A remote control positioning system for Be\((p,n)\) angular neutron spectrum measurements with superheated drop detectors

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INTRODUCTION

The present work is performed at the CN Van de Graaf accelerator of INFN-LNL as a scientific collaboration between the Department of Mechanical, Nuclear and Production Engineering (DIMNP) of the University of Pisa and the INFN-LNL in the framework of the SPES-BNCT project. This project aims at the construction of an accelerator-driven facility for BNCT (Boron Neutron Capture Therapy) of the skin melanoma and, at a later stage, of hepatic metastases in the explanted liver. An intense proton beam provided by the 5 MeV, 30 mA RFQ (Radio Frequency Quadrupole), the first accelerating stage of the designed 20 MeV superconducting linac of SPES, will be exploited as driver source. The proton beam impinges on a thick beryllium converter target generating neutrons via the \(^9\)Be\((p,n)\) reaction. The 1 mm thick target completely stops the protons. The fast energy neutron spectrum resulting from the Be\((p,n)\) reaction (average energy: 1.5 MeV) is not suitable for the BNCT treatment. A subsequent thermal spectrum shifter facility is necessary to slow down the emitted neutrons getting the required BNCT energy spectrum. As a consequence, the precise knowledge of the angular neutron yield of the Be\((p,n)\) reactions and the corresponding energy spectrum is required. Since existing literature data \([1]\) relative to 5 MeV protons are available only for normal incidence (0°) direction, further experimental measurements are required. The present work is devoted to the construction and setup of the experimental apparatus to perform angular spectrometry measurement by means of superheated drop detectors (SDD). The results will be a milestone for the SPES-BNCT project, because the obtained experimental data will be used as an input to the final design of the neutron spectrum shifter facility.

SUPERHEATED DROP DETECTORS

The SDD consists in a cylindrical vial (height 68 mm, diameter 19 mm) containing an emulsion of overexpanded halocarbon droplets in an inert gel matrix \([2]\). The interaction with neutrons nucleates the phase transition of the droplets and generates detectable bubbles. The bubble formation rate depends on the neutron energy and the detector temperature. By increasing this temperature (typically in steps of 5 °C from 25 °C to 55 °C), it is possible to generate a set of different neutron energy threshold responses and perform spectrometry measurements in the 0.1 – 10 MeV range. The energy spectrum is determined by a deconvolution of the data obtained by counting the rate of bubble nucleation during irradiation at different detector temperatures.

SDD POSITIONING SYSTEM FEATURES

In order to measure the angular energy distribution of the neutrons emitted by the \(^9\)Be\((p,n)\) reaction with SDDs, a detector vial positioning device, equipped with a remote control system, was designed, built and commissioned (Fig. 1). This system allows a complete control and monitoring of the angular spectrometer operation, including:
- setting the angular position of the detector in the \((0 – 135)^\circ\) range with respect to the proton beam axis;
- setting the distance between the SDD vial and the beryllium target in the \((0 – 2.5)\) m interval;
- setting the detector temperature in the \((0 – 55)\) °C interval;
- counting the number of nucleated bubbles.

The previous functions can be performed without interrupting the proton beam, i.e. without varying the operational conditions of the accelerator. The possibility to...
change the source to detector distance is used as a tool to properly compensate the variation of both the detector sensitivity with the gel temperature and the neutron source intensity at different angles. This is in the attempt to follow, as closely as possible, the rule of practice with the SDDs which requires operating at a constant bubble formation rate.

The developed system consists of a 3 m long aluminum rail (Fig. 1) rotating around a bearing support, which is fixed to the accelerator room floor and vertically aligned to the beryllium target. The angular movement of the rail is performed by means of a stepper motor equipped with a dedicated driver and mechanically coupled to a 40 mm diameter rubber wheel by a gear reduction system. The wheel moves along an aluminum circular rail fixed on the floor and suitably coated with a high friction material. The detector vial is vertically held on a trolley moving along the rail by another stepper motor and a gear belt transmission system (Fig. 2).

The centre of the vial is aligned with the proton beam direction axis (Fig. 3). The possibility to position a shadow cone on the rail between the detector vial and the accelerator target is foreseen: in this way is possible to evaluate the neutron background contribution due to scattering with accelerator hall walls, mostly at high angle values.

The two stepper motors are controlled by dedicated software, which calculates the number of steps required to reach a desired angular and longitudinal detector position.

Figure 2 Detail of the rail: the gear belt, the trolley and the detector vial in vertical position are visible.

Figure 3 Detector vial (on the left) aligned with the proton beam axis (the beryllium target is shown on the right).

Figure 4 Example of measurement with shadow cone in place.