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γ-Ray background sources in the VESUVIO spectrometer at ISIS spallation neutron source

A. Pietropaolo [a,b,*], E. Perelli Cippo [c], G. Gorini [a,b], M. Tardocchi [c], E.M. Schooneveld [d], C. Andreani [e], R. Senesi [e]

[a] CNISM Milano-Bicocca, Universitá degli Studi di Milano-Bicocca, Dipartimento di Fisica "G. Occhialini", Piazza della Scienza 3, 20126 Milano, Italy
[b] NAST Center (Nanoscienze-Nanotecnologie-Strumentazione), Universitá degli Studi di Roma Tor Vergata, via della Ricerca Scientifica 1, 00133 Roma, Italy
[c] Universitá degli Studi di Milano-Bicocca, Dipartimento di Fisica "G. Occhialini", Piazza della Scienza 3, 20126 Milano, Italy
[d] ISIS Facility, Rutherford Appleton Laboratory, Chilton, Didcot, Oxfordshire 0QX OX11, UK
[e] Universiá degli Studi di Roma Tor Vergata, Dipartimento di Fisica and NAST Center (Nanoscienze-Nanotecnologie-Strumentazione), via della Ricerca Scientifica 1, 00133 Roma, Italy

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A B S T R A C T

An investigation of the gamma background was carried out in the VESUVIO spectrometer at the ISIS spallation neutron source. This study, performed with a yttrium–aluminum–perovskite (YAP) scintillator, follows high resolution pulse height measurements of the gamma background carried out on the same instrument with the use of a high-purity germanium detector. In this experimental work, a mapping of the gamma background was attempted, trying to find the spatial distribution and degree of directionality of the different contributions identified in the previous study. It is found that the gamma background at low times is highly directional and mostly due to the gamma rays generated in the moderator–decoupler system. The other contributions, consistently to the findings of a previous experiment, are identified as a nearly isotropic one due to neutron absorption in the walls of the experimental hall, and a directional one coming from the beam dump.

1. Introduction

Spallation neutron sources [1] represent a great opportunity for both fundamental and applied science. The wide spectrum of the neutron beams produced from the interaction of high energy protons (in the GeV region) with heavy metal targets can be used in many applications. At the ISIS spallation source [2] these studies are accomplished using neutrons from meV to several tens of eV; the experimental techniques used range from neutron diffraction [3–7] to inelastic scattering [8–12], the latter being used e.g. to investigate the dynamics of hydrogenated systems. High energy neutrons (in the MeV region) are also used e.g. to simulate the spectrum of the atmospheric neutrons produced by the high energy primary cosmic rays. These neutrons are a growing concern for the reliability of electronic devices [13,14]. Moreover, neutrons in the eV–keV region can be used to develop innovative neutron-based imaging and tomographic techniques for cultural heritage applications [15]. One important aspect to be considered in all applications of pulsed neutron beams is the clear identification of the background sources. For example, the neutron detection techniques at epithermal energies on VESUVIO beamline [16] at ISIS are based on (n,γ) conversion, so that the γ-ray background needs to be investigated. In a previous experimental paper [17], a first investigation of the γ background in the VESUVIO spectrometer was performed by recording pulse height spectra with a high-purity germanium (HPGe) detector. These measurements allowed a clear identification of several γ-ray lines and the recognition of the possible γ-ray background sources.

In the present study, an yttrium–aluminum–perovskite (YAP) scintillation detector was used since a mapping of the γ-ray background was carried out by assessing the contribution of different γ-rays to the time of flight spectra recorded at different locations. Previous studies demonstrated that YAP is well suited for γ-ray measurements, as it is very insensitive to neutrons [18].

2. Experimental setup

The measurements were performed at the VESUVIO beam line operating at the ISIS spallation neutron source. The layout of the instrument is shown in Fig. 1. The water moderator at 295 K is placed at about 11 m from the sample position and operated in the so-called wing configuration [19] above the spallation target.

* Corresponding author at: CNISM Milano-Bicocca, Universitá degli Studi di Milano-Bicocca, Dipartimento di Fisica "G. Occhialini", Piazza della Scienza 3, 20126 Milano, Italy. Fax: +39 0 264482367.
E-mail address: antonino.pietropaolo@mib.infn.it (A. Pietropaolo).

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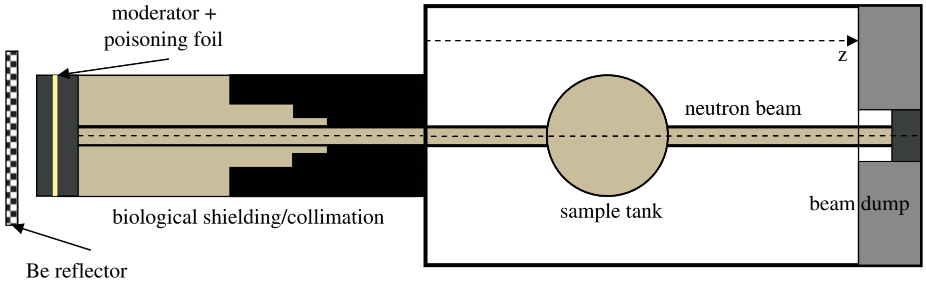

Fig. 1. Layout of the VESUVIO beam line at the ISIS spallation neutron source.

A gadolinium poisoning system is used to lower the Maxwellian component, together with a decoupler to reduce the intensity of the over-thermalized neutrons in the reflectors system. The beam dump, placed at about 5 m beyond the sample position, is mostly composed of hydrogen, iron and boron.

The YAP scintillation detector used for the measurements was initially placed on the top of the sample tank (about 30 cm from the beam axis) and surrounded by a lead shielding (10 cm thick) covering the whole solid angle. In order to study the background along different directions, small apertures were opened depending on the chosen direction to investigate. The signals from the detector were sent to the data acquisition electronics to record time of flight (tof) spectra. In this configuration, an investigation of the directionality of the γ-ray background was done, as discussed in the next section. Another set of measurements was performed by placing the detector, without shielding, at different positions within the experimental hall along the z direction shown in Fig. 1. In this way it was possible to record tof spectra at different places, thus providing a mapping of the γ-ray background.

3. Results and discussion

Fig. 2 shows three normalized tof spectra recorded by the YAP detector when placed on the sample tank and surrounded by the lead shielding. For these measurements no scattering sample was used. It can be noticed that the low tof tails are different in the three cases: in the case of shielding with an acceptance window towards the moderator, the rate is higher by a factor between 2 and 8 in the first 30−40 μs, as compared to the other cases (see Fig. 3). The other two spectra instead (with the lateral and rear aperture in the shielding) are similar, their ratio being about 1 over the whole time region. In the three spectra of Fig. 2, the peaks riding on top of the continuum are due to the radiative neutron capture in the shielding. Indeed, this was not made of pure lead and contained impurities such as antimony which has several neutron resonances in the epithermal region. The main contribution to the continuum in the low tof region comes from the moderator–decoupler system. Indeed, the γ-ray production mechanisms in the moderator and in the decoupling system are known to decay exponentially with different "relaxation times" whose magnitudes are in the order of few tens and few hundreds of microseconds, respectively [17]. Thus, the difference in the observed count rate may be possibly attributed to this highly directional component. Although the background from the beam dump is presumably directional, no difference between the background in the cases with lateral and rear apertures is observed. This is due to the large distance of the scintillator from the beam dump (about 5 m), so that the isotropic contribution from the lateral walls dominates over other contributions.

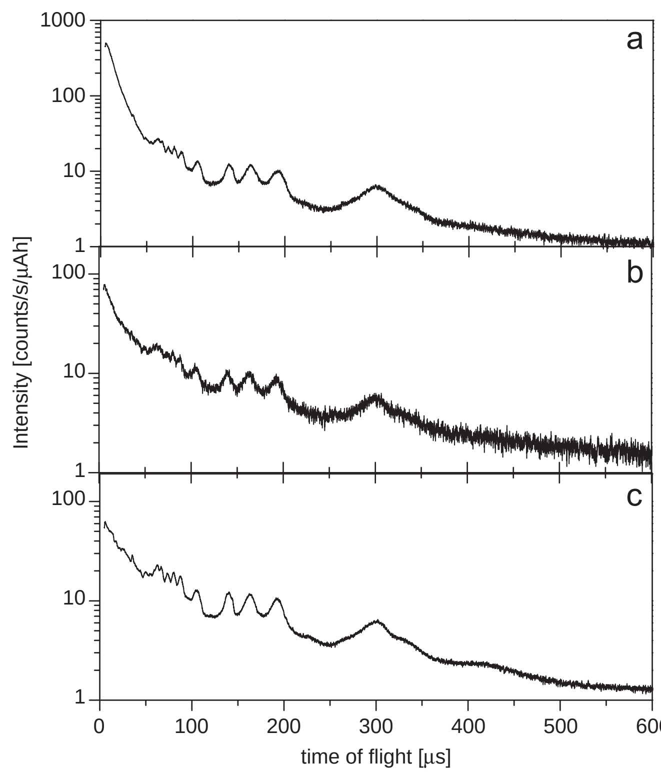

Fig. 2. Time of flight spectra recorded by the YAP scintillator in different shielding configuration: (a) shielding aperture towards the moderator (total current $I = 413\,\mu$Ah), (b) lateral aperture ($I = 100\,\mu$Ah) and (c) rear aperture, i.e. towards the beam dump ($I = 1315\,\mu$Ah).

It is worth reminding here that the count rate due to the different background components was written as [17]

$$B(t) = B_{iso}(t) + B_{dir}(t) + B'_z(t) + B''_z(t) + B_f(t) \quad (1)$$

where $B_{iso}(t)$ represents the isotropic contribution (mostly) due to the walls surrounding the spectrometer, $B_{dir}(t)$ is the term coming from the beam dump, $B'_z(t)$ and $B''_z(t)$ are due to a sort of γ-ray halo produced by the moderator–reflector–decoupler system, while $B_f(t)$ (the "gamma flash" component) represents a transient process at very short times. For a thorough explanation of the different terms the reader is referred to Ref. [17].

For the other set of measurements, i.e. those performed at different positions within the experimental hall, we calculated the count rates C_α and C_β in two different tof intervals α and β, delimited by dashed lines in the upper panel of Fig. 4.

The spectrum shown in panel (a) of the figure is relative to a measurement at intermediate z (i.e. near the sample tank), while

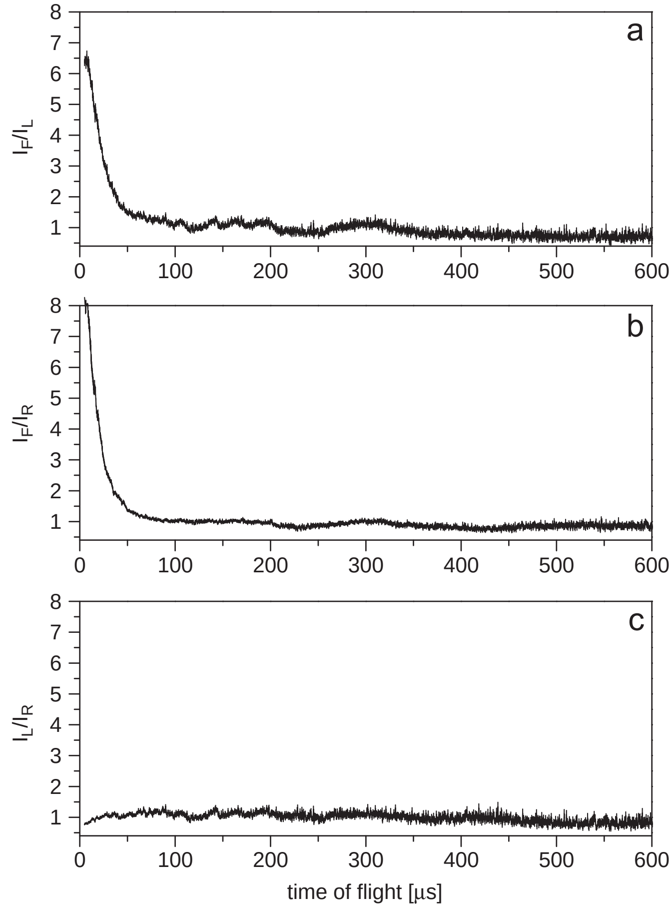

Fig. 3. Intensity ratio in the tof region up to 600 µs between spectra recorded with (a) front and lateral shielding windows, (b) front and rear windows and (c) lateral and rear windows.

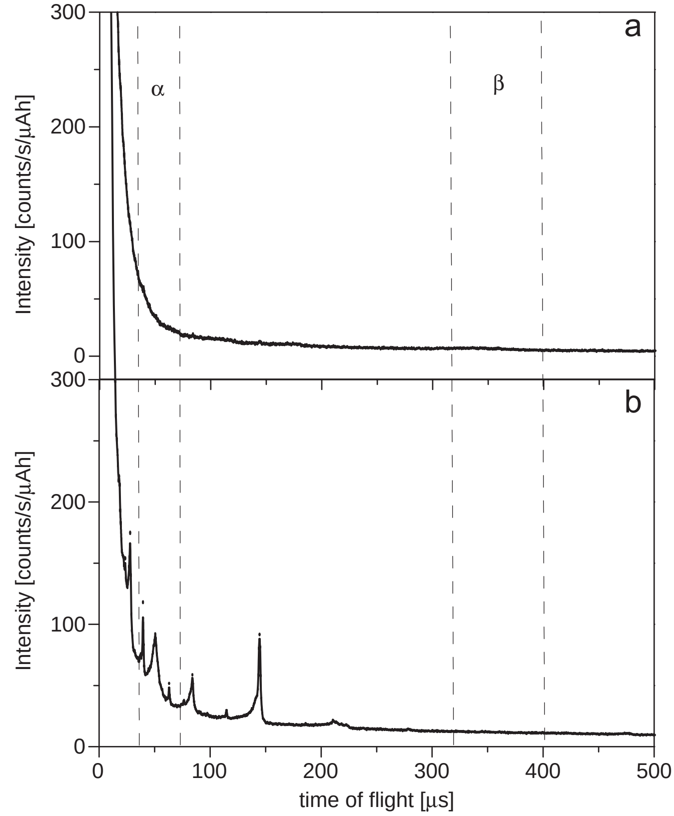

Fig. 4. Time of flight spectra recorded by the YAP detector at two different z positions, namely (a) in the proximity of the sample tank ($z = 225$ cm) and (b) near the beam dump ($z = 400$ cm). The vertical dashed lines define the tof intervals chosen calculate the count rates (shown in Fig. 5) in the two regions.

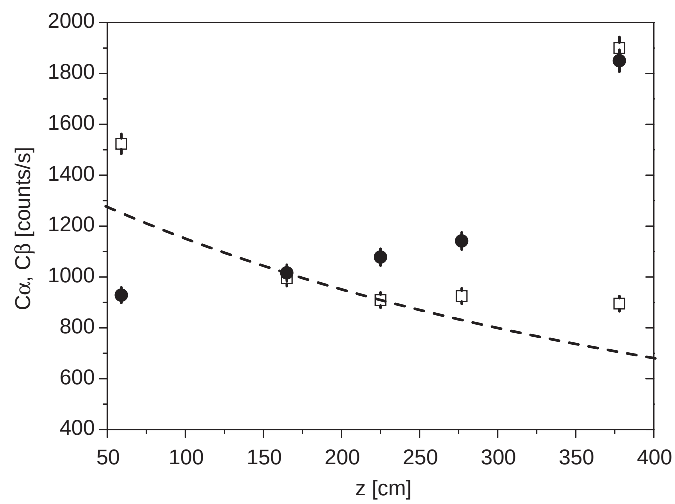

Fig. 5. Trend of the count rates (see text for details) in the regions identified in Fig. 4. The dashed line describes the trend of the intensity, normalized to the value at $z = 225$ cm) from the moderator–decoupler system.

that shown in panel (b) is relative to a measurement near the beam dump. In the former, no evident features are present, while in the latter, resonance peaks can be well identified against the continuum for tof values below 200 µs.

C_α and C_β show opposite trends with varying z, as shown in Fig. 5. In particular, C_α is decreasing with z, ranging from 1.6 kHz at 50 cm to about 0.9 kHz at 380 cm (i.e. closer to the beam dump position), while C_β varies from about 0.9 kHz at 50 cm to about 1.9 kHz at 380 cm. For $z = 380$ cm, C_α is found to be close to 1.9 kHz if the total counts are considered. This value is obtained if the structures (resonance peaks) are considered, while 0.9 kHz is obtained if one performs the counts sum over values obtained by interpolating the continuum beneath the peaks. Despite the collimation system is made of a material similar to the beam dump, the peaks structure is covered by the higher background level present at low tof.

As far as the C_α parameter is concerned, as a first guess one should expect a $1/(z+L)^2$ behavior as $z+L$ ($L \simeq 900$ cm) is the distance from the corresponding background source (the moderator–reflector system). The dashed line in Fig. 5 represents the $1/(z+L)^2$ function normalized to the count rate at $z = 225$ cm.

The count rate C_α, being calculated in a time region around 50 µs is dominated by the contributions of the γ-rays coming from moderator and reflector [17]. The differences between the experimental values of C_α and the dashed line are due to the contribution of the γ-rays produced in the collimation system (see Fig. 1) at low z and to the increasing contribution of the directional γ-rays from the beam dump at higher z. For C_β, that is calculated in the time region around 350 µs, the contribution of moderator and reflector is almost negligible [17]. A slow linear increase in the count rate between $z = 50$ and 300 cm is obtained, followed by a rapid increase in the proximity of the beam dump. This is compatible with a picture where the contribution of the isotropic component due to the walls surrounding the detector overwhelms the count rate (and it is almost constant along z) superimposed to a varying count rate due to the decreasing distance between beam dump and detector.

4. Conclusions

It is found that the γ-ray background at short tof values is highly directional and mostly due to the γ-rays generated in the moderator–decoupler system. The other contributions are identified as a nearly isotropic one due to neutron absorption in the walls of the experimental hall, and a directional one coming from the beam dump. The isotropic source provides an almost uniform background independent of position, while the beam dump, being a localized source, mostly contributes in its proximity.

A previous measurement performed with a HpGe detector gave only time integrated information, while in the present case the information was integrated over the whole γ energies. The results obtained in the present paper validate the assumption made in the previous measurement about the identification of the possible γ-rays background sources. Furthermore, they provide an estimate of the relative importance of the different background components at different times.

The results obtained, indicate that a further contribution to Eq. (1) should be added to yield a more complete expression of the background-induced count rate. This further contribution, that can be indicated as $B_{coll}(t)$, takes into consideration the γ-rays coming from the neutron collimation system of the instrument.

The approach used here in the VESUVIO beam line for background investigation can be extended at instruments operating at pulsed neutron sources and especially at the new beam lines of TS2 at ISIS.

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