On-Line Test Experiments on the Detection of α-Emitting ER Collected by Catcher Foils

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INTRODUCTION

We proposed to carry out a set of measurements of absolute production cross sections for Po to Th nuclei formed in very asymmetric complete fusion reactions \cite{1}. The aim of experiments is to obtain reference cross section data for the analysis of the fusion probability in less asymmetric and (nearly-) symmetric projectile-target combinations leading to (close) the same compound nuclei and deriving fission barrier heights with the standard statistical model analysis. We intended to use the detection of α-particles of evaporation residues (ER) collected by a catcher foil installed just behind a target \cite{1,2}.

EXPERIMENTS

In the first runs with the XTU-tandem accelerator we attempted to follow scheme early used in experiments of the ANU group, which implied the detection of α-particles in backward angles by an annular detector in pauses between beam pulses \cite{2}. Unfortunately, we could not realize it because of the insufficient beam rejection by a chopper system of the accelerator.

In following runs, studying the \(^{16}\text{O} + ^{194}\text{Pt} \rightarrow ^{210}\text{Rn}\)\footnote{The examples of α-spectra recorded in both the configurations are shown in fig. 2. Both runs were carried out at the \(^{16}\text{O}\) beam energy \(E_b = 100\) MeV using the Al catcher foil of 2.85 mg/cm\(^2\) of thickness. The upper panel (fig. 2a) presents the α-spectrum obtained in the run with six successive cycles of “collection–detection” in the configuration a), whereas the bottom panel (fig. 2b) shows}reaction, we tested the arrangements schematically shown in fig. 1. The upper part of the figure (fig. 1a) corresponds to the experiments performed in the regime of “ER collection – α-detection”, when the beam is switched-on and switched-off 10 minutes in duration. This regime allows effectively collecting and detecting α-radioactive Rn nuclei with a half-life \(T_{1/2} < 5\) min. A \(^{194}\text{Pt}\) target together with a catcher were installed at some angle to the beam direction that allowed reducing in energy losses of α-particles escaped at about right angle to a catcher foil. A solid angle subtended by a semiconductor surface-barrier detector (SSBD) placed 6.5 cm away from the target-catcher position at a backward angle to the beam was \(\sim 0.8\%\) for α-particles emitting in 4π.

Figure 1b corresponds to the experiments performed with the Al rotating catcher foil installed behind a target, at a short distance from it. Collected ER are continuously transported to the protected detection area, where their α-particles are registered by SSBD installed at about the same distance from the catcher plane as in the previous case. That corresponds to about the same geometrical efficiency for the caught portion of ER placed in front of SSBD, if the rotation time \(T_{\text{rot}} \ll T_{1/2}\) of products. This condition is fulfilled in our experiments for Rn nuclei produced in the \(^{16}\text{O} + ^{194}\text{Pt}\) reaction.

Both systems were supplied with four monitor detectors looking at the target at some forward angle. That allowed the transformation of observed α-counts into ER cross sections using elastically-scattered beam-particle counts recorded with the monitors.

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\textbf{Fig. 1. Schematic view on the configuration of α-decay measurements for ER produced in the \(^{16}\text{O} + ^{194}\text{Pt}\) reaction. a) ER are collected by a fixed catcher foil with the following detection of α-particles at a backward angle in the regime of “ER collection – α-detection”. b) ER are continuously collected and delivered to the detector by a rotating catcher foil installed at a short distance from a target.}
a similar spectrum recorded in the configuration b) (see fig. 1). ER produced in the reaction (designated in the upper panel) were identified according to the energies of α-particles and rough decay curves measurements carried out just after the end of the run.

**DISCUSSION**

As one can see in fig. 2a, positions of maxima of α-peaks are shifted to lower energies by ~0.3 MeV relatively to the values tabulated for identified nuclei [3]. These shifts are designated by the “left” (observed) and “right” (tabulated) vertical arrows connected by horizontal lines in the figure. In the case of the rotating catcher losses in α-energies is somewhat greater (see fig. 2b) because of a longer path for escaped α-particles. Widths of peaks allow to resolve the neighbor degraded α-lines of $^{205}$Rn and $^{204}$Rn (6.261 and 6.419 MeV original α-energies, respectively [3]) using a standard LSM-procedure with a Gaussian form for α-peaks. Note that the width of α-peaks observed with the rotating catcher (FWHM=136 keV) is somewhat greater than a similar value obtained with the fixed catcher (FWHM = 122 keV). Both the width values are lower than a similar one estimated from α-spectra obtained in the $^9$Be + $^{209}$Pb reaction with a pulsed beam (FWHM ~ 170 keV) [2] and are comparable with the values obtained in the off-line $^{12}$C + $^{209}$Bi catcher experiments [4].

The applicability of catcher techniques considered above is limited by the life time of producing nuclei. A scheme like shown in fig. 1a is suitable for ER α-activities with $T > 1$ min, when off-line measurements are unreasonable. A scheme with a rotating catcher can be applied for the detection of ER with $T > 1$ ms. Other limitation in use of a catcher technique is a low geometrical efficiency for the α-particles detection, which has to be accepted to obtain a better resolution. This value can be increased up to ~5 % without significant losses in resolution as show TRIM simulations [5]. In the case of a rotating catcher the higher geometrical efficiency can be accompanied by a number of detectors installed at the periphery of a catcher disk. TRIM simulations [5] of ER ranges and of α-energy degradation corresponding to a specified geometry of measurements seems to be useful in the further data analysis [6].

A doubtless preference of catcher foil technique is a 100 % ER collection efficiency in the case of use a thin target. This circumstance is important in the absolute cross section measurements for ER produced in fusion reactions. In our previous studies of fusion reactions leading to Ra and Fr nuclei [7], with the electrostatic deflector (ED) [9] we encountered with a two-humped dependence of the ER yield as a function of high voltage applied to the deflector. Such dependence is due to the presence of two components (equilibrated and non-equilibrated ones) in charge-state distributions of heavy recoil atoms of ER [10]. So experiments with ED on the measurement of ER excitation functions need in scanning of a high voltage at each beam energy, since the behavior of the yield cannot be evaluated a priori due to an unpredictable behavior of the non-equilibrated component of ER atoms with a beam energy [10,11]. The absolute cross section experiments with ED also need in measurements of angular distributions for ER to obtain integral cross sections. So with an improvement of background conditions and with an increase in the detection efficiency, a catcher foil technique could be applicable for absolute cross section measurements of ER produced in fusion reactions.

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