Search for Proton Radioactivity in $^{65}$As, $^{69}$Br and $^{77}$Y

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A search for proton radioactivity in $^{65}$As, $^{69}$Br and $^{77}$Y, produced as residues of fusion reactions, was carried out at the Orsay Tandem accelerator. The residues were collected at the image point of the spectrometer Soleno and implanted into the gaseous medium of an ionization chamber which was also used to detect the radioactivity protons. No such protons have been observed in the energy range of 250–600 keV and in the half-life interval of 10 μs–100 ms, within a production cross section sensitivity of 1 μb.

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1. Introduction

Proton radioactivity was recently discovered at Darmstadt and confirmed at Munich. Five nuclei with mass number greater than 100, i.e., $^{109}$I, $^{113}$Cs, $^{147}$Tm and $^{150,151}$Lu, have been found to be proton emitters in their ground state. Their half-lives range from a few microseconds to tenths of milliseconds and the energies of the emitted protons lie around 1 MeV. The last review on the subject is given in [1].

Because proton radioactivity is expected to be a general phenomenon for the most exotic nuclei located all along the proton rich side of the nuclear chart, we proposed to search for such a radioactivity in some nuclei in the neighbourhood of the mass number $A = 70$. In particular, we selected, in a first stage, the following nuclei: $^{65}$As, $^{69}$Br and $^{77}$Y, which are the proton richest nuclei obtainable by fusion $p2n$-evaporation reactions with $N = Z$ targets and projectiles. Indeed, experiments have been already performed for the search of proton radioactivity in $^{69}$Br [2] and $^{77}$Y [3] and others were announced in the case of $^{65}$As and $^{69}$Br [4] nuclei. Such investigations are promising since the last compilation of Wapstra et al. [5] for the atomic masses shows that most authors predict $^{65}$As, $^{69}$Br and $^{77}$Y as the heaviest of As, Br and Y isotopes to be unstable against $p$ radioactivity. We report in Table 1 the predicted proton separation energies which are mostly negative, reflecting thus a possible instability against $p$ emission.

The coulomb and centrifugal barriers brought into play in proton emission by $A = 70$ nuclei are so low that, in case of $p$ radioactivity, the kinetic energy of the emitted protons falls in the range of 300–500 keV corresponding to half-lives up to tenths of milliseconds. The main feature of the experiment de-

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<tr>
<td>$^{65}$As</td>
<td>+0.039</td>
<td>+0.079</td>
<td>-0.181</td>
<td>-0.011</td>
<td>-0.261</td>
<td>-0.321</td>
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<tr>
<td>$^{69}$Br</td>
<td>-0.111</td>
<td>-0.131</td>
<td>-0.531</td>
<td>+0.029</td>
<td>-0.661</td>
<td>-0.631</td>
<td>+0.009</td>
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<tr>
<td>$^{77}$Y</td>
<td>-0.251</td>
<td>-0.221</td>
<td>-0.781</td>
<td>-0.171</td>
<td>-0.981</td>
<td>-0.721</td>
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scribed in the present paper is to be the first one in which a detection sensitivity to this energy range was reached. The fact that the previous attempts to explore the region of $A \approx 70$ were made with a high $p$ energy threshold ($\geq 450$ keV) strongly supports the aim of the present study.

2. Experimental Procedure

The $^{65}$As, $^{69}$Br and $^{77}$Y nuclei were produced by fusion evaporation reactions, namely, $^{40}$Ca($^{28}$Si, $p$ 2$n$), $^{40}$Ca($^{32}$S, $p$ 2$n$) and $^{40}$Ca($^{40}$Ca, $p$ 2$n$). Beams of $^{28}$Si, $^{32}$S and $^{40}$Ca were obtained at the 15 MV Orsay Tandem accelerator. A natural self-supported Ca target of 750 $\mu$g/cm$^2$ was used. The fusion evaporation products were collected in the focal point of the superconducting solenoidal coil Soleno [6] operating at zero degree with respect to the beam, while a good rejection for scattered projectiles of higher magnetic rigidity was obtained. The large angular acceptance of Soleno ($3 \sim 10^\circ$) well adapted to the angular distribution of the fusion products allows an absolute collection efficiency of the order of 0.03-0.05 [7]. The collection time is equal to the time of flight (100-200 ns) of the ions along the distance separating the target and the detector which was placed in the image point of Soleno. The collected fusion products were implanted in the same detector destined to detect the expected radioactivity protons, because these protons of low energy cannot escape the medium of implantation of the emitting ions.

Although the collection with Soleno of fusion evaporation products was ideal with regard to many aspects, nevertheless, there were two major difficulties left:

- at Tandem energies, the energy and charge state distributions are broad; as a consequence, the magnetic rigidity of unwanted abundant fusion products, e.g., those corresponding to $2pn$, $3p$, ... evaporation are collected in the same way than the expected proton radioactive nuclei. The ratio of non radioactive products to radioactive ones is expected to be of the order of $10^5$.
- as the great part of the collected ions are $\beta$-emitters, there is a tremendous $\beta$-background at low energy, extending to around 500 keV in Si detectors, even in the thinnest ones, and to some tenths of keV in gaseous detectors; this fact made the use of Si detectors unacceptable in our experiment and lead us to construct and set up an ionization chamber whose gaseous medium served to implant heavy ions as well as to detect the emitted protons. The problem of detecting the very low amplitude signals of protons in the tail of high amplitude heavy ion signals was solved by using an especially built electronic rejection circuit placed after the preamplifier [8].

The ionization chamber was cylindrical and of axial electric field. Its anode was divided into three concentric compartments (Fig. 1). A 100 $\mu$s square-shaped pulsation of the beam was used.

Off-beam signals delivered by the ionization chamber were expected to be due to (see Fig. 1):

1) the radioactivity protons of 300-500 keV, which are searched for. The gas pressure in the chamber was chosen so that they would have ranges of 2-4 cm and hence loose their total energy in the gas, giving peaks in the energy spectrum. They should be detected either in the single energy spectrum $E_1$ of anode $n^o$ 1 or in the coincident energy spectrum $E_1 + E_2$ of anodes $n^o$ 1 and 2.

2) the well-known delayed protons [9-13] of energy ranging from 1 to 3 MeV originating from $^{65}$Ge in case of $^{40}$Ca($^{28}$Si, $2pn$) reaction, from $^{69}$Se in case of $^{40}$Ca($^{32}$S, $2pn$) and from $^{77}$Sr in case of $^{40}$Ca($^{40}$Ca, $2pn$). These protons of relatively high energy cross the gaseous medium of the chamber without stopping and give a broad signal $\Delta E$ in the energy spectrum. A large amount of them contributes to the coincident energy spectrum $E_1 + E_2$.

3) the $\alpha$-particles of the natural radioactivity originating in the construction material of the chamber. These enter the gaseous medium with energies up to...