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Uncertainty quantification of total delayed neutron yields and time-dependent delayed neutron emission rates in frame of summation calculations

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ABSTRACT

To contribute to further improvements of the nuclear data related to delayed neutron emissions, uncertainty quantification calculations for total delayed neutron yields, $\bar{\nu}_d$, and time-dependent delayed neutron emission rates after a burst fission have been carried out. Those are based on the summation calculations with fundamental nuclear data taken from JENDL/FPD-2011 and a partly-modified JENDL/FPY-2011. Sensitivities required for uncertainty propagation calculations are obtained efficiently by the help of the generalized perturbation theory for time-dependent problems.

It is found that $\bar{\nu}_d$ and neutron emission rates after a burst fission obtained in frame of summation calculations generally agree with the JENDL-4.0 evaluations within 2σ of nuclear data-induced uncertainty. While further improvements of the fundamental nuclear data are crucial, application of the summation calculations to actual problems is now not unrealistic, and further efforts from the application side are helpful.

1. Introduction

In the present paper, we will perform uncertainty quantification calculations for total delayed neutron yields and time-dependent delayed neutron emission rates after a burst fission in frame of the summation calculations.

Delayed (or β-delayed) neutrons play a significant role in nuclear fission reactors. One can operate and manage safely a nuclear fission reactor in a delayed critical state, in which fission chain reactions are sustained with a help of delayed neutron emissions from their precursors. Even if a nuclear fission reactor becomes beyond a prompt critical state, it has conventionally its inherent safety feature and it immediately returns below the prompt critical state. Delayed neutron emissions are quite important in both normal and accidental conditions, and they should be properly modeled in core design and safety analyses of nuclear fission reactors.

Nuclear fission reactor core analyses, especially reactor kinetics analyses, require nuclear data related to delayed neutron emissions, such as fission yields, decay constants, decay paths and their branching ratios of fission fragment nuclides. Historically, these data, which are inherent to each fission fragment nuclide, have been simply treated as family-wise data, in which several tens of nuclides having similar half-lives are lumped to one fictitious nuclide since there are a huge number of fission fragment nuclides and explicit treatment of them is unrealistic in actual applications. Delayed neutron emissions-related nuclear data represented by this simplified treatment have been evaluated from measurement data such as time-dependent delayed neutron emission rates after a burst fission. This simplified treatment has resulted in a great success in a nuclear reactor engineering field (Keepin et al., 1957; Tuttle, 1975).

The conventional modeling of delayed neutron emissions based on the simplified treatment, however, has a difficulty when it is adopted to nuclides to which no measurement data have been obtained in the past. Furthermore, this treatment neglects some physical behaviors, such as nuclide transmutations of fission fragment nuclides to other ones.

In 1989, Brady and England evaluated delayed neutron emissions-related data in frame of the so-called summation calculations, in which all the fission fragment nuclides are explicitly treated in the modeling of delayed neutron emissions. This study opened a new path for further improving delayed neutron emission-related nuclear data. Unfortunately, at the time, knowledge on such nuclear data of fission fragment nuclides was not rich, hence the evaluated data based on the summation calculation did not superior to the conventional one, and most of modern

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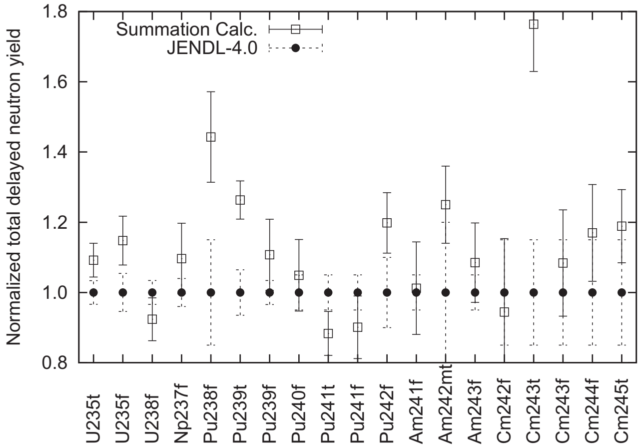

Fig. 1. $\bar{\nu}_d$ and its uncertainty obtained by summation calculations. "U235t" and "U235f" denote uranium-235 thermal fission and uranium-235 fast fission, respectively. In JENDL-4.0, $\bar{\nu}_d$ of the following nuclides are evaluated based on measurement data: uranium-235, -238, neptunium-237, plutonium-239, -240, -241, -242, americium-241 and -243. Note that $\bar{\nu}_d$ is normalized to the JENDL-4.0 evaluation.

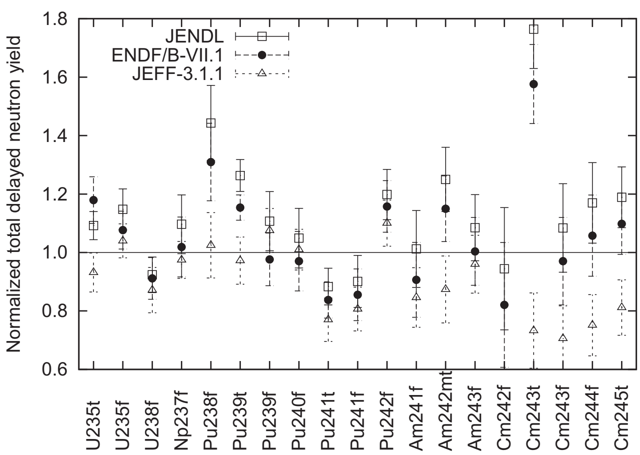

Fig. 2. $\bar{\nu}_d$ and its uncertainty obtained by summation calculations with several evaluated nuclear data files. Note that $\bar{\nu}_d$ is normalized to the JENDL-4.0 evaluation.

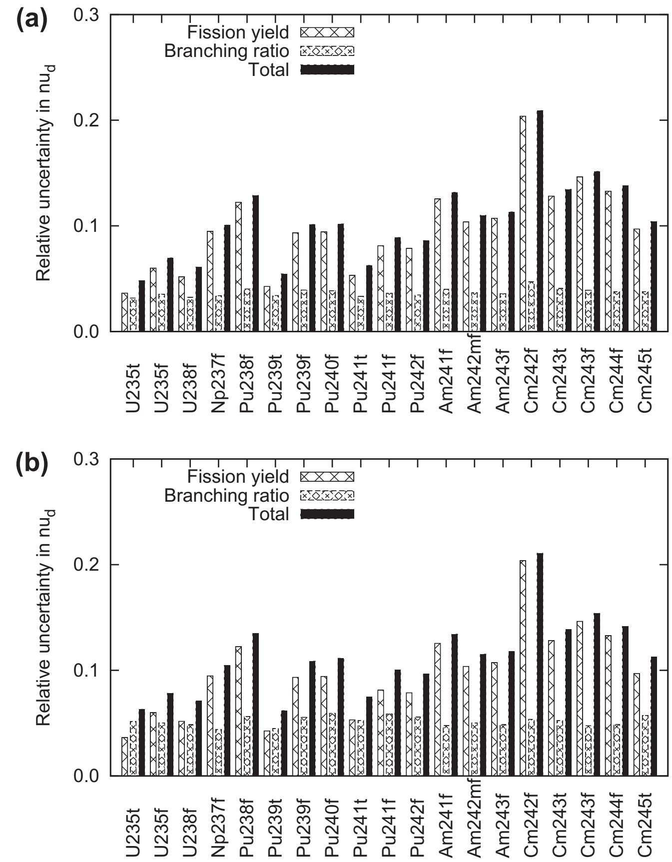

Fig. 3. Component-wise $\bar{\nu}_d$ uncertainty obtained by summation calculations. (a) One hundred percent relative uncertainty and (b) two hundreds percent relative uncertainty are assumed to nuclear data to which no covariance data are given in JENDL/FPY-2011 and JENDL/FPD-2011.

evaluated nuclear files except for ENDF/B have relied on the historically-used data.

During about twenty-five years after Brady and England's notable study, there have been advancements in the nuclear physics field, and now ones know delayed neutron emissions-related nuclear data of fission fragment nuclides much better than the past. This motivates researchers and engineers to attempt to realize more accurate and reliable representations of delayed neutron emissions in frame of the summation calculations.

In addition, some innovative concepts of nuclear fission reactors using minor actinide fuels have been proposed recently. In such reactors, delayed neutron emissions by minor actinides have non-negligible impacts on core characteristics. Since there are few measurement data of delayed neutron emissions by minor actinides, it is not easy to obtain the delayed neutron emissions-related nuclear data in frame of the conventional simplified treatment. In such cases, one should rely on the summation calculations with the detailed nuclear physics modeling.

It should be also noted that the current reactor physics simulations also require more detailed modeling of fission fragment nuclides to evaluate the related quantities. For example, a reliable simulation of delayed gamma-ray emissions, which are one of important heat generation phenomena in nuclear fission reactors, requires explicit modeling of fission fragment nuclides (Chiba et al., 2014).

Recently there have been many studies on delayed neutron emissions based on the summation calculations in a nuclear fission reactor engineering field. The authors of the present paper have carried out studies to specify important delayed neutron emissions-related nuclear data for evaluation of a reactor stable period, which is important quantity in a nuclear fission reactor operation, and to quantify these uncertainties using the covariance data given to the fundamental nuclear data (Chiba et al., 2013, 2014). The present paper follows these preceding studies; we will quantify uncertainties of total delayed neutron yields, $\bar{\nu}_d$, and time-dependent delayed neutron emission rates after a burst fission. These uncertainty information are quite beneficial for further improvements and advancements of the relevant nuclear data.

The present paper is organized as follows; Section 2 provides a brief description of the time-dependent generalized perturbation theory which is employed to obtain sensitivities required for uncertainty propagation calculations. Sections 3 and 4 are devoted to describe numerical procedure and results, respectively. Finally, conclusion of the present study and future perspective are described in Section 5.

2. Theory

We will quantify uncertainties of two delayed neutron emissions-related quantities: $\bar{\nu}_d$ and time-dependent delayed