Search for Element 112 Using the Hot Fusion Reaction ^{48}Ca + ^{238}U*

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Recent literature data on the synthesis of element 112 using the hot fusion reaction ^{48}Ca + ^{238}U → ^{286}112* seem to be contradictory concerning cross-sections and half-lives of the produced nuclei (see [1–4]). The most comprehensive studies were performed at the DGFRS of FLNR [2], where not only the reaction ^{48}Ca + ^{238}U, but also reactions leading to elements up to Z=118 were investigated.

In order to prepare an extensive experimental program at SHIP on the study of superheavy nuclei using hot fusion reactions and to confirm or disprove literature data, we selected the reaction ^{48}Ca + ^{238}U to start with.

The irradiations at SHIP, including various test reactions, took place from April 6th to June 9th, 2005. A detailed description of the experiment can be found in [5].

The ^{48}Ca beam was prepared from the ECR ion source of the UNILAC. Metallic, isotopically enriched ^{48}Ca (89.5 %) and the oven technique were used. Ions with charge state 10^{+} were extracted and accelerated to Coulomb barrier energies. A mean current of 1.2 pμA was reached on target at a duty factor of 28 % (5.5 ms wide pulses at 20 Hz repetition frequency). The consumption of ^{48}Ca was 0.6 mg/h on the average.

The targets were prepared from the chemical compound UF$_4$. Layers of 488, 408 and 451 μg/cm^2 were evaporated on backing foils of 42 μg/cm^2 carbon and subsequently covered with carbon layers of 10 or 20 μg/cm^2. Details of the target preparation are given in [6]. The target thickness was controlled on-line by registration of elastically scattered projectiles and scattering of 20 keV electrons [7]. The data showed a continuous decrease of the thickness during irradiation. The target wheel was replaced at the latest, when the losses reached a value of 30 %. We estimated a mean fading of 20 % of target thickness for the calculation of the cross-section. A total of 14 uranium target wheels were used. The uranium content of new and irradiated targets including the performance of the whole experimental set-up was tested by measuring the yield of fusion products from reactions with a ^{22}Ne beam supplied for two days at half time of the experiment. This test confirmed the results obtained by the measurements using scattered projectiles or electrons.

Properties of SHIP and of the detector system are described in [8]. Since that time, however, the detector system was improved. A Si veto detector was mounted behind the stop detector and the single crystal Ge detector was replaced by a four crystal Ge clover detector. The new set-up is shown in Fig. 1. During the uranium irradiation the first of the TOF detectors was removed after few days, which resulted in reduced scattering of the ions and deeper implantation into the Si stop detector.
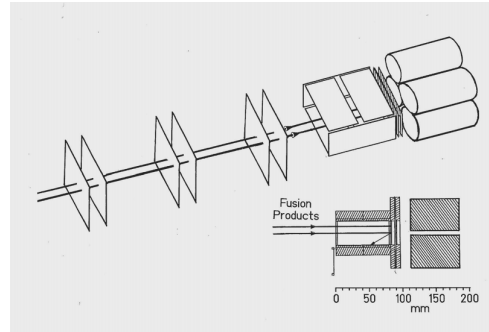

Figure 1: Detector set-up at SHIP. For details see text and description in [8].

We used three different ^{48}Ca beam energies during the experiment. Duration of the irradiations, beam energies, beam doses and cross-section data are summarized in Tab. 1. Chronologically, energies were chosen as given in the table from top to bottom.

Table 1: Parameters and results of the ^{48}Ca + ^{238}UF$_4$ irradiation studied at SHIP.

days	E_{proj} / MeV	E* / MeV	dose / 10^{18}	n	σ / pb
20.9	239.3	37.0	12	0	<0.6
16.8	236.2	34.5	10	1	0.7 +1.6 −0.6
14.8	233.3	32.0	7	0	<0.8

E* is the excitation energy of the compound nucleus at half-thickness of the target layer; n is the number of events. Cross-section limits given are "one-event" limits which do not include statistical fluctuations.

No spontaneous fission (SF) events or α decay chains were measured at excitation energies of 37.0 and 32.0 MeV. Three SF events were measured at E* = 34.5 MeV. However, these events occurred within 12 hours after the test reaction ^{22}Ne + ^{238}UF$_4$. The period of interest is shown in Fig. 2. The total kinetic energies (TKE) of these SF events are 149.4, 141.3, and 154.8 MeV (energy calibration based on α particles), respectively, which agrees well with the energies of SF events from ^{255}No or ^{256}Fm measured during the test reaction. We assign these three

events to the decay of ^{256}Fm produced in a p3n evaporation channel, taking into account well known half-lives and branching ratios of nuclei in the region of interest.
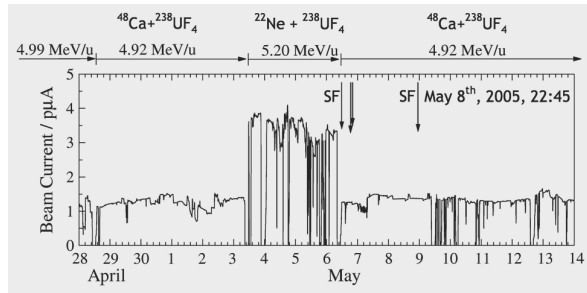

Figure 2: Mean beam currents in particle µA and appearance of SF events during the irradiation of an ^{238}UF$_4$ target with ^{48}Ca projectiles. A ^{22}Ne beam was used for testing purposes from May 3rd to 6th.

A forth SF event was measured on May 8th, 2005, also marked in Fig. 2. The measured parameters clearly identify this event as SF. The energies, based on α calibration, are E_{stop} = 190.4 MeV and E_{box} = 15.3 MeV. These data are shown together with the energies from SF of ^{252}No (produced in the calibration reaction ^{48}Ca + ^{206}Pb) in Fig. 3. The considerable high TKE is clearly visible. In order to determine the true TKE we used the known TKE of the ^{252}No decay, which is 195 MeV [9]. The difference to the peak position at 158.7 MeV in Fig. 3 is 36 MeV. This energy difference was added to the TKE of the SF event from May 8th, which resulted in a TKE of 242 MeV. Assuming a width of the TKE distribution similar to that of ^{252}No, we determine a one σ uncertainty of ±15 MeV for the TKE of this one event.
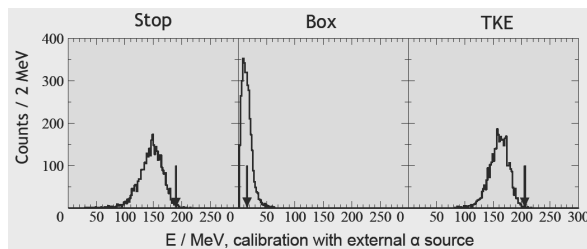

Figure 3: Detector response to SF fragments of ^{252}No produced in the test reaction ^{48}Ca + ^{206}PbS in comparison with the energy of the two SF fragments of the event measured during the ^{48}Ca + ^{238}UF$_4$ irradiation.

The following further properties of the SF event were measured: No signals from the TOF detectors, coincident signals of 386 and 2068 keV in two of the Ge detectors, and appearance of the event during the beam pause at 12.508 ms after beginning of the macro-pulse period which starts with the 5.5 ms wide beam pulse. Finally, the event occurred in strip number 9 of the 16 strip stop detector at a vertical position of 30 mm from the bottom.

The signal from the 28 segment box detector was derived from segment number 13.

At the position of the SF event in the stop detector we searched for preceding α particles and the implanted evaporation residue. Within a reasonable position window of ±1 mm and a time window of 1000 s, we found a total of 29 implantations (5 MeV < E < 30 MeV), but no α particle was measured. Due to the low discriminator level (200 keV) for detection of α particles escaping from the stop detector, we exclude non-registration of such events with high probability. Most (25) of the implantation events coincide with background events from elastically scattered target nuclei. Only one, the first one, appears within an energy-TOF window where we expect signals from implanted evaporation residues. The measured time difference between implantation and SF is 7.57 s, which corresponds to a half-life of (5.2 +25.1 –2.4) s.

Aiming at confirmation of results on element 112 using the hot fusion reaction ^{48}Ca + ^{238}U, we measured one SF event. Although we cannot assign this one event to a certain isotope on the basis of our present data, we find agreement with decay data which were assigned to the isotope ^{283}112 in [2], using the same reaction. However, if we tentatively assign our SF event to the isotope ^{283}112 in accordance with the interpretation given in [2], then we have to introduce an adequate SF branching of this nucleus, because no α particle was measured between implantation and SF. More experimental work is needed in order to obtain an independent and unambiguous confirmation of previous results. As a next step of technical improvement we explore the production of metallic uranium targets which result in higher efficiency of the SHIP separator than targets of chemical compounds. Using these targets we plan to study the reaction ^{50}Ti + ^{238}U → ^{288}114*. According to theoretical predictions, the evaporation of 4 neutrons is most likely at Coulomb barrier energies [10], and the produced isotope ^{284}114 should be the parent of at least three safely to correlate α decays with half-lives of a few hundred microseconds [11]. The chain could end at ^{272}Hs, ^{268}Sg or ^{264}Rf by SF after further α decays. With this next experiment we follow our strategy to fully exploit the use of relatively unproblematic uranium targets before starting experiments using more radioactive actinide targets like ^{242}Pu, ^{244}Pu, or ^{248}Cm.

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