The Reaction ^{48}Ca + ^{248}Cm → ^{296}116* studied at the GSI SHIP

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Introduction

The favorite method proposed for producing superheavy nuclei in the laboratory was the fusion of heavy isotopes in the reaction ^{48}Ca + ^{248}Cm → ^{296}116* [1–3]. Using the gas-filled separator SASSY in Berkeley and the velocity filter SHIP in Darmstadt this reaction was studied over a wide range of excitation energies in 1982–83 [4]. In these experiments upper cross-section limits of 200 pb were determined for the production of element 116 isotopes at a range of lifetimes from 10 µs to 1d. In the range from 1d to 1 y upper limits of 20 pb were reached using chemical separation.

During the course of a systematic study of hot fusion reactions using a ^{48}Ca beam and various actinide targets, the reaction ^{48}Ca + ^{248}Cm was studied again at FLNR in Dubna in 2000–03. Six decay chains were assigned to the isotope ^{292}116 and five to ^{293}116 [5].

In a resumption of the experiments at SHIP using actinide targets we planned to repeat the irradiation of ^{248}Cm targets with ^{48}Ca ions, however, now at higher beam intensities and with larger area targets and improved detector system. Main aims of the new investigation were, firstly, testing the use and the safe handling of large area radioactive actinide targets at SHIP, secondly, to independently confirm synthesis and decay data of isotopes of element 116 published in [5], and, thirdly, to prepare future search experiments for new elements beyond the already known element 118 [5] using heavier beams and a ^{248}Cm target.

Experimental Techniques

Our study of the reaction ^{48}Ca + ^{248}Cm → ^{296}116* was performed from June 25 to July 26, 2010. During the first part ending on July 12, a beam energy of 265.4 MeV was chosen, in the second part ending on July 24 the beam energy was increased to 270.2 MeV.

The ^{48}Ca beam was delivered from the ECR ion source and the accelerator UNILAC at GSI. Metallic, isotopically enriched ^{48}Ca (89.5 %) and the ECR oven technique were used. Mean currents of 576 and 444 *p*nA (1 *particle* nA = 6.24×10^9 particles/s) on target were applied during irradiations at beam energies of 265.4 and 270.2 MeV, respectively.

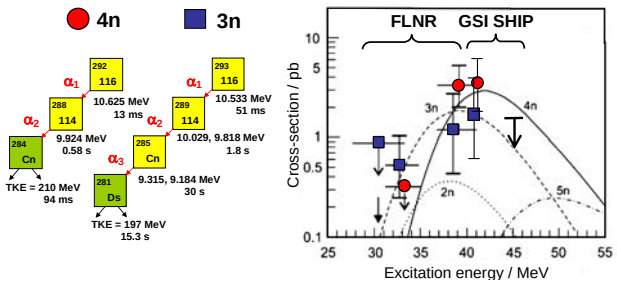

Figure 1: Cross-sections measured for the reaction ^{48}Ca + ^{248}Cm in [5] and in this work. Data of the decay chains are α energies from this work, half-lives deduced from Fig. 3 and energies of spontaneous fission from [5].

The target material was provided by LLNL. An amount of 20 mg ^{248}Cm was delivered to the Institute of Nuclear Chemistry of the Johannes Gutenberg-University in Mainz. There, eight targets were produced by molecular plating [6]. Thin titanium foils of 1.05 mg/cm^2 thickness served as backing material for the Cm_2O_3 layer of 0.460 mg/cm^2 thickness.

The eight targets were mounted on the circumference of the rotating wheel which we usually use in SHIP experiments. The rotation speed of the wheel was 375 turns/min, so that all eight targets were irradiated within a period of 160 ms. The wheel rotated synchronously to the 50 Hz pulse structure of the beam. The length of the curium-oxide layer of 36 mm was determined so that it fits to the duration of a beam pulse of 5.2 ms. The total amount of ^{248}Cm deposited on the wheel was 9.43 mg.

Properties and operation of SHIP are described in [7,8]. In most irradiations an asymmetric setting of the first SHIP quadrupole triplet was used. Field gradients were calculated by a Monte Carlo method [9]. The setting resulted in an efficiency of 22 % for residues from 3n and 4n evaporation channels at the given target thickness.

In the focal plane of SHIP, event chains consisting of implanted evaporation residues and their subsequent α decay and/or spontaneous fission were identified by position-and-time correlations. Detection method and detector system are described in [8,10].

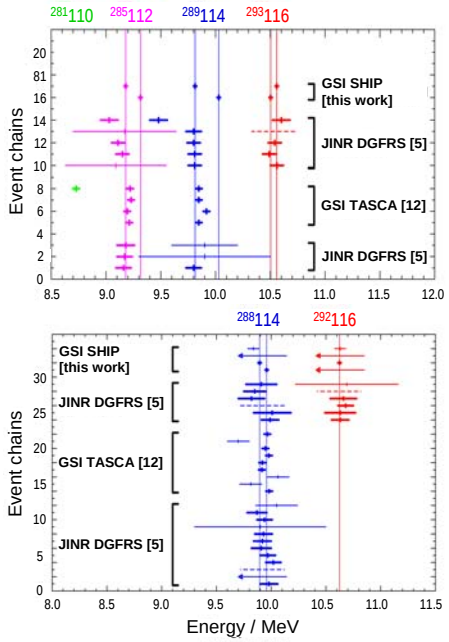

Figure 2: Comparison of α energies of event chains measured in this experiment with literature data for the decays of ^{293}116 and ^{292}116 produced in the reaction ^{48}Ca + ^{248}Cm [5] and of ^{289}114 and ^{288}114 produced in the reaction ^{48}Ca + ^{244}Pu [5,12]. The chains are terminated by spontaneous fission of ^{281}Cn and ^{284}Cn, respectively. Bold symbols with error bars mark energies of α's completely stopped in the stop detector, thin larger error bars mark energies obtained by summing of signals in stop and box detectors. Arrows mark escaped α's depositing only an energy loss in the stop detector from which, however, position and time can be deduced, and dashed lines mark missing α decays.

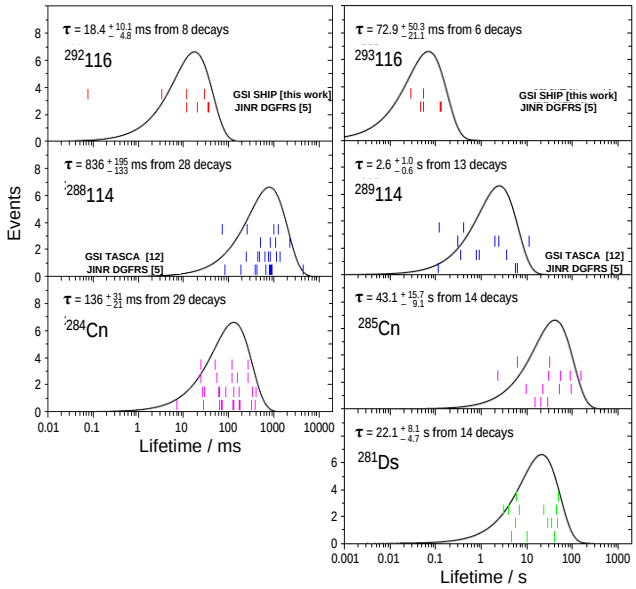

Figure 3: Lifetimes of decays studied in this work in comparison with results given in [5,12]. Note the different time scale in the left (ms) and right (s) column.

Results

The excitation energies of the compound nuclei for reactions at the center of the target thickness were 41.0 and 45.2 MeV, respectively. These energies completed the excitation function which was studied at lower energies in [5], see Fig. 1. At 41.0 MeV we observed six decay chains, two were assigned to ^{293}116 (3n channel) and four to ^{292}116 (4n channel). No event was observed at E* = 45.2 MeV. The measured cross-sections or cross-section limits are shown in Fig. 1. They agree well with expectations based on the results given in [5] and also with theoretical predictions [11].

Alpha energies are compared with literature data in Fig. 2, measured lifetimes are shown in Fig. 3. We conclude that α energies as well as lifetimes agree well with literature data measured for the reactions ^{48}Ca + ^{248}Cm [5] and ^{48}Ca + ^{244}Pu [5,12] and thus represent another independent confirmation of results obtained in previous work. However, as a new result we observed α-decay fine structure in the decay chain of ^{293}116. The occurrence of fine structure or isomeric states was predicted in [13] for these odd-A nuclei where low spin and high spin quasi-particle states are close in energy.

The agreement of the cross-sections measured at SHIP and at the gas-filled separator DGFRS rules out the previously discussed production by αxn channels. In this case our cross-sections would have been at least a factor of five smaller due to the sensitive velocity dependence of the separation by SHIP.

A convincing argument for ruling out pxn channels is given by the systematic of odd particle hindrance factors of partial fission half-lives of the nuclei studied in [5].

The positive results of our experiment and the safe handling of the radioactive target material demonstrated that SHIP is well prepared for further studies using actinide targets, in particular ^{248}Cm. The synthesis of isotopes of even elements confirmed now for elements 112, 114 and 116 represents a reliable base for assigning unambiguously new decay chains which are expected to occur from synthesis of element 120 in the reaction ^{54}Cr + ^{248}Cm.

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