Production and decay of element 114: high cross sections and new nucleus ^{277}Hs*

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Introduction

Discoveries of new superheavy elements (SHE) were reported from FLNR, Dubna, Russia [1], including observations of element 114 isotopes produced in the ^{48}Ca+^{242,244}Pu reactions. Successful independent studies of some of the reactions studied in Dubna were reported [2,3], most recently also the observation of one atom each of ^{286,287}114 produced in the ^{48}Ca+^{242}Pu reaction at LBNL [4]. Predictions on the existence of an "island of stability" in the region of SHE have substantiated, despite the small number of observed events in every confirmation experiment. All successful confirmation experiments reported cross sections lower than those from FLNR by factors of two or more. Nevertheless, these cross sections are unexpectedly high compared to extrapolations from lighter systems [5], and intriguingly constant over a large range of 112≤Z≤118. A thorough understanding of the underlying production mechanism is still missing; location and extension of the "island of stability" in the region of spherical SHE is still far from being established. To help shedding more light on these problems, a ^{48}Ca+^{244}Pu experiment was performed at the gas-filled TransActinide Separator and Chemistry Apparatus (TASCA) [6,7], which was optimized for the study of ^{48}Ca-induced fusion reactions with actinide targets. TASCA's efficiency for this nuclear reaction type is currently unsurpassed.

Experimental

The UNILAC accelerated a pulsed ^{48}Ca beam (~2•10^{12} s^{-1}), which passed through $^{244}PuO_2$ targets (average thickness: 438 μg/cm^2 ^{244}Pu). Beam energies inside the targets were 241.3-246.2 MeV (E*=39.8-43.9 MeV; hereafter referred to as 42-MeV run) and 236.4-241.0 MeV (E*=36.1-39.5 MeV; 38-MeV run). 2.44•10^{18} (42-MeV run) and 1.15•10^{18} (38-MeV run) projectiles passed through the targets. Nuclear reaction products entered TASCA, operated in "high transmission mode" [7], and were separated in 0.8 mbar He gas. The detection system consisted of a Multi Wire Proportional Counter (MWPC) and a focal plane detector box (FPDB). The FPDB consisted of a Double Sided Silicon Strip Detector (DSSSD; pitch size: 1 mm; 144 vertical / 48 horizontal strips) and Single Sided Silicon Strip Detectors (SSSSD) mounted perpendicular in the backward hemisphere of the DSSSD [8]. The MWPC provided a signal for ions recoiling from the target and allowed distinguishing these from radioactive decays of species implanted in the DSSSD. The energy resolution of the FPDB was 25 keV FWHM for 8.1 MeV α-particles fully stopped in the DSSSD and 170 keV for α-particles that deposited a fraction of their energy inside the DSSSD and the remainder in the SSSSD. The detection efficiency was 72% for α-particles and 100% for SF. The efficiency for focusing element 114 EVRs into the DSSSD was (60±6)% [9]. Data acquisition was triggered by events registering more than 300 keV in the DSSSD or more than 500 keV in a SSSSD. More details are given in [10,11].

Results

We searched for decay chains from ^{288,289}114 and their daughters [1]. Upon identification of a chain, additional α-particles occurring in the same pixel as the chain, in between registration of the EVR and the terminating SF, were searched. Due to a damaged target, the background rate was increased during portions of the runs. SFs terminating decay chains recorded during these periods were required to occur outside beam pulses. Based on the event rate only 0.02 (^{289}114) and 0.05 (^{288}114) random chains from unrelated background events were expected. The search yielded nine EVR-α-SF chains (^{288}114) and four EVR-α-α(-α)-SF chains (^{289}114). Ten chains were measured in the 42-MeV run and three chains in the 38-MeV run (Figs. 1 and 2). The agreement of our data (Table 1) with that of [1] is good in all cases except for chain #9. The data measured for the EVR, the first, and the second α-particle suggest assigning chain #9 to ^{289}114→^{285}112→ ^{281}Ds. ^{281}Ds then decayed by emission of a (8.727±0.025)-MeV α-particle 5.688 s after the decay of ^{285}112, during the beam-off period, where background is low. ^{281}Ds has

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undergone SF in all ten previously observed decays [1] with $T_{1/2}=11.1^{+5.0}_{-2.7}$ s. Based on background rates, the probability to register an α-like event with properties as exhibited by the observed one is only 0.1%. We thus assign it to a so far unobserved α-branch in ^{281}Ds. Considering this α-decay and the thirteen measured SF decays from [1] and our work, an α-decay branch b_α of 9^{+16}_{-7} % results after correcting for detection efficiency differences for α-decay and SF. The chain was terminated 4.5 ms later by SF of new ^{277}Hs.

The B•ρ of element 114 EVRs in 0.8 mbar He was measured to (2.29±0.11) T•m.

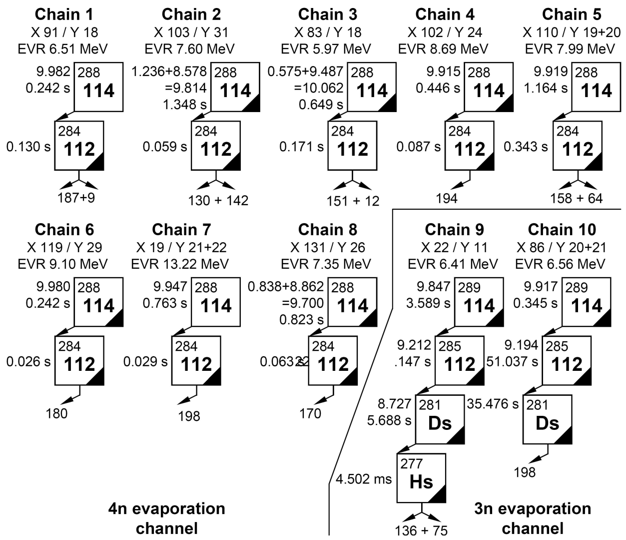

Figure 1: Decay chains assigned to ^{288}114 (chains 1-8) and ^{289}114 (chains 9, 10) observed during the 42-MeV run. A black triangle in the lower right corner of a box indicates that the beam was off at the time of the event.

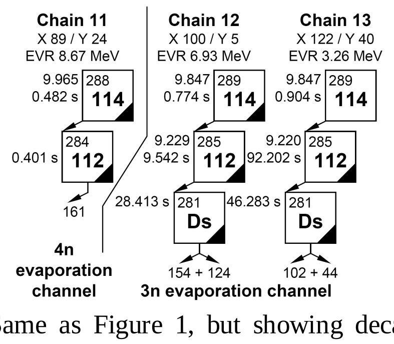

Figure 2: Same as Figure 1, but showing decay chains observed during the 38-MeV run.

Table 1. Decay properties ([1] and this work)

Isotope	Decay	$T_{1/2}$ (this work)	$T_{1/2}$ (combined)
^{289}114	α	$0.97^{+0.97}_{-0.32}$ s	$2.1^{+0.8}_{-0.4}$ s
^{288}114	α	$0.47^{+0.24}_{-0.12}$ s	$0.69^{+0.17}_{-0.11}$ s
^{285}112	α	30^{+30}_{-10} s	29^{+11}_{-6} s
^{284}112	SF	101^{+50}_{-25} ms	99^{+24}_{-16} ms
^{281}Ds	SF/α:91/9	20^{+20}_{-7} s	13^{+5}_{-3} s
^{277}Hs	SF	3^{+15}_{-1} ms	3^{+15}_{-1} ms

Discussion

Z=108 is a deformed proton shell closure in N~162 isotopes. The observed ^{277}Hs lifetime is short compared to half-lives of the Hs isotopes near the deformed N=162 shell closure, indicating reduced shell stabilization in the N=169 nucleus ^{277}Hs. Macro-microscopic model predictions of $T_{1/2}$(SF) for the neighboring isotopes are 46 ms (^{276}Hs) and 0.98 ms (^{278}Hs), the geometric mean being 6.7 ms [12]. This is similar to our observed lifetime. The odd neutron is expected to hinder SF decay significantly. Thus, the drop in $T_{1/2}$(SF) when increasing N above 162 may be more severe than suggested by [12]. ^{275}Hs (N=167) decays by α-particle emission with $T_{1/2}$=0.19 s [1]. The experimental trend with prevalent α-decay in Hs isotopes with N=157-167, but predominant SF in lighter as well as in heavier isotopes is close to that in [10], which suggests dominant α-decay from N=154 to N=166 but SF for N>168. This indicates that stability vanishes rapidly with increasing distance from N=162.

Measured cross sections in the 38-MeV run were $8.0^{+7.4}_{-4.5}$ pb (3n channel) and $2.8^{+4.2}_{-2.1}$ pb (4n channel), and in the 42-MeV run, $3.5^{+3.3}_{-2.0}$ pb (3n channel) and $9.8^{+3.9}_{-3.1}$ pb (4n channel). Error bars include statistical uncertainties only (68.3% confidence level); the systematic uncertainty is estimated to 14%. In contrast to any other confirmation experiment, we confirm the large cross sections as reported from FLNR [1]. In fact, our measured cross sections are higher than those reported from the DGFRS. These high cross sections call for investigations of the details of the production mechanism. Production rates that follow from these values encourage using this nuclear reaction to produce relatively long-lived isotopes of element 114, in particular for envisaged chemical investigations [13] or for γ-spectroscopic studies that allow shedding light on the nuclear structure in this SHE region and may facilitate unique Z identification.

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