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A comprehensive approach to estimate delayed-neutron data of actinides and minor-actinides

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Abstract

A project is described on a comprehensive approach to improve accuracy of delayed-neutron data of actinides and minor actinides by the summation calculations. This project consists of 1) measurement of fission fragment mass distribution (FFMD) of nuclei for which direct measurements using neutrons are not practical, 2) estimation of independent fission yields by developing a dynamical model of fission, 3) improvement of a β-decay theory for better reproductions of decay characteristics of fission fragments, 4) nuclear data evaluation based on the above activities and summation calculations of decay-heat and delayed neutron data and 5) benchmark by using reactor data. Through these activities, understanding of the basic fission process will be advanced as well.

Keywords: Nuclear data, delayed-neutron, surrogate method, Langevin theory, Gross theory of β-decay, reactor benchmark

1. Introduction

Nuclear fission is the fundamental physical process underlying nuclear energy systems, one of the important sources of energy. Application of the fission to technology has been progressed quite rapidly shortly after discovery of the fission. In contrast, understanding of the basic fission process itself has advanced relatively slowly. For example, our knowledge on the origin of the mass-asymmetric division of fission fragments, prompt and delayed neutrons and their energy spectra, from neutron impact on ^{233}U, ^{235}U and ^{239}Pu is still in a qualitative (or phenomenological) level. Needless to say, the situation is much worse for minor actinides for which direct measurement is difficult to be performed due to difficulties in preparing target materials.

Delayed neutron data is one of the key information to evaluate kinetic behavior of nuclear reactors during normal operation. Furthermore, reactivity ρ of nuclear reactors in transient status and that of other

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subcritical nuclear facilities such as accelerator-driven system for nuclear-waste transmutation may be given by using the reactor period T (a measurable quantity) as

$$\rho = \frac{\ell}{T+\ell} + \frac{T}{T+\ell}\sum_{i=1}^{6}\frac{\beta_{i,eff}}{1+\lambda_i T} \tag{1}$$

where ℓ denotes mean lifetime of prompt neutrons, $\beta_{i,eff}$ the effective delayed-neutron fraction of group i, and λ_i its decay constant. That is, an observable (T) and the reactivity (one of the most important design criteria) is connected through the delayed neutron data. Therefore, if the delayed-neutron data is uncertain, the reactivity determined by this relation is uncertain as well.

Delayed neutrons appear after β-decay of fission fragments which are populated mostly as neutron-rich nuclei. Estimation of the delayed-neutron data requires, hence, a comprehensive knowledge on the fission of relevant nuclei, namely, how the fission fragments are populated in nuclear chart and how they decay toward stable nuclei if not measured directly as was done by Keepin[15, 16]. They are also related closely to the problems of decay heat and emission of reactor antineutrinos, the latter attains strong recent interest since it is related to the fundamental problem such as neutrino oscillation and possibility of reactor monitoring for non-proliferation of nuclear materials. Therefore, it is desirable to understand these problems systematically in a process of understanding the physical phenomena related to the nuclear fission. Brady and England[4] has made a first and pioneering attempt toward this direction, and carried out a summation calculation. However, there are still many open problems left in this field because the physics of fission and neutron-rich nuclei are complicated and actually are matters of the front-edge nuclear physics. For example, if we compare the reactivities calculated by using 6-group delayed neutron data measured by Keepin et al.[15] and those calculated by Brady and England for major actinide like ^{235}U, they disagree about 10% for a wide range of the reactor period. Therefore, many efforts must be done in order to make more accurate the micro-physics information, i.e., fission fragment yield and their decay data, necessary for the summation calculation of delayed neutrons to a practical level.

In this work, we introduce new experimental techniques and theoretical frameworks to make more accurate the summation calculation of delayed neutron data. Existing data for the major actinides are also analyzed simultaneously. The latter will serve as a benchmark of the present approach.

2. Method

2.1. Overall framework

We will conduct the following comprehensive and systematic researches to improve our knowledge on the delayed neutrons as collaboration between Tokyo Tech. and JAEA as a 4-year project supported by MEXT. Firstly, mass distribution of fission fragments (MDFF) will be measured by the surrogate method. It will yield excitation-energy dependence of MDFF both for major and minor actinides, the latter are hard to be obtained by other methods. Secondly, independent fission yield of major and minor actinides will be estimated by a multi-dimensional Langevin theory which is tuned to reproduce the MDFF data obtained by the surrogate method. Thirdly, gross theory of β-decay will be extended to reproduce available up-to-date data for the half lives of β-decay, spectra of β-rays and γ-rays including recent TAGS (Total Absorption Gamma-ray Spectrometer) data and delayed neutron emission probabilities of relevant nuclei. The improved gross theory will be used to estimate the decay heat, delayed-neutron emission and emission of antineutrinos (including their spectra). Furthermore, a statistical decay model based on the Hauser-Feshbach theory[12] will be employed to estimate prompt neutron emission which modifies the independent fission yields as well as the delayed-neutron emission probability and spectra of delayed neutrons. Finally, a temporary evaluated nuclear data library will be generated and summation calculation of the decay heat and delayed-neutron related quantities will be carried out, which will be tested against integral data. This information will then be used to further update various components emerging in the former stages of this project until a satisfactory agreement is obtained. The flow of the present work is schematically illustrated in Fig. 1.

Major items of the present project will be described in more details in the followings.