ARTICLE IN PRESS
Nuclear Inst. and Methods in Physics Research, A ▮ (▮▮▮▮) ▮▮▮–▮▮▮

Contents lists available at ScienceDirect

Nuclear Inst. and Methods in Physics Research, A

journal homepage: www.elsevier.com/locate/nima

The Multi-Blade: The ^{10}B-based neutron detector for reflectometry at ESS

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ARTICLE INFO

Keywords:
Neutron detectors (cold and thermal neutrons)
Gaseous detectors
Boron-10
Neutron reflectometry

ABSTRACT

The Multi-Blade detector has been designed to be used on the reflectometry instruments at the upcoming European Spallation Source. It is a ^{10}B-based gaseous detector, built as a modular stack of multi-wire proportional chambers organised on a circle around the sample. The detector has been fully characterised. The gamma and fast-neutron sensitivity has been measured at the Source Testing Facility in Lund University, Sweden; the working capability in a reflectometry instrument has been demonstrated with measurements at CRISP in ISIS, UK; and the count-rate capability of the detector will be measured the summer of 2018 at the Budapest Neutron Centre, Hungary.

Contents

1. Introduction

The upcoming European Spallation Source (ESS) [1] in Lund, Sweden, is foreseen to be the world brightest neutron source. The combination of the unprecedented neutron flux and the ^{3}He-crisis [2,3] have called for new detector development. In particular, neutron reflectometry is facing a large challenge in terms of rate capability and spatial resolution.

The state-of-art detector technology for neutron reflectometry, mainly ^{3}He-based, has a spatial resolution that is limited to approximately $2 \times 8\,\mathrm{mm}^2$ and a maximum count-rate capability of 40 Hz integrated over the whole beam intensity on the detector [4]. The latter corresponds to a few hundreds of Hz/mm^2.

The detector requirements for the two reflectometry instruments planned for ESS, ESTIA [5] and FREIA [6], are listed in Table 1. The spatial resolution required for the new instruments is more than double the present; further, the instantaneous count-rate capability is foreseen to be three orders of magnitude larger than what can handle present detectors.

Developed in a collaboration between ESS, Lund University, Linköping University, Sweden, and the Wigner Research Centre for Physics, Hungary, the Multi-Blade detector has been designed to cope with these challenging requirements.

2. The Multi-Blade detector

The Multi-Blade detector is a ^{10}B-based gaseous detector for cold and thermal neutrons [7]. It is a modular detector where each module, called *cassette,* acts as an independent multi-wire proportional chamber (MWPC). The detector is operated at atmospheric pressure with continuous gas flow (Ar/CO_2 80/20 mixture). Thus, the window of the detector can be submillimetre thickness. Compared to the typical few millimetre thickness for the windows for a high-pressure ^{3}He detector, this will reduce the self-window scattering (request to be below 10^{-4} of the incoming flux for the two instruments at ESS). The cassettes are arranged over a circle around the sample and each of them holds a *blade* (a substrate coated with $^{10}B_4C$) and a two-dimensional readout

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https://doi.org/10.1016/j.nima.2018.10.058
Received 27 June 2018; Received in revised form 8 October 2018; Accepted 9 October 2018
Available online xxxx

Please cite this article in press as: F. Messi, et al., The Multi-Blade: The ^{10}B-based neutron detector for reflectometry at ESS, Nuclear Inst. and Methods in Physics Research, A (2018), https://doi.org/10.1016/j.nima.2018.10.058.

Table 1
Detector requirements for the reflectometry instruments of ESS.

ESS requirements:	Estia	Freia	State-of-art
Wavelength (Å)	4–10	2.5–12	1–30
Instantaneous rate @detector ($n/mm^2/s$)	10^5	10^5	$\sim 10^2$
Spatial res. (mm)			
High res. direction	0.5	0.5	2
Low res. direction	4	2.5	8
Gamma sensitivity	$<10^{-6}$	$<10^{-6}$	$<10^{-7}$
Fast-neutron sens.	–	–	$<10^{-3}$
Number of channels	4800	2880	~128

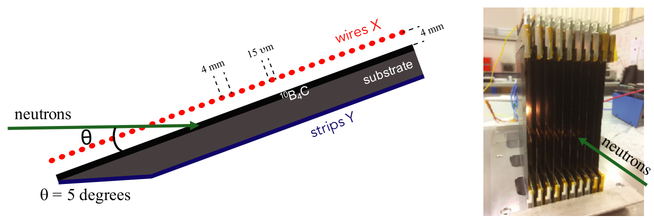

Fig. 1. Section of a blade, top view (on the left) and a photo of the MB-16 prototype during assembling (on the right).

system. The high resolution dimension is instrumented with a plane of wires, while the orthogonal dimension by a plane of strips. Each $^{10}B_4C$-converter blade is inclined at 5° with respect to the incoming neutron beam (see in Fig. 1). This special geometrical arrangement is responsible for three main advantages: first, the neutron-conversion power is improved. In fact, while the path that an impinging neutron will travel in the boron layer is increased (by a factor $\sin\theta$), the escape path of the reaction products stay, at maximum, the thickness of the coating. The detection efficiency of the Multi-Blade detector has been measured to be ~44% @ 2.5 Å. The second advantage regards the count-rate capability. This is defined as the maximum number of detectable neutrons per mm^2 *impinging the active area of the detector.* As the blade are inclined inside the detector, this is equivalent to spread the incoming flux across a much larger surface on the MWPC (again, by a factor $\sin\theta$). At present, a lower limit of 1.6×10^3 neutrons/mm^2/s has been measured, limited by the read-out electronics capability. Similarly, the pitch of the wires projected to the surface of the detector is reduced and the spatial resolution of the detector thus improved. This, together with the position reconstruction algorithm used results in 0.6 mm and 2.5 mm resolution for the high- and low-resolution directions, respectively.

3. Characterisation

The Multi-Blade detector has been fully characterised and the majority of the results have been published singularly.

The sensitivity of the detector to gamma-ray [7] and to fast neutrons [8] has been characterised at the Source Testing Facility (STF) of Lund University [9]. At 10^{-7}, the gamma-ray sensitivity has been measured to be in line with the state-of-art technology. The fast-neutron sensitivity has been measured, for the first time for ^{10}B-technology, to be 10^{-5}: two order of magnitude better than the actual detectors. A further test, foreseen in July 2018, will measure the fast-neutron sensitivity of the Multi-Blade detector using *tagged neutrons*.

The current prototype version of the Multi-Blade was tested in CRISP [10] at ISIS [11]. The reflectivity of several samples were measured and the capability of the Multi-Blade to perform in a real reflectometry instrument was demonstrated [12,13].

Further tests are foreseen by summer 2018 at the Budapest Neutron Centre, Hungary on the final Multi-Blade prototype version at present under construction. These tests aim to provide a lower limit of the count-rate capability of the detector.[1]

Tests at PSI are foreseen for autumn 2018. These tests aim to measure the uniformity of the detector in a reflectometry instrument where the correct geometry of the Multi-Blade detector can be accessed.

4. Summary

The Multi-Blade detector concept has been developed for neutron reflectometry at ESS. The design has been improved several times and the final prototype detector has been characterised. Tests have been conducted at the Source Testing Facility in Lund, Sweden and at the CRISP reflectometry instrument at ISIS, UK. The results confirm that the Multi-Blade technology is to be consider mature for neutron reflectometry.

Acknowledgements

This work is being supported by the BrightnESS Project, Work Package (WP) 4.2 (EU Horizon 2020, INFRADEV-3-2015, 676548). The work was supported by the Momentum Programme of the Hungarian Academy of Sciences, Hungary under grant no. LP2013-60.

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[1] Given the available rate (~500 kHz/mm^2 on a broad energy spectrum) compared to the expected rate at ESS.

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