NEW INSIGHTS INTO THE DISCOVERIES OF ELEMENTS 113, 115 AND 117

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The discovery of new higher Z elements and the determination of their decay properties provide important insights into our understandings of the behaviour of nuclear matter under extreme conditions of high Z and important tests of the prediction of an island of stability around N=184 and high Z (114 or even 120-126). The synthesis of odd-Z superheavy nuclei provides more detailed information than even-Z nuclei about the nuclear structure of these nuclides because of their longer decay chains as a result of strong fission hindrance caused by the unpaired nucleons. For the first time the Z=115 nuclei and their odd-Z decay products including Z=113 isotopes were observed in 2003 [1,2]. Three decay chains of $^{288}115 \rightarrow {}^{284}113 \rightarrow {}^{280}\mathrm{Rg} \rightarrow \ldots {}^{268}\mathrm{Db}$ and one decay chain of $^{287}115 \rightarrow {}^{283}113 \rightarrow {}^{279}\mathrm{Rg} \rightarrow \ldots {}^{267}\mathrm{Db}$ were discovered in the $^{243}\mathrm{Am}(^{48}\mathrm{Ca},3\text{-}4n)$ complete-fusion reaction. In 2006 two decay chains of the lighter isotope $^{282}113$ were synthesized in the $^{237}\mathrm{Np}(^{48}\mathrm{Ca},3n)$ reaction [3]. The discovery of element 117 [4,5] has been reported using the $^{249}\mathrm{Bk}+{}^{48}\mathrm{Ca}$ reaction; five decay chains of $^{293}117 \rightarrow {}^{289}115 \rightarrow \ldots {}^{281}\mathrm{Rg}$ and one chain of the heaviest isotope

$^{294}117 \rightarrow {}^{290}115 \rightarrow ... {}^{270}$Db were observed in 2009–2010. A relatively high stability of all these odd-Z activities is caused by the influence of presumably spherical nuclear shells at Z=114-126 and N=184. The sequential α decays of the isotopes ^{282}113, ^{287,288}115 and ^{294}117 lead to $^{266\text{-}270}$Db (N=161–165) that are already located in the vicinity of deformed nuclear shells at Z=108 and N=162.

For the synthesis and identification of these odd-Z nuclei, we used the Dubna gas-filled recoil separator that selects only complete-fusion-evaporation reaction products which are strongly forward peaked and suppresses the yield of transfer reactions and reactions with emission of charge particles (pxn, αxn, etc.) [6]. We have performed a new series of experiments to obtain more detailed information on the decay properties of odd-Z nuclei, to measure the excitation functions of the ^{243}Am+^{48}Ca and ^{249}Bk+^{48}Ca reactions at a more extended range of projectile energies, and to make a cross-bombardment consistency check on the reported discoveries of elements 113, 115, and 117 [1,2,4,5]. The first results of an ongoing experiment with ^{249}Bk target are given in [7]. Since April 23, 2012 we have observed five and two new decay chains of ^{293}117 and ^{294}117 activities, respectively. Here we shortly present the results on the synthesis of the $^{287\text{-}289}$115 isotopes in the ^{243}Am+^{48}Ca experiments performed with a few breaks between November 1, 2010 and March 31, 2011 [8] and then between September 30, 2011 and February 26, 2012. An extended review of the latest results obtained in the ^{243}Am, ^{249}Bk +^{48}Ca experiments will be presented in [9]. In the second run described below the experimental studies of the formation of superheavy nuclei in the ^{243}Am+^{48}Ca reaction and of their decay properties were continued at two beam energies: $E_{\rm lab}$=241.0 MeV corresponding to the excitation energy E^*=34.2±2.2 MeV for ^{291}115 compound nuclei, and $E_{\rm lab}$=253.8 MeV (E^*=44.8±2.3 MeV).

At the lower ^{48}Ca beam energy, $E_{\rm lab}$=241.0 MeV, seven long decay chains of the isotope ^{288}115 were detected. The energies of the α particles and the half-lives of the nuclei in these chains, as well as the energies of the fission fragments and the spontaneous-fission half-life, within statistical uncertainties and the energy resolution of the detectors, match the previously observed 24 decay events of ^{288}115 produced in the 3n-evaporation channel of the ^{243}Am+^{48}Ca reaction [1,2,8]. The long decay chain of ^{288}115 isotope is characterized by five subsequent α decays occurring within about one minute and ending with a fission of ^{268}Db occurring within many hours after the last α transition ($T_{1/2}$=27 h).

In this run, three other chains of the $\alpha \rightarrow \alpha \rightarrow$SF type that last typically only about 30 seconds were also detected. Such a decay pattern is characteristic for the neighboring heavy isotope ^{289}115 that was observed for the first time as the α-decay daughter activity of the ^{293}117 isotope produced in the reaction ^{249}Bk(^{48}Ca,4n)^{293}117 [4,5,7] and later as an evaporation residue (single event) in the rare reaction channel ^{243}Am(^{48}Ca,2n)^{289}115 [8]. The agreement of decay energies and half-lives of the nuclei in the $^{289}115 \rightarrow {}^{285}113 \rightarrow {}^{281}$Rg decays provides independent identification and consistency checks via cross bombardments in different fusion reactions of ^{243}Am and ^{249}Bk targets with ^{48}Ca.

At the higher ^{48}Ca beam energy, E_{lab}=253.8 MeV, we observed a single long decay chain of the ^{287}115 isotope. The decay properties of this chain agree well with data recorded in the first experiment from 2003 [1,2]. The 2003 experiment was also performed at the energy E^{*}=45 MeV. In both cases these events were attributed to the ^{287}115 isotope produced in the 4*n*-evaporation channel of the ^{243}Am+^{48}Ca reaction [1,2]. Being the product of this channel, it could therefore not be observed in the ^{243}Am+^{48}Ca reaction at lower energies.

Of all the 33 observed decay chains, six chains only were detected completely during beam-on intervals. At the same time in the high-energy part of the α-particle spectrum, where the decays of daughter nuclei ^{272}Bh to ^{284}113 (E_{α}=8.7–10.1 MeV) are expected in the 243-MeV ^{243}Am+^{48}Ca experiment, 79 events only were detected with average counting rate of about 2 h^{-1}. This demonstrates very low random probability for detection of 13 α particles which belong to the decays of the daughter isotopes of ^{288}115 and occur within about 1-min time interval after the decay of the parent nucleus. All of the signals of α and SF types following the signals of the ER implantation are in strict position correlation, which indicates that they belong to the decay of these implants. The

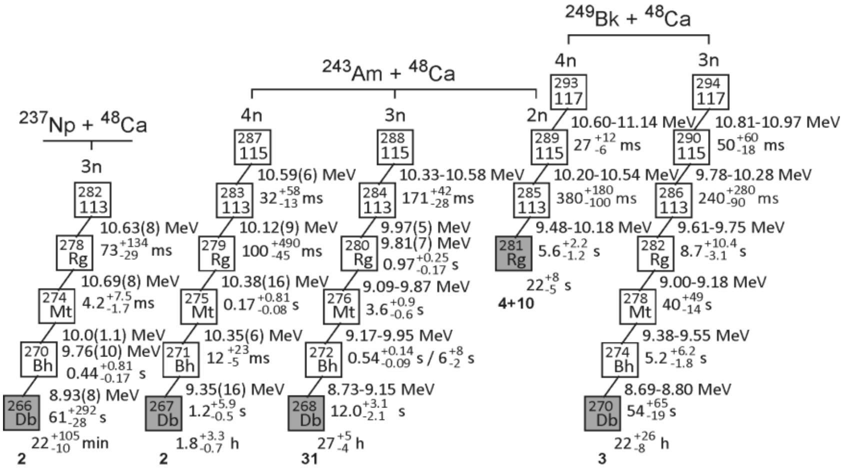

Figure 1. Summary of the decay properties of the isotopes of elements 113, 115 and 117 observed for the first time among the products of ^{48}Ca beam and ^{237}Np, ^{243}Am and ^{249}Bk target reactions. The number of the detected decay events of a given isotope is shown at the bottom of the chains. The energies of the emitted α particles and half-lives are given for all 23 new α emitters observed in these experiments. For 5 new spontaneously fissioning nuclei marked by grey squares, i.e., the isotopes of Db and Rg that terminate the α-decay sequences with spontaneous-fission, the half-lives are listed. The value for ^{268}Db was obtained combining the results of [1,2,8,10,11] and those of the present work.

decay sequences of the isotopes of elements 115 and 113 produced in the reactions ^{243}Am(^{48}Ca,2–4n)$^{289\text{-}287}$115 are shown in Figure 1. This figure also displays decay chains of the heaviest isotope ^{290}115 – the daughter of the isotope of element 117 synthesized in the ^{249}Bk(^{48}Ca,3n)^{294}117 reaction [4,5,7] and a lighter isotope of element 113, ^{282}113, product of the ^{237}Np(^{48}Ca,3n) reaction [3].

Experimental values of the cross section for the production of the isotopes of element 115 measured in the ^{243}Am+^{48}Ca reaction at various excitation energies of the compound nucleus, ^{291}115, are given in [9]. Generally, the behavior of the production cross section of ^{288}115 agrees well with the calculated dependence $\sigma_{3n}(E^*)$ [12] and experimental data which have been accumulated in previous experiments on the synthesis of ^{287}Fl and ^{290}Lv isotopes in the ^{242}Pu(^{48}Ca,3n) and ^{245}Cm(^{48}Ca,3n) reactions [6], respectively. The measured production cross sections of isotopes of element 115, $^{287\text{-}289}$115, with different decay properties, depending on ^{48}Ca beam energy, establishes that these events are the products of the 2n-, 3n-, and 4n-evaporation channels.

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