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The charge polarization and its impact on prompt fission neutron multiplicity

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Abstract

Prompt neutrons emitted from fission fragments of actinides show a specific induced-energy dependence. The mass distribution of prompt neutrons emitted from light fragments are independent of induced energies, while the number of prompt neutrons originating from heavy fragments increases with increasing induced energy. The understanding of the mechanism of this behavior has been a long standing problem, and cannot be solved unless we assume very artificial conditions such as fragment-mass dependent temperatures. Therefore, the neutron multiplicity has been used as fitted information in major models for prompt neutron spectra. In this paper, we evaluate the prompt neutron multiplicity as a function of the fission-fragment product of the n-induced fission of U-235 based on the fission configuration derived from the Langevin equation. We found that the charge polarization, which is the deviation from the unchanged charge distribution (UCD) assumption, can directly produce the specific induced-energy dependence of prompt neutrons without extra assumptions.

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Keywords: Fission, Charge polarization, Isotopic distribution, Nuclear data evaluation uclear fission, fission neutrons;

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1. Introduction

The search for the deviations from the unchanged charge distribution (UCD) in fission has been stimulated by even older studies on the effect of the Coulomb repulsion of the protons in the ground state. Especially, it is essential for the safety of nuclear reactors to have a fission theory to estimate the charge polarization at scission, because the border line of the delayed neutron emission is very close to the UCD line. Recent development of experimental techniques can provide precise measurements of the charge deviation from the UCD and the mass distribution at low excitation energies at the same time. However, it is still an open question what is the origin of the odd-even fluctuation in the charge polarization.

Prompt neutrons emitted in neutron induced fission of actinides show a specific energy dependence. The mass distribution of prompt neutron of light fragments is independent of energy, while the number of prompt neutrons originating from heavy fragments increases with increasing energy. However, understanding of the mechanism of this behavior has been a long standing problem, and cannot be solved unless we assume very artificial condition such as fragment-mass dependent temperatures. Therefore, the neutron multiplicity has been used as fitted information to calculate prompt neutron spectra.

Most calculations of the prompt fission neutron spectra of actinides, the charge polarization has been treated by a simple model or has been considered to be negligible. The Point-by-Point model developed by the Bucharest University group uses experimental data or Wahl's systematics [1,2] for the charge distribution; the CGMF code of Los Alamos National Laboratory[3] and FIFREIN code of CEA-Cadarache[4] also adopt Wahl's systematics for the charge distributions, while the FREYA code [5] of Lawrence Livermore National Laboratory and Lawrence Berkley National Laboratory uses the UCD [1]. In Wahl's systematics [2], the polarization is represented by combination of three linear functions. As mentioned above, the influence of the charge polarization on prompt neutrons are not clear, because the fitting procedure of neutron multiplicity covers contribution from the charge polarization in these major models.

In this paper, we elucidate the influence of the charge polarization (deviation), derived by the Langevin model, which has good prediction power without fitting parameters to the mass distributions and total kinetic energy (TKE) distributions, on prompt fission neutron multiplicity. In order to estimate the charge polarization, we minimized the sum of the nuclear symmetry energy and the Coulomb energy. As a result, we found that a mass-asymmetry-dependent elongation of a fissionning nucleus plays a key role to reproduce the whole structure of the charge polarization. We also found that the behavior of the polarization is quite different from the Wahl's systematics especially between A=109 and A=127, although the polarization of our model is almost consistent with the phenomenological GEF[6] model. Based on our charge polarization, we evaluated prompt neutron multiplicity as a function of mass number. Then we found that the charge polarization, we can produce the same effect as sdoes the excitation energy on the prompt neutron multiplicity as a function of mass number.

2. Formalism

In this section, we derive the charge polarization (the deviation from UCD assumption) using scission configurations derived from three-dimensional Langevin calculation for n-induced fission of ^{235}U at neutron energies E_n=5.55 MeV and 0.5 MeV. The Langevin calculation provides masses, charges, shapes of fission products as well as dynamical quantities such as TKE at scission point. Then we can calculate the Coulomb energy and symmetry energy for each scission shape. Charge polarization ΔZ is calculated by minimizing these energy sum. We describe the fission using the two-center shell model parametrization. Then we briefly introduce how to derive the fission configurations as a result of the three dimensional Langevin calculation. We define the charge polarization, then calculate it by minimizing the energy of the whole system consisting of fission fragments with respect to the charge degree of freedom. Here, we use two different criteria to decide the charge division at scission, which was proposed in the previous study [8].