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Nuclear Physics A734 (2004) 196–199

NUCLEAR PHYSICS A

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In–Flight Separation and Mass Selection of Heavy Evaporation Residues.

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Aiming at an increase in the identification ability and higher sensitivity in the experiments on the synthesis and study of the decay properties of superheavy nuclei, the separator VASSILISSA has been upgraded. After preparatory experiments, the experiment aiming at the synthesis of the isotope $^{283}112$ in the reaction ^{48}Ca + ^{238}U was performed. The obtained results on the decay mode, half-life and production cross-section are in agreement with those obtained in our first experiment.

1. INTRODUCTION

Decay properties and formation cross sections of the isotopes $^{277}110$, $^{283}112$ and $^{287}114$ were studied in 1998 - 1999 employing high intensity ^{48}Ca beams and ^{232}Th, ^{238}U, ^{242}Pu targets [1–3] using the electrostatic separator VASSILISSA [4].

Aiming at the continuation of the experiments on the synthesis and study of decay properties of superheavy nuclei the separator VASSILISSA was upgraded: the old 8° bending magnet behind the separator was replaced with a mass analyzer, based on a 37° dipole magnet, which together with new time–of–flight and focal plane detectors provides the mass resolution at the level of 1.5 -2 % for heavy nuclei with A≈300. Ion optical calculations and the mass evaluation method are described in [5].

2. EXPERIMENT

VASSILISSA together with the new mass analyzer was tested with a number of complete fusion reactions induced by heavy ions. Evaporation residues produced in reactions between ^{40}Ar and ^{164}Dy, ^{208}Pb targets, as well as $^{44,48}Ca$ and ^{174}Yb, ^{178}Pt, $^{204,206,208}Pb$ targets, were used in the analysis. Results of the tests are presented in [6–8].

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0375-9474/$ – see front matter © 2004 Published by Elsevier B.V.
doi:10.1016/j.nuclphysa.2004.01.033

In the test reactions nuclei were identified according to known decay properties using ER - α or ER - SF correlation analysis. From measured positions of the ER's implantation into the focal plane (detector strip number) and its time-of-flight Bρ and v were calculated. Than using these values the corresponding A/Q rations were obtained for each event. From these ratios, for known masses, ion charge distributions of implanted ER's were derived [8]. The results obtained for ^{217}Th and ^{254}No ER's are shown in Fig. 1.

In December 2002 – February 2003, we repeated the experiment performed in February - March 1998 [2] aiming at the synthesis of the isotope ^{283}112. Historically, it was the first experiment with a positive result, focused on the synthesis of superheavy elements in ^{48}Ca induced reactions. Thus the reproduction of the data obtained 5 years ago using more advanced technique seemed to be of great importance. In the improved background conditions we also planned to determine the mass of this isotope, which could help us to make more definite conclusions on the nature of the observed SF-activity. An additional reason was the non-observation of any events in the reaction ^{48}Ca + ^{238}U $\rightarrow$ $^{286}112^*$ studied with the BGS separator at Berkeley and reported in [9].

Depleted ^{238}U was used for the preparation of targets. Targets of U_3O_8 with average uranium thicknesses of (350 $\pm$ 10) μg/cm^2 were fabricated by electroplating the material onto 0.74 mg/cm^2 Ti backing foils. The projectile energy was varied by extracting the beam from the appropriate radius of the U400 cyclotron. The accuracy of the absolute beam energy determination was checked using the magnetic spectrometer MSP144 [10] and was about 0.5 % at the level of 243 MeV. The upgraded VASSILISSA provided an additional suppression of unwanted reaction products by the factor of about 100. At a beam intensity of $\sim 4{\cdot}10^{12}$ 1/s, the total counting rate of all events at the focal plane detectors was 5–10 1/s.

3. RESULTS

The U target irradiation started at the beam energy $E_{1/2}$ = 230 - 231 MeV in the middle of the target, which was close to that used in the previous experiment [2]. During a period of 29 days a beam dose of 5.9×10^{18} projectiles was collected.

No SF events were detected during this irradiation. Possible decay chains of the $\mathrm{ER}\xrightarrow{E_{ER},t_{ER}} \alpha_1 \xrightarrow{E_{\alpha_1},t_1} \alpha_2 \xrightarrow{E_{\alpha_2},t_2} \cdots$ type were searched for within time intervals 5 μs$\leq t_i \leq$ 1000 s and 8 MeV $\leq E_\alpha \leq$13 MeV. No such decay chains were found during this irradiation. This corresponds to the upper cross-section limit of 2.2 pb at a confidence level of 68 % at the beam energy $E_{1/2}$ = 230 - 231 MeV.

In the second irradiation the energy of bombarding ions was increased up to $E_{1/2}$ = 234 MeV, which resulted in the excitation energy of the compound nucleus ^{286}112 E^* = 35.5 MeV. During a period of 15 days a beam dose of 4.7×10^{18} projectiles was collected. Two spontaneous fission events were detected in this irradiation. The first event was measured in the strip number 12 and the second - in the strip number 32. The higher strip numbers correspond to the higher magnetic rigidity of ions which passed the 37° deflection magnet.

In the correlation analysis of possible decays of the $\mathrm{ER}\xrightarrow{E_{ER},t_{ER}} \alpha_1 \xrightarrow{E_{\alpha_1},t_1} \cdots \mathrm{SF}\xrightarrow{E_{f_1,f_2},t_{SF}}$ type the closest recoil-like signals were found at τ_1 = 180.5 s before the first SF-event (position difference Δy_1 = 0.6 mm) and at τ_2 = 1459.5 s (Δy_2 = 0.8 mm) before the

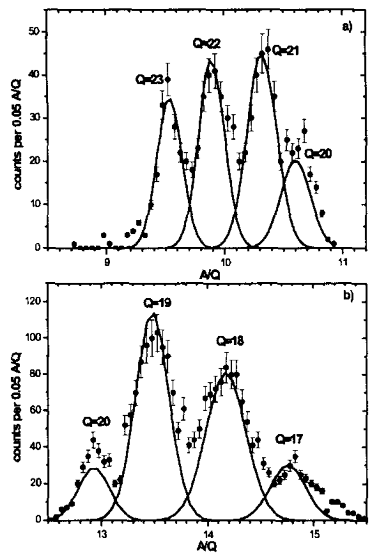

Figure 1. A/Q-distributions: a) of ^{217}Th; b) of ^{254}No ER's. Derived charge states are indicated.

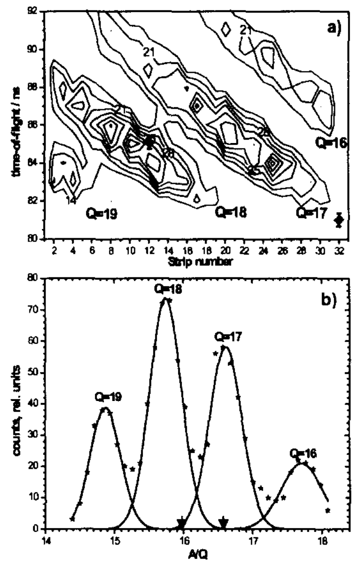

Figure 2. "Positions" of the observed events on the "strip number – TOF"-plane a) and derived A/Q-ratios b), together with computer simulated distributions of ^{283}112 after passing through VASSILISSA separator.

second one. No other recoil-like or α-like signals were found in the time interval up to 10^4 s. Fig. 2-a shows "positions" of the observed events on the "strip number – TOF"-plane together with a computer simulated distribution of ^{283}112.

We performed mass determination of SF activities observed in the ^{48}Ca + ^{238}U reaction according to the described procedure. Positions of the implanted ER's on the focal plane were converted into magnetic rigidities Bρ. Combining the Bρ values with the corresponding times of flight we derived the ratios $A_1/Q_1 = 16.0$ for the first event and $A_2/Q_2 = 16.6$ for the second one. These values are marked with arrows in Fig. 2-b. The distribution of A/Q-ratios expected for ^{283}112 is also shown. Taking into account that charges and masses must be integer numbers, we can find the most probable charge states Q_1=18, Q_2=17 and the masses $A_1 = 288$, $A_2 = 282$. Clipping the upper mass limit by the mass of the compound nucleus $A_{CN} = 286$, we obtain the mass interval $280 \leq A \leq 286$.

4. SUMMARY

This result first of all indicates that the observed nuclides belong to the region of superheavy nuclei and their masses are close to those expected for the complete fusion products of the reaction ^{48}Ca + ^{238}U. Thus, the products of transfer reactions can be excluded from the consideration.

The mean value of the two measured time intervals together with four previously measured events [2,3] results in a lifetime of 445^{+305}_{-130} s or the half-life $T_{1/2} = 310^{+210}_{-90}$ s, which coincides well within error bars with reported earlier values. No α-decays were observed in all performed experiments.

The cross-section calculated from the observation of two fission events at the beam energy of $E_{1/2}$ = 234 MeV in the half-thickness of the target is $3.0^{+4.0}_{-2.0}$ pb. Earlier we reported [2] the value of $5.0^{+6.3}_{-3.2}$ pb. The difference between the beam energy at which the SF events were observed in the described experiment and the beam energy in the experiment performed 5 years ago [2] can be explained by an uncertainty of the absolute energy measurements and/or the use of different backing foils for the targets support.

In the experiment on chemical isolation of element 112 produced in the ^{48}Ca + ^{238}U $\rightarrow$ $^{286-x}$112 + xn reaction performed at Dubna in 2001 [11], highly volatile SF activity was observed. The calculated formation cross-section of detected activity was $2.0^{+0.9}_{-0.7}$ pb.

Chemical properties of element 112 also synthesized in the ^{48}Ca + ^{238}U reaction were investigated in 2003 at the GSI (Darmstadt) [12] using a cryogenic detector. Condensation of the SF activity attributed to element 112 was observed at a very low temperature. The reported production cross-section of about 3 pb is in agreement with the results, obtained at VASSILISSA and in the chemical experiment at Dubna.

The non-observation of any events in the reaction ^{48}Ca + ^{238}U $\rightarrow$ $^{283}112^{*}$ at the beam energy $E_{1/2}$ = 231 MeV [9] can be probably explained by the improper absolute beam energy value or/and by the choice of the separator BGS field settings according to the calculated mean charge of ER's in helium, which has an unexplainable deviation from the known systematics.

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