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Isotopic yield in cold binary fission of even–even $^{244–258}$Cf isotopes

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Abstract

The cold binary fission of even–even $^{244–258}$Cf isotopes has been studied by taking the interacting barrier as the sum of Coulomb and proximity potential. The favorable fragment combinations are obtained from the cold valley plot (plot of driving potential vs. mass number of fragments) and by calculating the yield for charge minimized fragments. It is found that for ^{244,246,248}Cf isotopes highest yield is for the fragments with isotope of Pb ($Z = 82$) as one fragment, whereas for ^{250}Cf and ^{252}Cf isotopes the highest yield is for the fragments with isotope of Hg ($Z = 80$) as one fragment. In the case of ^{254,256,258}Cf isotopes the highest yield is for the fragments with Sn ($Z = 50$) as one fragment. Thus, the fragment combinations with maximum yield reveal the role of doubly magic and near doubly magic nuclei in binary fission. It is found that asymmetric splitting is favored for Cf isotopes with mass number $A \leq 250$ and symmetric splitting is favored for Cf isotopes with $A > 252$. In the case of Cf isotope with $A = 252$, there is an equal probability for asymmetric and symmetric splitting. The individual yields obtained for the cold fission of ^{252}Cf isotope are compared with the experimental data taken from the γ-γ-γ coincidences technique using Gammasphere.

Keywords: Spontaneous fission; Heavy particle radioactivity

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1. Introduction

More than seventy-five years of research on nuclear fission have clearly shown that, the low energy fission of heavy elements ($Z > 90$) was one of the most complex phenomena of nuclear reactions. Most of the nuclear reactions take place through the binary fission process, a low energy fission, where the fissioning nucleus ends up in two fission fragments and the fragments were formed after the fission barrier has been overcomed. In 1939 Hahn et al. [1], discovered that the uranium atom was fragmented into two parts, which are more or less equal in size. Bohr and Wheeler [2] developed a theory of fission based on the liquid drop model. The authors gave a theory of the effect based on the usual ideas of penetration of potential barriers.

Experimental studies of cold fission started in the early 80s by Signarbieux et al. [3], Armbruster et al. [4], and found that the relative yields of different fragmentation modes are governed by the available phase space of the system at scission, determined by the nuclear structure properties of the fragments. The cold spontaneous fission of many actinide nuclei into fragments with masses from 70 to 160 were observed and studied [5–9] and found that in these cold decays both the final fragments were in the ground states and confirmed the theoretical predictions by Sandulescu et al., [10,11]. The first direct observation of cold fragmentation in the spontaneous fission of ^{252}Cf was carried out [7,8] using the multiple Ge-detector Compact Ball facility at Oak Ridge National Laboratory where four pairs of neutronless fragmentations that of ^{104}Zr–^{148}Ce, ^{104}Mo–^{148}Ba, ^{106}Mo–^{146}Ba and ^{108}Mo–^{144}Ba were observed. Further in 1996 Sandulescu et al. [12], and Dardenne et al. [13], observed cold fragmentation in the spontaneous fission of ^{252}Cf with the Gammasphere consisting of 72 detectors where the correlations between the two fragments were observed clearly. Sandulescu et al. [12], using a simple cluster model predicted correctly the most important cold fragmentations observed in the spontaneous cold fission of the nucleus ^{252}Cf, where the double-folding potential barrier with the M3Y nucleon–nucleon forces gave the relative isotopic yields. The results were in good agreement with the experimental data [12,14].

Ramayya et al. [15], observed and presented the evidence for cold binary and ternary fission in the spontaneous fission of ^{252}Cf using triple gamma coincidence technique with Gammasphere and identified several correlated pairs whose yields were extracted. Gonnenwein et al. [16], observed the presence of doubly magic ^{132}Sn fragment in the cold fission of ^{252}Cf, which was predicted some years ago by Kumar et al. [17].

Moller et al. [16,18], reported spontaneous decay of ^{252}Cf using a twin ionization chamber where two distinct mass regions of cold fission were observed: the first region includes the mass split 96/156 up to 114/138 and second one comprises only a narrow mass range around the mass split 120/132. Mirea et al. [19], computed the cold fission path in the potential energy surface of ^{252}Cf by using the two-center shell model, based on the idea of the cold rearrangements of nucleons during the cold fission process and obtained a satisfactory agreement with experimental yields by considering variable mass and charge asymmetry beyond the first barrier of the potential surface. Mirea et al. [19], analyzed the data obtained by Hambsch et al. [5], from the cold fission yields of ^{252}Cf, and showed that the cold fission of ^{252}Cf is strongly connected with the cold valley of the doubly magic isotope ^{132}Sn.

The ground state decay properties (nuclear mass, deformation, α decay energy, α decay half-life, spontaneous fission half life etc.) of even–even isotopes of superheavy (SH) elements with $Z = 104$–170 have been studied by Smolanczuk [20] based on the macroscopic–microscopic model in which a multi dimensional deformation space describing axially symmetric nuclear shapes are used. Within the Hartree–Fock–Bogoliubov (HFB) approach with the finite-range and