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An Method to Quantify Control Rod Worth Uncertainty Propagated from Nuclear Data

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Abstract

One of the main issues of nuclear reactor design is the accurate calculation of control rod worth. However, in the calculation results there exists uncertainty inevitably, which is propagated from uncertainty in input parameters, computing models and calculation methods. Therefore, carrying out control rod worth uncertainty quantification is urgent but full of challenges, especially for application of a feasible method for propagating input uncertainties to control rod worth. In this paper, a new uncertainty analysis method for quantifying uncertainty of control rod worth propagated from macroscopic cross sections has been proposed. The basic idea is to use efficient sampling method to propagate nuclear data uncertainties through the function between control rod worth and all macroscopic cross sections. This is done by applying perturbation theory. Numerical results indicate that the new method proposed in this paper is an effective way to quantify uncertainty of control rod worth propagated from nuclear data.

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Keywords: Control rods worth; Uncertainty; Perturbation theory; Sampling

1. Introduction

Nuclear reactor core design and safety analysis both need an accurate calculation of control rod worth, which provides precise and adjustable control of reactivity and specifies safety margin of reactor. However, uncertainties inevitably exist in the control rod worth calculation. For quantifying uncertainty of control rod worth, there are three

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main uncertainty aspects need to be studied in-depth. Firstly, uncertainty exists in nuclear data, manufacture tolerance of control rod and fuel rod. Secondly, calculation models as well as methods make a large contribution to the total uncertainty of control rod worth. Thirdly, the reactor core state will change due to the movement of control rod, such as xenon oscillations, which may also introduce a large uncertainty to control rod worth. As a result of these uncertainty sources, the total uncertainty of control rod worth should be large. However, the accurate control rod worth uncertainty and the contribution of each factor to the total uncertainty is unknown, especially for new types of nuclear reactor.

Although much effort has been put into uncertainty quantification of k_{eff} and power distribution for different types of nuclear reactors [1-3], there is no systematic uncertainty analysis for control rod worth up to now. In fact, uncertainty sources of control rod worth are complicated and correlative. Especially, there is no feasible method for propagating input uncertainties to control rod worth. Therefore carrying out uncertainty analysis of control rod worth is urgent and worthy of exploration as soon as possible, but this research may be full of challenges.

In this paper, a new uncertainty analysis method for quantifying uncertainty of control rod worth propagated from macroscopic cross sections was proposed. The function between control rod worth and macroscopic cross sections, flux and adjoint flux was established based on perturbation theory. Then sampling statistical method was applied to quantify the uncertainty of control rod worth propagated from nuclear data. Finally, a mini core model was established and the uncertainty of differential control rod worth propagated from macroscopic cross sections in one rod position was quantified.

2. Uncertainty quantification method

There are many uncertainty factors contributing to the total uncertainty of control rod worth, such as macroscopic cross sections, methods and so on. These uncertainty inputs are complicated and mutually coupled, as shown in Fig.1.

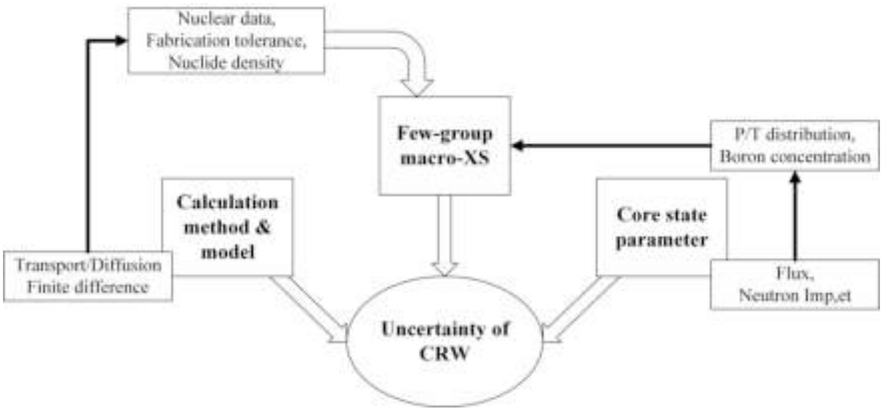

Fig. 1. Uncertainty sources of control rod worth

The relation between control rod worth and macroscopic cross sections, flux, adjoint flux can be represented as $\rho_{CR} = f(\Sigma, \phi, \phi^*)$. The traditional method to evaluate control rod worth is to carry out twice critical calculations firstly and then the control rod worth can be calculated by:

$$\Delta\rho = \frac{1}{k_{eff1}} - \frac{1}{k_{eff2}} \tag{1}$$