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Loss of the associated α-particles in the tagged neutron generators

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ABSTRACT

The reported loss of α-particles in the 14 MeV tagged neutron generators has been investigated using two neutron generators equipped with α-particle counters and two neutron detectors. One neutron detector was put right in the middle of the tagged neutron cone and another one was put outside the cone. By measuring the difference between double (neutron–neutron) and triple (α-neutron-neutron) coincidences it is possible to deduce the α-particle loss since the number of triple coincidences should be equal to the number of double coincidences. In all measurements performed a deficit of triple with respect to double coincidences has been observed. This deficit was smallest for the threshold of α-particle Constant Fraction Discriminator (αCFD) being 0 and maximum allowed voltage of α-particle detector being -1.7 kV. The smallest measured deficit value was equal to $13 \pm 1\%$. From the observed results it was concluded that the deficit was due to a number of non-detected α-particles that loose sufficient quantity of energy while traveling to the detector because of collisions with particles present in the neutron tube and/or in the tritium target. These α-particles will not be detected as they fall under the threshold of αCFD discriminator. Magnetic fields present in the system worsen the situation since they are forcing α-particles to travel larger distances because of toroidal movement and undergoing additional collisions. Tagged neutron technique has many kind of applications and it is particularly important for high accuracy nuclear cross-sections measurements when α-particles losses must be carefully assessed.

1. Introduction

The 14 MeV neutrons are produced by using $d+t \rightarrow n+\alpha$ reaction ($Q=17.590$ MeV) having a pronounced peak in the cross section for deuteron bombarding energy around 100 keV. Usually deuteron beam is impinging on TiT target resulting in isotropic emission of neutrons in the center of mass.

The detection of neutron beam and associated α-particles ($E_\alpha=3.5$ MeV) emitted in a corresponding solid angle defines the so-called “tagged neutron beam” which allows time-of-flight analysis and significant electronic reduction of background in the studies of the neutron induced reactions [1]. The “tagged” neutrons interact with the interrogated object and can produce γ-radiation and/or neutron radiation by allowing the non-destructive chemical analysis of the interrogated object at the position of interest, usually with 5 cm space resolution. This approach is typically used for material identification in neutron screening systems developed recently for passenger luggage [2], airplane [3] and sea containers [4,5] screening.

For most of the 14 MeV neutron applications, and especially for cross sections determination, it is necessary to make a neutron flux measurement. In addition, the neutron flux has to be monitored due to tritium consumption over the time. For the tagged neutron accelerators it is assumed that number of neutrons could be deduced from the counting rate of the α-particle detector after the correction for the geometrical efficiency. However, in some experiments performed with triple (α-neutron-neutron) and double (neutron–neutron) coincidences, the α-particle deficit was noted. The experiment in which 15% of the alphas were not counted had a set-up including a plastic scintillator located in the cone of the central α-detector pixel and another plastic scintillator located about 50 cm away from the first detector and at the 45° angle with respect to the line between the neutron production spot in the generator and the first detector. Simple kinematics of elastic neutron–proton scattering shows that at the angle of 45°, the neutrons arriving at the second detector should have energy of the 7 MeV. By measuring the triple coincidences between the alpha pulse and the detection of neutron in each of the detectors, the coincidence rate between detectors for which there was an alpha pulse was determined. The double coincidences rate included coincidences between the two neutron detectors only. The

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ratio of the triple coincidence rate to the double coincidence rate was 0.85.

The same measurements were repeated by Mihalczo at al. [6]. However, as the neutron source they used two completely different designs of API d+t generators produced by Thermo Fischer; one was API-120 neutron generator and another one was produced in 1990s and contained focusing lens. Both neutron generators had alpha particle detectors made of thin ZnO coating, over-coated with a very thin layer of aluminum to stop scattered deuterons, tritons and light produced on the fiber optic face plate. The results for the ratio of the triple to double coincidence rate were 86% and 85%, respectively.

The above described experiments showed 14%–15% deficit in alpha particles, counted independently of the type of generator or α-particle detector used. We decided to look into this problem with two different experimental set-ups using API-120 and 300 keV Cockcroft–Walton accelerator, respectively. The results are showed in this paper.

2. Experimental set-up

The experimental set-up with API-120 neutron source is shown in Fig. 1. The neutron source API-120 (acquired from ThermoElectron) was equipped with YAP(Ce) α-particle detector with crystal thickness of 0.5 mm and diameter of 19 mm. One side of the crystal is coated with 1 mg/cm^2 of silver in order to avoid impact of low energy particles (mainly electrons). Crystal is attached to inner side of the fiber optic plate (FOP) 7.5 cm distant from tritium target, while the photomultiplier tube (PMT) was attached at the outer side of FOP. YAP(Ce) with FOP and PMT are the components of the alpha particle detector assembly.

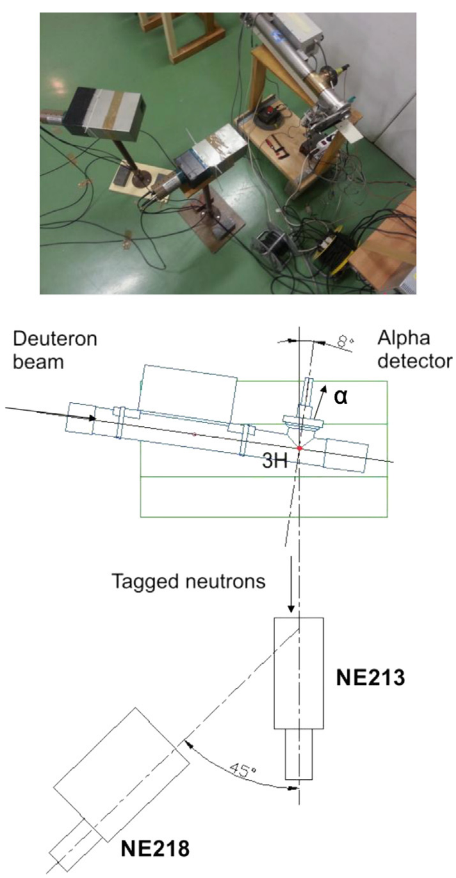

Fig. 1. Experimental set-up with API-120.

The axis of the neutron accelerator tube, along which the deuterons are accelerated, has been inclined for 8° in order to place the neutron detector, the 3“ × 3” NE213, precisely inside the cone of tagged neutrons at the position of neutrons maximum intensity (Fig. 1). The second neutron detector, the 3“ × 3” NE218, was placed outside the tagged neutron cone under an angle of 45° with respect to the cone axis. The distance between two neutron detectors was 50 cm, the same as the distance between detector NE213 and tritium target inside the API-120.

Experimental set-up on Cockcroft–Walton accelerator is shown in Fig. 2. At the end of the beam line there is a tritium target position. The alpha detector, the YAP(Ce), has crystal thickness of 1 mm and diameter of 19 mm. It was placed under the angle of 53° with respect to the incident deuteron beam at the distance d=21 cm from tritium target. The crystal which is attached on safire window placed in CF63 flange has the PMT Hamamatsu R1450. The first neutron detector, the 3” × 3” NE213, was placed at the distance of 160 cm from the tritium target. At this distance the horizontal tagged neutron beam radius (FWHM) is 16 ± 3 cm, as shown in Fig. 4. The vertical profile has similar shape. The second neutron detector, the 3” × 3” NE218, was placed outside the cone of tagged neutron beam under the angle of 45° with respect to cone axis, 50 cm distant from the detector NE213 (as in set-up with API-120). The deuteron beam energy was 100 keV.

The electronics set-up used in both measurements are shown in Fig. 3. The NE213 output pulse was a START pulse for nnTAC, measuring coincidences between two neutron detectors and it was also a START pulse for α-TAC, measuring the coincidences between NE213 and alpha detectors. SCA outputs from both TACs were taken to an AND gate generating trigger signal for the computer A. Output from nnTAC was split into the computer A, being triggered by triple coincidences and computer B triggered by double coincidences. Double coincidences were coincidences between two neutron detectors; triple coincidences were coincidences between two neutron detectors and an alpha detector. Each computer had ADC card with four inputs so four signals were measured simultaneously by each computer: output from nnTAC, output from α-particle detector, output from NE213 and output

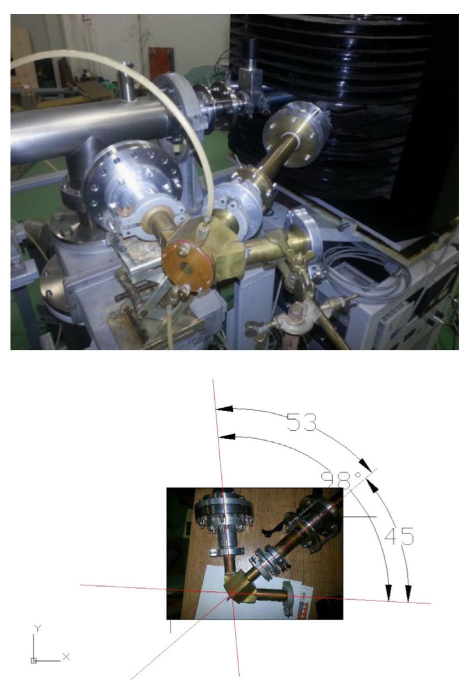

Fig. 2. End of Cockcroft–Walton accelerator beam line with water cooled tritium target and associated alpha detector chamber.