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Complete determination of neutron yield from 62 MeV protons on ^{9}Be for the design of a low – power ADS

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Abstract. Within the European Partitioning & Transmutation research programs, infrastructures specifically dedicated to the study of fundamental reactor physics of future fast neutron-based reactors are very important. In this respect, an Accelerator Driven System low-power prototype, based on a 70 MeV proton beam impinging on a thick Beryllium converter, was recently proposed and designed within the INFN-E project. The world data on neutron yield from Be target are scarce in this proton energy range. This lack of data calls for a dedicated measurement which was performed at INFN Laboratori Nazionali del Sud, covering a wide angular range, from 0 to 150 degrees, and an almost complete neutron energy interval, from thermal up to the beam energy. In this contribution the results are discussed together with the description of the proposed ADS facility.

1 Introduction

The development of advanced fuel cycles for the minimization of radioactive waste production, plays an important role in the research on innovative nuclear energy systems. Therefore the study of fundamental physics and engineering parameters of fast future reactors became necessary. The Accelerator-Driven Systems (ADS), based on a fast subcritical reactor core where fission chain is maintained in a steady-state by supplying neutrons from an external source, could offer a promising opportunity.

Starting from the above considerations, INFN, in collaboration with Ansaldo Nucleare, proposed a low power prototype of neutron amplifier [1]. A high safety level is guaranteed by limiting the thermal power to 200 kW, with a neutron multiplication coefficient around 0.95. The fast subcritical core consists of a solid lead matrix and 60 UO_2 active fuel element enriched at 20%, which are cooled by a continuous Helium gas flow through small channels between fuel elements.

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Such a facility would permit the study of fast ADS physics and the investigation of some technical aspects, for instance the issues related to system safety and licensing. The proposal considers as external neutron source the 70 MeV, 0.75 mA proton cyclotron facility, already foreseen for the INFN SPES project at Laboratori Nazionali di Legnaro, Italy, and a Beryllium target as proton to neutron converter.

Several neutron yield measurements have been carried out in the past at proton energies close to the one of the present project [2-5], but they are rather incomplete both in angle and in neutron energy range. So a dedicated and more detailed neutron production measurement was necessary. It was done using the proton beam delivered by the Superconducting Cyclotron at Laboratori Nazionali del Sud (LNS), Italy.

In this contribution we present the neutron production yield data measured at LNS in an almost complete energy range and covering polar angles from 0 to 150 degrees.

2 The experimental setup

Neutrons were produced bombarding a 3 cm thick Be target with a 30-50 pA 62 MeV proton beam. The repetition rate of the proton beam was adjusted, by suppressing four bunches out of five, to obtain a time separation between two consecutive bunches equal to 125 ns. Each bunch had a width of 1.5 ns.

The Be target, having a cylindrical shape with a diameter of 3.5 cm, was inserted in a Teflon holder specifically designed to minimize background and guarantee a good electric insulation. The target assembly included the beam current readout together with a guard ring for delta-electron suppression, in order to ensure accurate beam current measurement directly on the target for absolute data normalization. A 100 cm long carbon fiber tube was used for the last part of the beam line to reduce the gamma background due to neutron interaction.

The energy of neutrons produced in the target were measured by the Time of Flight (ToF) technique using eight 4 cm long Aluminium cylindrical cells filled with liquid scintillator EJ301. The neutron ToF was measured with respect to the RF signal from the cyclotron. The gamma flash was used in order to select the correct RF peak. Also, the Pulse Shape Discrimination (PSD) technique was used to separate neutrons from γ's.

The Neutron Detectors (ND) were installed at two different distances around the target as schematically shown in Figure 1.

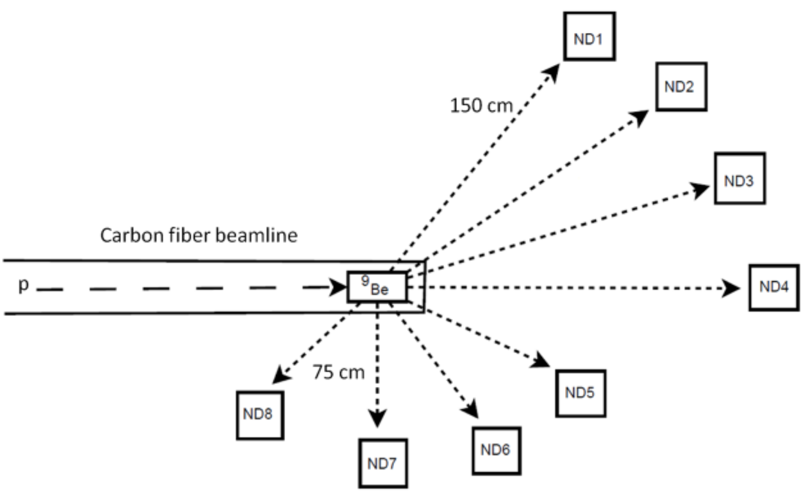

Figure 1. Schematic view of the experimental setup. The Beryllium target, installed inside the carbon fibre tube, is connected to a digital beam current integrator. The near/small detectors are placed at 75 cm from the Be target while the far/large detectors at 150 cm. Both small and large detectors were moved to cover 16 angles from 0° to 150°.

Four detectors, defined as *far detectors* and placed at 150 cm from the target, had a diameter of 4.6 cm, and other four, defined as *near detector* and located at half distance (75 cm) from the target, had a diameter of 2.3 cm. Both far and near detectors installed in this configuration share the same solid angle.

With this experimental set-up we have been able to (i) achieve low background contribution, (ii) cover a large angular range moving the detectors at different angles from 0° to 150° and (iii) cover a large energy range: from 0.5 to 2 MeV with near detectors and up to 62 MeV with far detectors. The two different dynamic ranges were selected by adjusting the threshold value on the detectors deposited energy. This threshold prevented also the low energy neutrons (E_n < 0.2 MeV) from previous beam bunch to contaminate the spectrum. In order to achieve a complete energy coverage, dedicated runs were taken using a Canberra ^{3}He detector (see Refs. [7,10] for details).

3 Data reduction and results

The measured data were analyzed off-line first of all removing the backgrounds. There are two main types of background: (i) the environmental background caused by particles not coming from the target but from surrounding materials as for example beam line and other installations nearby, and (ii) the gamma produced by nuclear reactions, that can be subtracted combining ToF information and PSD performed integrating separately and comparing the whole detector output signal and its tail. The first type of background has been measured in dedicated runs obscuring the detector with a 50 cm long 4.6 cm diameter steel shadow bar. To avoid the interference between detectors only two shadow bars in front of most distant detectors were installed simultaneously. Thanks to the choice of light materials for beam line and detector supports, to the empty floor of experimental hall and to the large distance between the detectors and walls and roof, these contributions resulted to be quite small (few percent in average).

Once removed the background, the data were corrected for the detector efficiency, deduced by Geant4 Monte Carlo simulations [6], implementing complete detector geometry and material description. The Geant4 efficiencies were validated in a dedicated measurement [7] in the neutron energy range covered by ^{252}Cf spontaneous fission source. To exclude bin migration effects data bin sizes on the neutron energy were chosen according to the energy resolution obtained in simulations.

The systematic uncertainties on evaluation efficiency (resulted to be 10% for both type of detectors) and on the normalization were studied carefully as described in detail in Ref. [7].

Fully differential neutron yields have been measured at 16 angles from 0 to 150 degrees covering a neutron energy from 0.5 MeV to the beam energy. Such a broad kinematic coverage was necessary to obtain complete and detailed information on neutron production. The energy and angular distributions of the measured neutron yield are shown in Figure 2.

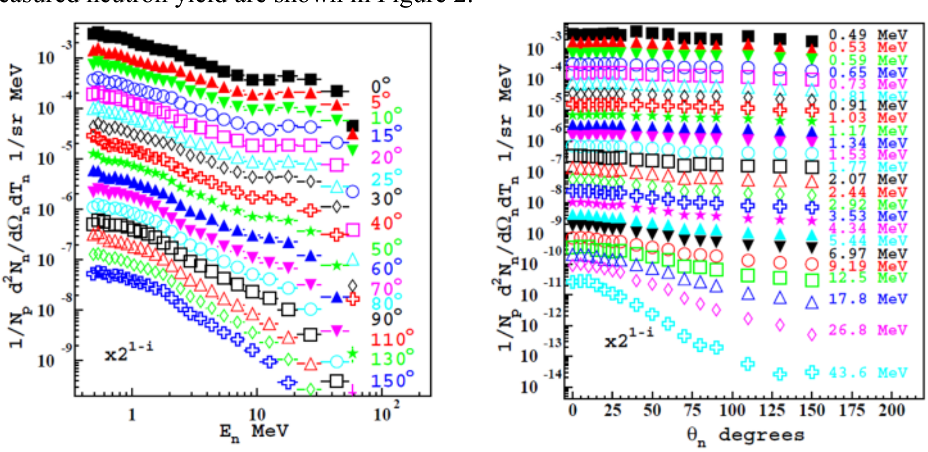

Figure 2. Energy (left panel) and angular (right panel) differential distribution of the neutron production yield.

The neutron yield measured by the ^{3}He tube integrated over the neutron energy from zero to 0.5 MeV is compared to the liquid scintillator data in Fig. 3, left panel.

Also the integrated energy yield was calculated for each angle, combining liquid scintillators and ^{3}He tube data, and its angular dependence is shown in Figure 3, right panel.

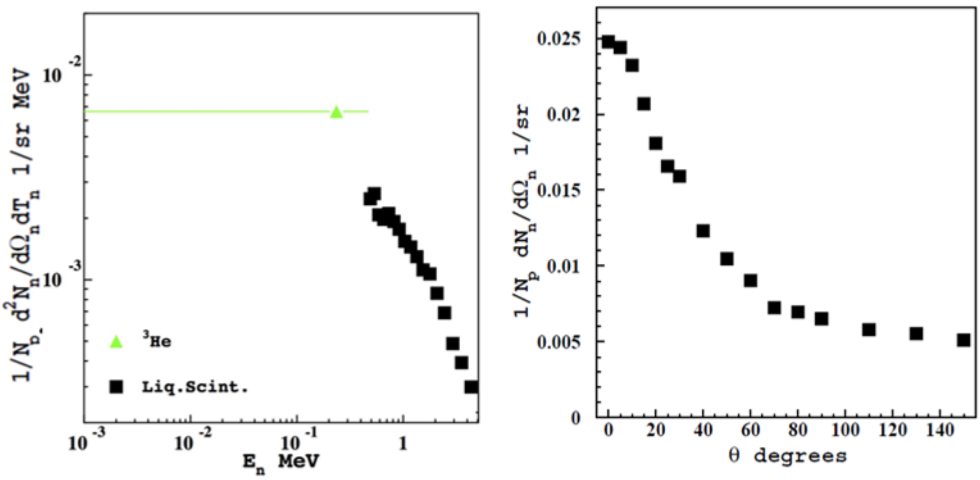

Figure 3. ^{3}He detector yield in comparison with liquid scintillator on the left panel. Angular dependence of the integrated neutron yield on the right panel.

Integrating the neutron yield also over the angle, the total neutron yield $N_n/N_p = 0.1003 \pm 0.003_{stat.} \pm 0.0053_{sys.}$ n/p was obtained. This value can be compared to the value of 0.110 ± 0.007 n/p measured at 65 MeV by Tilquin at al. [8] using the manganese bath technique. Also, the comparison with MCNP simulations [9], giving $N_n/N_p = 0.103$ n/p (ENDF VII) and $N_n/N_p = 0.096$ n/p (LA150), shows a good agreement with our experimental results.

4 Conclusions

The neutron yield produced by a 62 MeV proton beam impinging on a thick Beryllium target was measured for the first time from thermal up to beam energy, covering an angular range from 0 to 150 degrees [7].

A general good agreement with the few, incomplete existing data and with simulations was found. This supports the use of our data set for the precise determination of the external source term of the proposed ADS facility.

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