator to the sample located inside an aluminium sample tank, passing through a set of collimators. The beam dump situated ca. 5 m from the sample position is mainly composed of elements such as hydrogen, boron, and iron. The HPGe detector was placed at an angle $\theta \simeq 45^\circ$ with respect to the centre of neutron beam and at a distance of approximately 0.7 m from the sample position. Due to geometrical constrains, the detector was placed between the sample tank and the beam dump as shown in figure 2. The HPGe was powered in order to provide high voltage to diode and low voltage to the preamplifier. The pulse-height spectra were acquired using the ORTEC MAESTRO acquisition software[10]. The internal lower level discriminator was set to 100 keV in order to limit the deadtime. The spectra recoded, for an IPC (Integrated Proton Current) of 75 μA, correspond to the prompt-gamma activation spectra from the elements presents in the beamline.

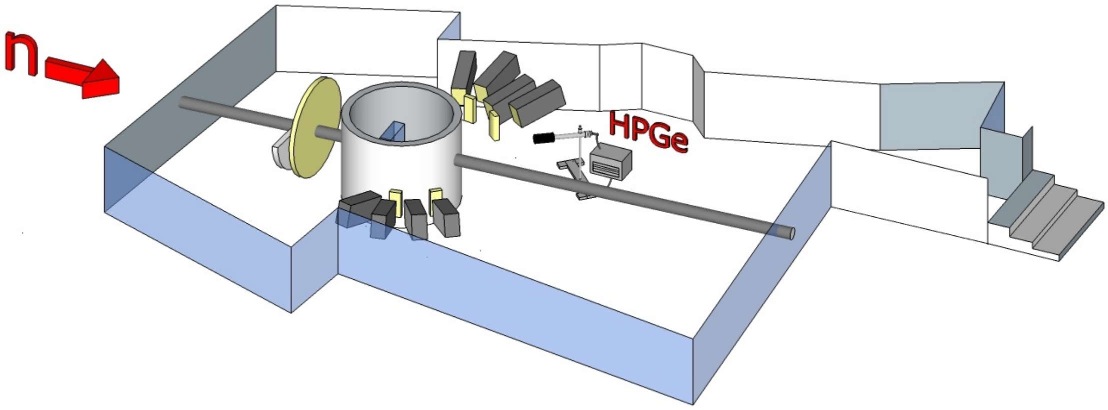

Figure 2. Sketch of the HPGe detector position in the layout of VESUVIO blockhouse used both in 2013 and 2017 measurements. The blue square inside the tank represent the nominal sample position during routinely DINS experiments.

Table 1. General characteristics of the HPGe detector used.

	Detector details
Material	HPGe, n-type
Crystal configuration	Coaxial
Crystal diameter	83 mm
Cup length	170.5 mm
Crystal length	168 mm
High Voltage bias	-3800 V
Relative efficiency	44.5 %
Endcap diameter	93 mm
Manufacturer and year	ORTEC 2013

3. Results and discussion

The energy calibration, to convert electronic channels into energy bins, was performed using well-known peaks in the background spectra, arising from radiative capture in elements present in the beamline. For example, by exploiting the gamma-ray line at 478 keV emitted by the decay of the excited ^{7}Li to the ground state in the reaction $n + {}^{10}B \rightarrow {}^7Li^* + \alpha$, clearly recognizable by its shape, the neighbouring gamma ray corresponding to 511 keV, due to electron-positron annihilation following pair production, and the 1292 keV line of ^{115}In present in the detector contact.

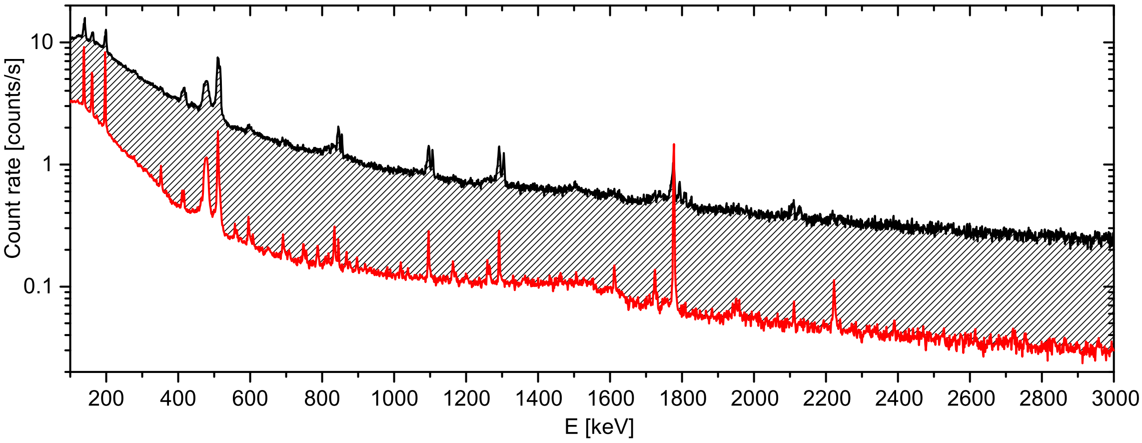

Figure 3. Comparison between normalized γ-ray spectra background acquired on February 2017 (black line)and on May 2013 (red line). The dashed area represents the increase in the count rate.

Figure 3 shows the comparison between the background spectra acquired on February 2017 and on May 2013 in the 100 keV-3 MeV energy region. Both spectra are normalized to their own acquisition time (live time), and the differences in the peak-to-background ratio are attributable to the logarithmic scale used to emphasize the increment in the baseline on the entire energy range, showing that there is a rigid shift of the background, as expected. The ratio of the count rate of the two spectra in the entire energy range is about five, demonstrating that an increase in the flux of thermal neutrons results in an increase in the gamma background, as shown in figure 3. Despite this, the off-peak continuum has the same overall shape in the two spectra. Both background spectra have high count-rate, especially in the low energy region, due to Compton scattering processes between photons and electrons in the walls of the block house or between electrons inside the detector. The main effect of the Compton continuum is the loss of correlation between the intensity in a particular energy channel and the parent prompt gamma emission line. This limits the signal to background ratio hindering an optimised quantification of elements content in the prompt-gamma activation analysis [11]. Figure 4 shows background spectra from 2013 and 2017 (before and after moderator upgrade), normalized to their respective total area for a better comparison between the peaks in the energy region 100 keV-825 keV. Blue dashed lines are a guide to identify significant gamma peaks and each one was labelled for the corresponding element identification [12].

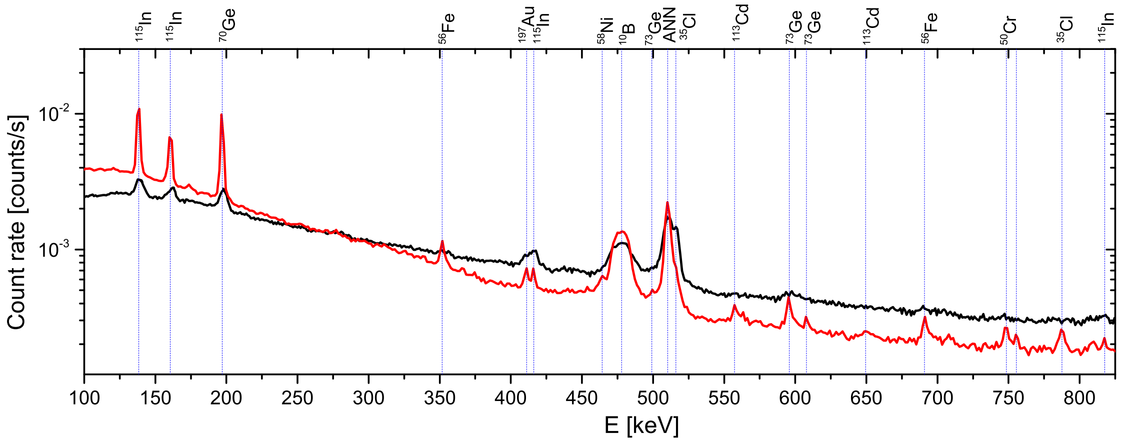

Figure 4. Background spectra obtained during 2013 (red line) and 2017 (black line), that is before and after moderator upgrade, in the γ-energy range 100 keV-825 keV. Blue dashed lines identify the most significant gamma peaks and each one was labelled for the corresponding element.

The latter made use of databases in refs.[13, 12] published by the Chemical Research Center of Budapest and by the International Atomic Energy Agency (IAEA), respectively. Figure 4 shows that the elemental composition assigned to the two spectra does not show differences. A similar analysis over the entire energy range confirms the above findings. The spectra show peaks from indium (that is one of the materials surrounding the diode [14]), germanium itself from the detector active material, peaks from iron contained in flanges and collimators, boron present in large quantities in the beam dump and in the walls of the block house, and gold peaks from analyser foils. Also, we are expecting that not all elements respond in the same way to the increase in thermal neutrons, due to the dependence of the cross-section (n,γ) from the energy of the neutrons . This is reflected, as shown in Figure 4, in the change of the relative intensities of the peaks attributed to the same element in the two compared spectra. In fact, there is an increase in the intensity of peaks due to elements with intense cross section (n,γ) in the thermal energy range at the expense of elements that have a large cross section in the epithermal range, the latter remaining unchanged after the upgrade.

4. Outlook and Conclusion

In this work we present gamma-background spectra acquired on the VESUVIO spectrometer in the years 2013 and 2017 in order to assess the effect of the moderator upgrade on the background measured by the YAP scintillators. The results demonstrate that the elemental composition assigned to the two spectra does not show differences, yet an increase in the background count rate due to the increase of thermal-neutron flux on the sample is evident. Figure 5 shows a direct comparison of the background measured by the YAP detectors before and after the moderator upgrade. This figure was obtained by calculating the ratio of the time of flight spectra, summed over the 64 forward scattering detectors (YAP), between two measurements with the same experimental set-up carried out before and after the upgrade. The two spectra were normalised to IPC. As can be seen in the ToF region 2500-19000 μs, corresponding to neutron energy less than ca. 100 meV, there is a marked increase in the measured background which saturates to a value of 1.6 ± 0.1. In order to obtained other information about the Time of Flight (ToF) structure of the observed background, we plan to set up a biparamentric acquisition [15] ToF vs Energy to understand if this increase may be significant in the Time of Flight range 50 μs -600 μs of interest for DINS measurements. In addiction, despite the background has increased by a constant factor in the whole range considered, the efficiency of YAP is not constant but decreases with increasing energy. Therefore in the DINS spectra this increase in the background is mitigated by the efficiency of the YAP. Background spectrum is strongly sensitive to the detector's position within the VESUVIO block house, therefore calling for additional measurements could be made by moving the germanium detector in different position in order to obtain a map of the background. We finally suggest the possibility to include a thermal-neutron filter along the incident beam, so as to suppress the component of the background induced by the absorption of thermal neutrons in the blockhouse and beam dump.

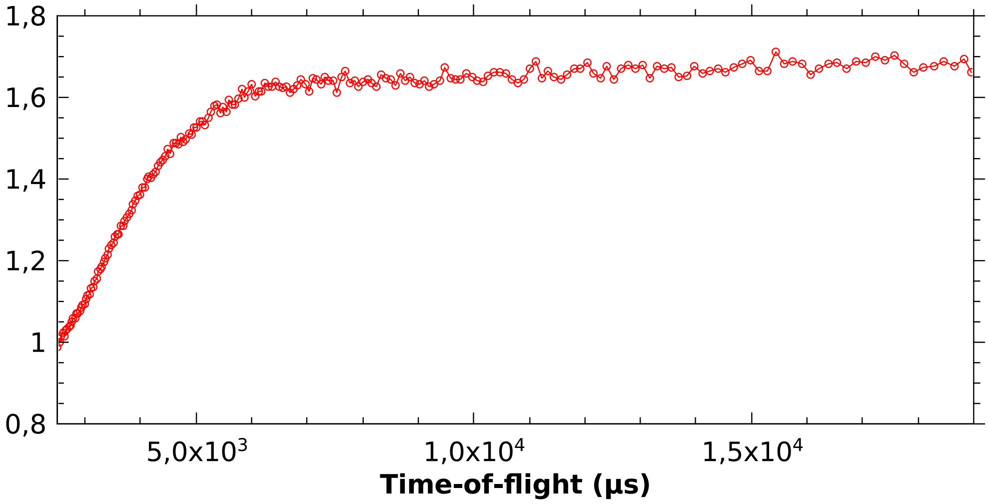

Figure 5. Ratio between the time of flight background spectra measured by the YAP on March 2015 and on May 2017, respectively before and after the moderator upgrade.

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