Search for the "Missing" α-Decay Branch in ^{239}Cm

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Our first series of experiments yielded an upper limit of 3×10^{-5} for the α-decay branch of ^{239}Cm [1,2] produced in the ^{12}C + ^{232}Th reaction. In these experiments only α-spectra were evaluated as the γ-spectra were not clean enough to identify γ-lines from the decay of ^{239}Cm or its daughter ^{239}Am. Due to the use of 3.9 μm thick Cu catcher foils in a rotating catcher wheel behind a rotating target setup γ-spectra dominantly showed lines from the decay of ^{153}Sm, ^{150,151}Pm, and ^{147,149}Nd. Those homologous rare earth elements, produced in fission with cross sections of about 5 mb, were stopped in the Cu catcher but were only partly separated in the chemical procedure. ^{71,72}As and ^{69}Ge, produced in reactions of ^{12}C with the Cu catcher, created an additional background.

In recent experiments 1 μm thick Cu foils produced by the GSI target laboratory were used in 120-150 mbar He in stationary target-catcher setups. These foils are sufficiently thick to stop all fusion products (0.3 μm range) but thin enough to let most fission products pass (3-6 μm range) and to minimize interaction of the ^{12}C beam with the Cu catcher. This provided a breakthrough and allowed identifying the 188 keV γ-line assigned to ^{239}Cm [3] as well as γ-lines of the EC-decay daughter ^{239}Am. ^{239}Cm was produced in (≤ 0.4 μA_{part}) ^{12}C + ^{232}Th reactions. A faster and more efficient chemical separation procedure was applied [4]. Instead of two different elution media with 0.25M and 0.30M α-HIB the whole separation was conducted with 0.40M α-HIB at pH=4.6. Figure 1 shows improved elution curves from a cation exchange resin. Since this time all samples contained only small amounts of Sm and Pm, we added ^{244}Cm as a tracer making the yield determination even more reliable. Overall yields varied between 75% and 90%.

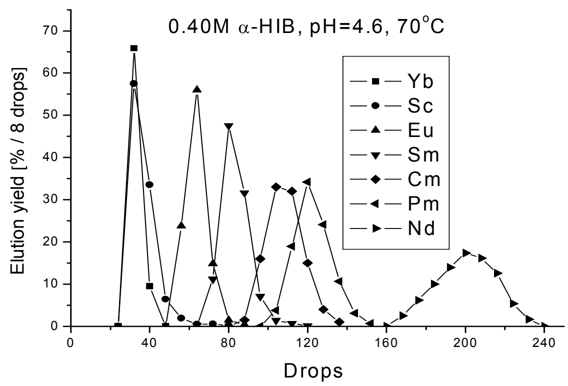

Figure 1: Chromatogram with tracer elements. Drops 80 to 150 were selected as the Cm fraction.

We performed irradiations at 74, 70 and 66 MeV ^{12}C energies in the middle of the 360 μg/cm^2 Th targets. 74 MeV was selected because at this energy HIVAP calculations predict the highest ^{239}Cm cross section. However, as we cannot exclude that α-events observed around 6.4 MeV stem from tailing of the 6.52 MeV α-lines of ^{238}Cm, which is abundantly produced at this energy and which has a similar half-life, no attempt was made to determine an α-decay branch in ^{239}Cm from this experiment.

70 MeV was selected because interfering ^{238}Cm should be produced less by a factor of 80, whereas production of ^{239}Cm should drop by a factor of 1.7 only. Finally, 66 MeV was chosen because ^{240}Cm has its production maximum there. This allowed to check if events around 6.4 MeV can be produced by α-β-pileup. Though the ^{240}Cm activity was higher than in the other experiments, not a single α could be detected between 6.35 and 7.0 MeV during the first day of measuring time. The 188 keV γ-line, assigned to ^{239}Cm [3], was measured in experiments at 70 and 74 MeV irradiation energy. In addition, the 229 and 278 keV γ-lines of the daughter product ^{239}Am were detected. Since at 70 MeV irradiation energy HIVAP predicts a factor of 2000 lower cross section for ^{239}Am as compared to ^{239}Cm, we feel safe to attribute all measured ^{239}Am to ^{239}Cm daughters. As the absolute intensity of the ^{239}Cm 188 keV γ-line is not known, we started our analysis with the assumption of 100% abundance. Based on this we calculated how much ^{239}Am is produced in the ^{239}Cm EC-decay. As the experimentally observed amount of ^{239}Am at 70 MeV is a factor of 2.8±0.8 higher, we concluded that the 188 keV γ-line has an intensity of about 36%. The error (90% c.i.) includes uncertainties in the half-life of ^{239}Cm between 2 and 4 h and in the Cm-Am separation yield between 30% and 70%. The 70 MeV experiments yielded five α-decays between 6.36 and 6.45 MeV within the first 10 h of measurement. An average background of 0.625 events, determined in a long background measurement without a sample, was subtracted (note that the background with a sample could be somewhat higher). This yields a ratio of α-decay to EC decay of $\leq 1.9\times10^{-5}$ (90% c.i.) and $\leq 1.4\times10^{-5}$ (68.3% c.i.) for the decay of ^{239}Cm.

References

[1] Z. Qin et al., GSI Scientific Report 2004, p.190
[2] Z. Qin et al., GSI Scientific Report 2005, p.197
[3] E. Browne, Nucl. Data Sheets 98, 665 (2003).
[4] Z. Qin et al., GSI Scientific Report 2004, p.191.