Development of a facility for research of charged particle emission induced by fast neutron reactions

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Abstract A facility has been constructed for research of charged particle emission induced by fast neutron reactions ((n, x) reaction) based on the white neutron source and the quasi-monoenergetic neutron source which will be provided by the upgrade of the HI-13 Tandem Accelerator at China Institute of Atomic Energy (CIAE).

The facility mainly consists of a cylindrical vacuum chamber with the diameter of 100 cm and the height of 50 cm, a target changer with 5 target frames and eight ΔE-ΔE-E telescopes. Each telescope consists of two silicon detectors and a CsI crystal. Eight telescopes were mounted with 20° angle intervals; they can cover the detection angle from 20 to 160 degrees. ΔE-ΔE-E Techniques were used to obtain good particle identification (PID) for protons, deuterons, tritons, ^{3}He and α particles over an energy range from a few MeV up to 100 MeV. All operations inside the vacuum chamber, i.e., changing the target sample, calibration with an alpha source, or rotation of the telescope table, can be made without breaking the vacuum.

Detailed description of the reaction chamber and the telescopes will be given in this report. The test results and the application of the facility in the future are also presented.

Key words intermediate energy neutron, (n x) reaction, ΔE-ΔE-E telescopes

PACS 29.25.Dz, 29.90.+r, 29.30.Ep

1 Introduction

The needs of nuclear data for neutron-induced light-ion production at intermediate energies have been increasing, both in the foundation research and varietyof applications. Such as nuclear structure research, in particular for investigations of the isovector components of nucleon-nucleus interactions using of the Charge-exchange reactions, radiation treatment of cancer therapy, neutron dosimetry at high altitude and space, single event effects in microelectronics, and transmutation of nuclear waste.

In nuclear medical, radiation protection and cancer therapy fileds, the fast neutron data of double-differential cross-sections and Kerma Coefficients on neutron-induced reactions with biologically relevant materials, e.g., carbon, nitrogen, oxygen is needed. In accelerator-driven transmutation applications, the proposed technologies involve high-energy neutrons created in proton-induced spallation of a heavy target element.

The importance of cosmic radiation effects on aircraft electronics has recently been highlighted. At commercial flight altitudes, as well as at sea level, the most important particle radiation is due to neutrons, created in the atmosphere by spallation of nitrogen and oxygen nuclei, induced by cosmic ray. When, e.g., an electronics memory circuit is exposed to neutron radiation, charged particles can be produced in a nuclear reaction. The released charge can cause a flip of

Received 8 July 2008
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the memory content in a bit, which is called a single-event upset (SEU). To get a deeper understanding of these phenomena, more detailed cross-section information on neutron-induced charged particle production at intermediate energies is needed.

To fulfill the needs of better nuclear data for fast neutron cancer therapy, as well as for other applications, we have constructed and tested a new experiment set-up, dedicated for research of the (n, x) reactions based on the white neutron source and quasi-monoenergetic neutron source which will produced by the upgrade of the HI-13 Tandem Accelerator at CIAE.

In this paper, the facility and its performance are described in detail.

2 Description of the facility

2.1 The neutron source

The neutron beam facility of the HI-13 Tandem Accelerator at CIAE has been described in detail in previous publication, and a 100 MeV proton cyclotron (CYCIAE-100) has been proposed and it is under construction. Based on this cyclotron, 70—100 MeV neutrons can be produced by the ^{7}Li (p, n) reaction. The white neutron source and quasi-monoenergetic neutron source are shielded and collimated before bending on the target.

2.2 The chamber system

The cylindrical scattering chamber was installed directly after the last neutron collimator. The chamber is about 100 cm in diameter and has a height of 50 cm. There are four ports on the wall of the chamber: two of them in the neutron beam line were used for the pulse neutron beam transport (with a diameter of 8 cm), the third one for a turbo vacuum pump and the last one is used to observe the inside of the chamber. There are 40 LEMO connectors mounted in the cylindrical feedthrough assembly at the bottom of the chamber, signal and bias for all detectors are brought out and feed into the chamber by there connectors.

Figure 1 shows the arrangement inside the vacuum chamber. The reaction target is located at the centre of the chamber and can be engaged in the beam or away from it without breaking the vacuum. A rotational target frame system was designed, which contains five target frames, and each target typically has diameters of 40—50 mm. The angle between the plane of the target frame and the neutron beam is 45°. The structure of the rotational target frame system is shown in the Fig. 2.

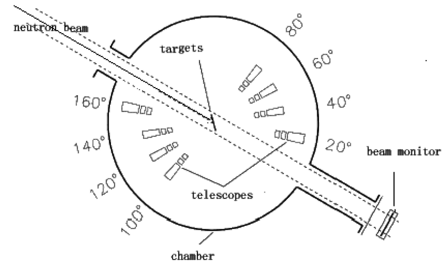

Fig. 1. Schematic view of the reaction chamber.

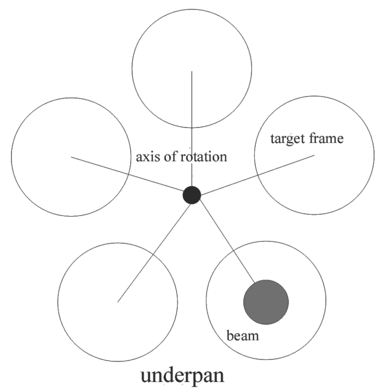

Fig. 2. The structure of the rotational target frame system.

Eight telescopes are mounted on the bottom plate of the chamber. The angle interval is 20°, covering the scattering angles from 20° to 160°. The telescopes are mounted in two sets which can cover both the forward and the backward hemispheres, and they are mounted on eight rails, thus the position of the telescopes and the distance between the target and the detector can be adjusted in the range from 16 cm to 32 cm. The centre of the telescopes is at the same height as the beam axis and the centre of the target. All the telescope rails are installed on a turnable plate. The rotation of the bottom plate can be controlled outside, without breaking the vacuum during operation.

The vacuum is better than 10^{-6} mbar during the experiment. All operations inside the vacuum chamber, i.e., changing the target sample, calibration with an alpha source, or rotation of the telescope table, can be made without breaking the vacuum.

2.3 The telescopes

In order to suppress the background and obtain a good PID for light charged particles over an energy range from a few MeV up to 100 MeV. The ΔE-ΔE-E techniques have been used. A schematic view of the detector arrangement for the telescope is shown in Fig. 3.

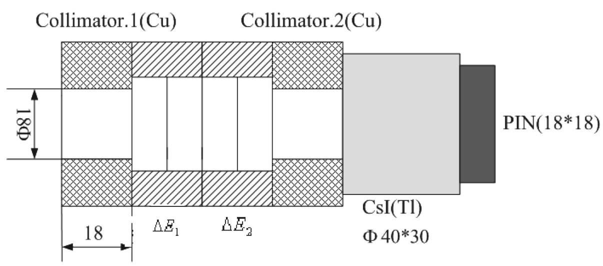

Fig. 3. Detailed structure of the telescope.

Each telescope consists of two ΔE detectors and one E detector. The ΔE detectors are fully depleted standard ORTEC silicon surface barrier detectors, while the thickness is 25 or 50 μm for the first (ΔE_1) and 50 or 500 μm for the second (ΔE_2). They all have a sensitive area of 450 mm^2. CsI(Tl) crystals are used as E detectors because of several superior properties, e.g., high light conversion yield and high density, which makes them very efficient as stopping medium for various charged particles. Furthermore, the crystals are only slight hygroscopic and relatively easy to handle. The E detectors were used with a diameter of 40 mm and a length of 30 mm, which is a sufficient thickness to stop 100 MeV protons.

Photodiodes (PD) of the Hamamatsu S3204-08 (25.5 mm×25.5 mm) model were chosen to read out the light from the CsI(Tl) crystals. The spectral response function of a PD matches well the emission spectrum of the crystal, and they are very compact and thus well suited for an application where space is limited.

3 Experimental tests and results

The chamber system has been machining finished in August, 2006. To investigate the characteristics of the chamber, the vacuum of the chamber, the precision of the rotational target frame and the performance of the telescopes, etc., have been tested.

The vacuum in the chamber can reach 7×10^{-6} mbar in one hour. The precision of the distance between the E detector of the telescope and the target centre can be controlled better than 0.3 mm, and the detection angle can be controlled better than 0.5°. The energy resolution of the ΔE detector for the α particles from ^{241}Am is better than 0.5%, while the E detector (CsI(Tl) crystal coupled to a Phillips XP2020 PMT) for the 662 keV γ-rays from a ^{137}Cs source is better than 10% (FWHM). Meanwhile, three pulse-shape-discrimination (PSD) methods were applied to study the PID for CsI(Tl) crystal, especially for the PID of light charged particles. Good PID has been obtained.

4 Conclusion

A facility has been constructed for research of (n, x) reactions induced by intermediate neutrons based on the white neutron source and quasi-monoenergetic neutron source which will be provided by the upgrade of the HI-13 Tandem Accelerator at CIAE. The facility has been tested and shows good capability for light charged particle energy spectra measurement.

With this facility, the (n, x) reactions, the (n, f) reactions and the light charged particles emission induced by other projectiles can be investigated. This will greatly improve our capability for research of neutron induced nuclear data at intermediate energy.

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