Prompt γ radiation measured with a NaI scintillation detector: a beam monitor for neutron scattering instruments which needs no space in the beam

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Prompt γ radiation measured with a NaI scintillation detector: a beam monitor for neutron scattering instruments which needs no space in the beam

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Abstract. We investigate the possibility of using the prompt γ rays emitted by aluminum windows in order to monitor the neutron flux of the beam. A NaI scintillation detector is used to detect the prompt γ rays. No additional material apart from the unavoidable Al windows along the flight path is placed in the beam. The performance of the monitor is compared to that of a standard BF3-monitor placed in the beam. Influences of a magnetic field on the photomultiplier of the NaI monitor is discussed, as well as the influence of activation gammas. At an instrument using a beam chopper the time behaviour is discussed.

1. Introduction

Usually, beam monitors are placed directly in the beam, with a low sensitivity of the order of $10^{-4} - 10^{-5}$, for example He3- or BF3 monitors. Two Al-windows are unavoidably in the beam, producing some absorption, small angle scattering and prompt γ radiation. Prompt γ rays from absorption of neutrons in aluminum, which is the main material used for neutron windows, have a significant contribution of high energetic gammas, e.g. for aluminum at 7.7 MeV [1] [2], compared with the activation γ's of Al which have the main contribution at 1.7 MeV [3]. With a scintillation detector sensitive also to high energy gammas, where the lower energies are filtered and discriminated away, a beam monitor without additional material besides the unavoidable Al windows can be realized. Fig. 1 shows the absorption coefficient of lead as a function of energy. At the J-NSE neutron spin echo spectrometer [4, 5, 7] at the FRM II research reactor of the TU München this type of monitor has been tested and showed that it is a relieble and easy to handle possibility as a beam monitor. Time behaviour has been investigated at the SPHERES backscattering spectrometer [8], where the phase space transform chopper imposes a time structure on the incoming neutron beam.

2. Experiment

Neutron capture releases the total binding energy of a neutron in the order of 8-10 MeV mostly in the form of one to several γ-photons. A fraction of them has energies close to the total binding

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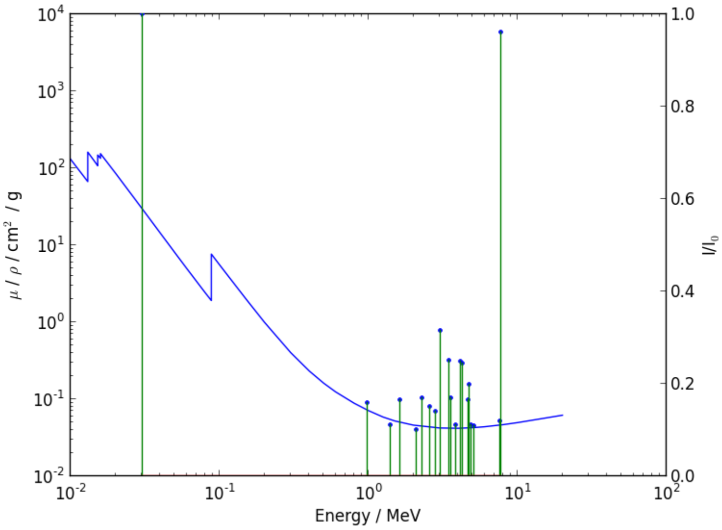

Figure 1. Absorption coefficient of lead as a function of γ energy and the relative intensities of the prompt γ lines of Al (with more than 10% rel. intensity). Lead acts as a filter for the low energy γ's from the produced radioactive Al-28 isotope and others. A very strong prompt γ line is above 7 MeV. Data from [9] and [2].

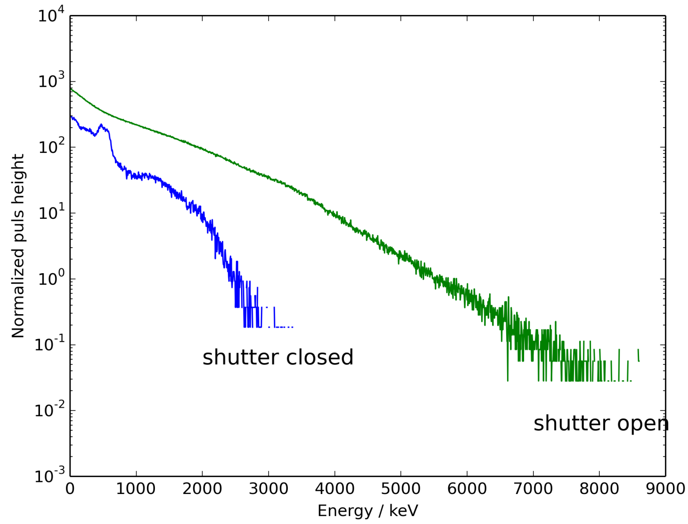

Figure 2. Pulse height spectra of the NaI monitor. The peak at closed beam is attributed to the 511 keV line of positron-electron annihilation. The low energy part contains contributions from activation decay, the high energy part is used for monitoring the beam intensity.

energy. To detect them with a scintillation detector, a rather large scintillation crystal is needed. In the present experiment, we used a SCIONIX scintillation detector with a NaI crystal with 76 mm diameter and 102 mm height to detect the prompt γ's emitted from the aluminum windows in front of the first main coil of the J-NSE spectrometer.

A first data acquisition of the analog output has been taken with the monitor placed

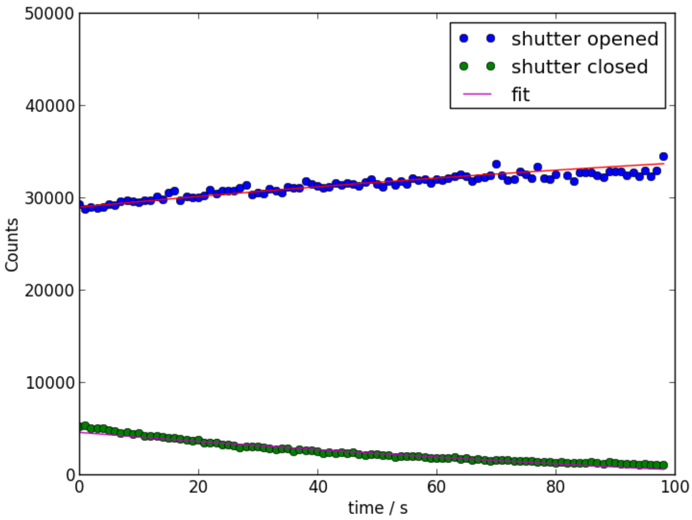

Figure 3. Monitor at a position about 1.4m away from the beam, without lead shielding. Count rate at the analog output with open beam (blue) and closed beam (green) as a function of time. Counting time was 1 sec. The activation gammas are counted with these settings. Fits are made with the Al decay time of $T_{1/2}$=2.246 min.

underneath the lead shielding of the polarizing unit. The built up and decay of the activation γ's from Al is clearly visible in the analog pulses of the monitor (see Fig. 3). Without the lead acting as a high energy filter, the NaI scintillator alone is therefore not suitable as a beam monitor. The situation can be improved by pulse height discrimination, by this means the obvious Al-28 decay signal with a half life time of 2.2414 minutes (BNL data) (β-decay with associated 1.78 MeV γ [6]) can be suppressed. However, the high count rate of low energy γ's leads to saturation and dead-time effects.

2.1. Low γ discrimination

The use of the NaI-counter as a beam monitor requires that the low energy γ's are cut away. As a filter, the lead hutch of the second polarizer of the J-NSE spectrometer has been used with its 50 mm thickness to absorb preferentially the low energy γ rays. Fig. 2 shows pulse height spectra of the analog signal of the NaI-monitor with the shutter of the neutron beam open ("beam open") and closed ("beam closed") respectively. With the beam closed, there is still a significant number of pulses at lower energies. They can be filtered to a large amount by some (typically 5 cm) Pb. With an adequate threshold for the digital signal it is possible to be only sensitive to the high energy part of the spectrum, where most of the prompt γ-lines from Al are found.

Measurements with a Pb filter realized by placing 50 mm lead between the NaI detector and the beam (i.e. placing the detector outside the lead hutch of the long wavelength polarizer) lead to a significantly reduced count rate of the analog output by one order of magnitude. The ratio of the count rate with beam open and close is about 15 and can be largely improved for the digital output in combination with the appropriate trigger level. A good sensitivity to the prompt γ rays could be achieved in this way. In this monitor position, the count rate with the reactor not running is at about 2-3 cps. The remaining dark count rate is due to the unshielded position towards other instruments in the neutron guide hall.

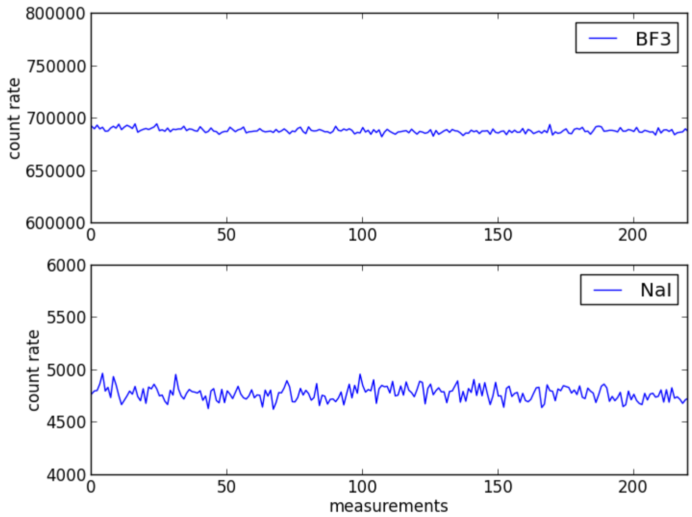

Figure 4. Detector counts versus number of measurement. Top: BF3-monitor, Bottom: NaI-monitor. Spectra are time normalized (counts per second), resulting in the different levels of noise.

2.2. Reliability

The time behaviour of the NaI monitor has been compared to the J-NSE standard BF3 monitor which covers the whole beam cross section. A series of 220 measurements is shown in Fig. 4. The standard deviation has been compared to the square root of the count rate as the expected deviation. The standard deviation of the BF3-Monitor is 2369, the square root of the count rate 829, while for the NaI monitor (with a much lower overall absolute count rate) the two values are 73 and 69 respectively. It has to be pointed out that above a magnetic field of 2 Gauss at the position of the monitor the photomultiplier tube of the NaI counter has been disturbed despite of it's μ-metal shielding. The count rate drops for a field of 4 Gauss by 1/3 compared to the undisturbed count rate. A suitable magnetically stable position is therefore needed.

2.3. Time behaviour

At the backscattering spectrometer SPHERES the time response of the monitor has been tested. At the end of the neutron guide, inside the housing of the spectrometer, is the phase space transform chopper with added Pb shielding on the front side. The monitor was placed on top of the neutron guide shielding towards the chopper. Shown are counts versus chopper phase for monitor (shifted by 20000) and a large angle detector tube (separated into elastic and inelastic counts). The count rate of the NaI monitor followed exactly the opening and closing of the chopper. The Al windows in front of the chopper produce a constant high count rate which is then modulated with the frequency of the chopper. The response is as fast as the response of the detectors just behind the chopper (Fig. 5). The steps in the first $\sim$24 degree of the chopper open and reflecting phase corresponds to a flight distance of $\sim$1.6 m. We attribute it to prompt γ radiation from neutrons passing the Al window in front of the Doppler monochromator. The wiggling structure during the reflection phase of the chopper is in our opinion due to slightly varying absorption of the chopper wheel and reflection of the different crytals. The average count rate is nontheless a measure of the incoming neutron flux. A really time resolved operation needs a good shielding towards all unwanted sources of γ radiation.

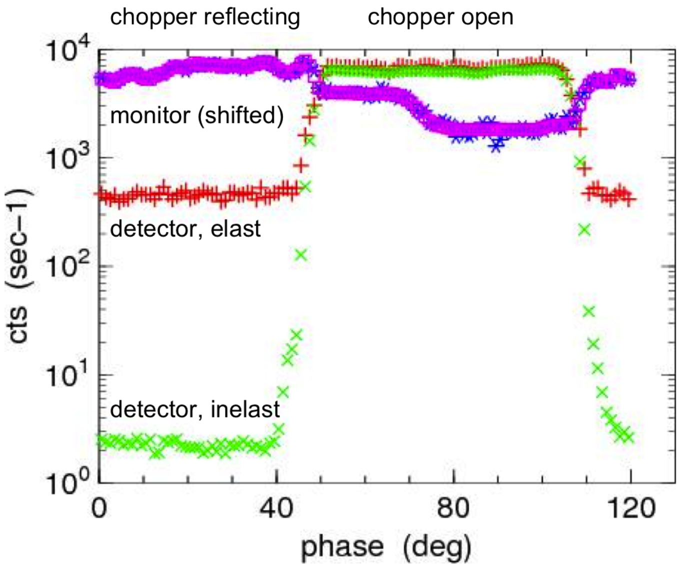

Figure 5. NaI monitor at a chopper instrument, the backscattering spectrometer SPHERES. The time structure of the monitor follows the opening and closing of the chopper (see text).

3. Practical setup as a beam monitor

Fig. 6 shows a sketch of how the prompt γ radiation can be used. A thin lead shielding (depending of the γ intensity) of about 5 cm filters all low energy γ rays, a thicker lead shielding (about 10 cm) blocks the main part of the remaining γ rays from other sources. The general hall background can be substracted with a second background monitor, which has to be placed in a equivalent throughout thick shielding (without the thin lead filter towards the beam).

4. Conclusion

The NaI monitor is an easy to use plug-and-play device which performed similarly to the currently used traditional BF3-beam monitor for the 60x60 mm^2 beam. The stability and reproducibility at the same settings of the instrument seems to fulfil the requirements of the NSE spectrometer. It has the advantage that no additional material is needed in the beam since Al-windows producing the required prompt γ's are available anyway and thus no losses of intensity due to the monitor are encountered. The monitor has a slight dependence on the magnetic field of the main coils, it is visible at the present position as a drop of count rate as the B-field is at about 4 Gauss. The signal-to-background ratio at the current position is 20. The monitor was not shielded against γ's coming from other experiments or neutron guides. A better placement and a lead shielding around the monitor will certainly improve the background situation. The magnetic field sensitivity might be reduced with a μ-metal shielding. One only needs to ensure that the influence of the shielding on the magnetic field homogeneity of the instrument is negligible. Between neutron guide and second polarizer would be such a position at the J-NSE spectrometer, which is further away from the main coils with two Al-windows present. The temperature dependence has not been studied, here the monitor has been operated in an air conditioned stable environment. Variations in temperature will have a certain influence on the efficiency of the monitor. The sensitivity to external background could be further reduced by a differential measurement with a second NaI-monitor, placed in an equivalent position concerning the γ sources from other experiments, but shielded against the prompt γ's of the own instrument.

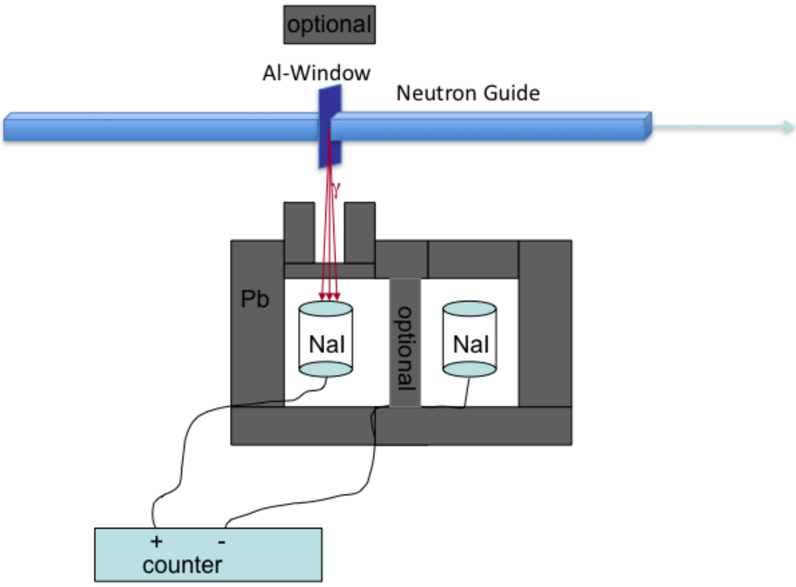

Figure 6. Measurement principle for the NaI beam monitor. A thin lead shielding of about 5 cm filters all low energy γ rays, a thicker lead shielding (about 10 cm) blocks the main part of the γ rays from other sources. The general hall background can be substracted with a second background monitor.

5. Acknowledgement
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