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Importance of self-shielding for improving sensitivity coefficients in light water nuclear reactors

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ABSTRACT

In order to perform sensitivity analyzes in light water reactors where self-shielding effect becomes important, a new method has been developed for calculating sensitivity coefficient of core characteristics relative to the infinite dilution cross-sections instead of the effective cross-sections. This method considers the change of the self-shielding factor due to cross-section perturbation for different nuclides and reactions. SRAC and SAINT codes are used to calculate the improved sensitivity; while the accuracy of the present method has been verified by MCNP code and good agreement has been found.

1. Introduction

The fundamental objective of nuclear safety is to ensure that under normal and credible abnormal conditions nuclear facilities are operated in an acceptably safe manner (NEA Regulatory Guidance Booklets, 2011). In reactor physics field, there are some core characteristics closely related to safety such as K_{eff}, Doppler reactivity coefficient, control rode worth etc., where sensitivity studies are excellent tools for understanding the reliability of these characteristics.

Sensitivity calculations have been used for a variety of purposes such as; sensitivity analysis, uncertainty estimation, design optimization, determination of target accuracy requirements, adjustment of input parameters, and evaluations of the representativity of an experiment with respect to a reference design configuration (Palmiotti and Salvatores, 2012).

For sensitivity analysis, sensitivity coefficients are the key quantities that have to be evaluated. They are determined and assembled, using different methodologies, in a way that when multiplied by the variation of the corresponding input parameter they will quantify the impact on the targeted quantities.

Design optimization phases of selected reactor and fuel cycle concepts will need improved data and methods in order to reduce margins, both for economical and safety reasons. The ultimate goal is a design that has low uncertainties (Palmiotti and Salvatores, 2012). Industry and utilities want reduced uncertainties for economical reasons (design and operation), while regulatory bodies want guaranteed margins that they can trust by enlarging the respective validation domains.

It is then important to define which nuclear data have to be improved in order to quantify target accuracies and to select a strategy to meet the requirements needed. It must be recognized that some reactor parameters are more significant than others to accurately calculate core characteristics such as k_{eff}; where sensitivity studies can be employed to assess the impact of small deviations in these parameters. If the calculated k_{eff} is especially sensitive to a particular parameter, an error in that parameter could have a corresponding large contribution to the system, and so more margin between the operating and safety limits may be needed.

The use of sensitivity analysis techniques are intended to help provide a formal and rigorous approach to the determination of area (s) of applicability for criticality safety validation.

Due to enormous computing time required by the forward calculation method; sensitivity coefficients are usually calculated by using the generalized perturbation theory (GPT) (Kennedy et al., 2012) for systems where the number of responses of interest is low compared to the number of inputs. GPT involves the solution of the adjoint form of the eigenvalue equation; it has been mainly

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Table 1
Isotopic data for UOX cell.

Region	Isotope	Radius (cm)	Density (atom/cm^3)	Temperature (K)
Fuel	U^{235}	0.4645	4.6539E+20	1023
	U^{238}		1.8344E+22	
	O^{16}		4.2607E+22	
Cladding Zircaloy-4	O^{16}	0.536	3.0828E+20	700
	Cr		7.5866E+19	
	Fe		1.4834E+20	
	Zr		4.2427E+22	
	Sn		4.8183E+20	
Coolant	H	0.7610	6.6629E+22	583
	O^{16}		3.3334E+22	

adopted in reactor physics where the source of uncertainty is mainly related to the neutron cross-sections.

Sensitivity coefficients of individual core characteristics such as k_{eff}, power distribution and control rod worth are calculated relative to cross-section changes of each reaction type (fission, capture, scattering) for many energy groups. TSUNAMI module (Rearden, 2009) in SCALE code is a representative sensitivity calculation code. In Japan we have developed SAGEP (Takeda and Umano, 1985), SAGEP-T (Takeda and Asano, 2006) and SAINT (Takeda and Nakano, 1986) codes based on the generalized perturbation theory with use of diffusion theory, transport S_n method, and collision probability method, respectively.

However, the sensitivity coefficients are usually calculated by changing the effective cross-sections. The effective cross-sections are the product of the infinite- dilution cross-sections and the self-shielding factors. The self-shielding factor varies with other cross-section changes due to change of the background cross-section, and the interaction effect has to be considered in estimating the sensitivities.

The purpose of this paper is to derive a new method to calculate the sensitivity which shows the core characteristics changes due to the change of the infinite dilution cross-sections. The present method introduces a correction *TERM* to the conventional sensitivity coefficient. Therefore, the conventional approximation utilized hitherto with this correction *TERM* can be used to calculate the improved sensitivities.

To check the accuracy of the present method, numerical calculations are performed for a representative PWR cell model. Approximated (conventional) sensitivity coefficients are calculated by SAINT code which can treat cell geometry using the collision probability method, and then the improved sensitivity coefficients are calculated by using the present method. Finally the improved and approximated sensitivity coefficients are compared with a reference one calculated by MCNP code.

The paper is organized as follow: The relation between improved and approximate sensitivity coefficients is derived in Section II, and numerical results are shown in Sec. III. Section IV summarizes the conclusion.

2. Theory

Core characteristics such as k_{eff}, power distribution and control rod worth are calculated by using effective cross-section in deterministic methods. Usually the effective cross-sections are

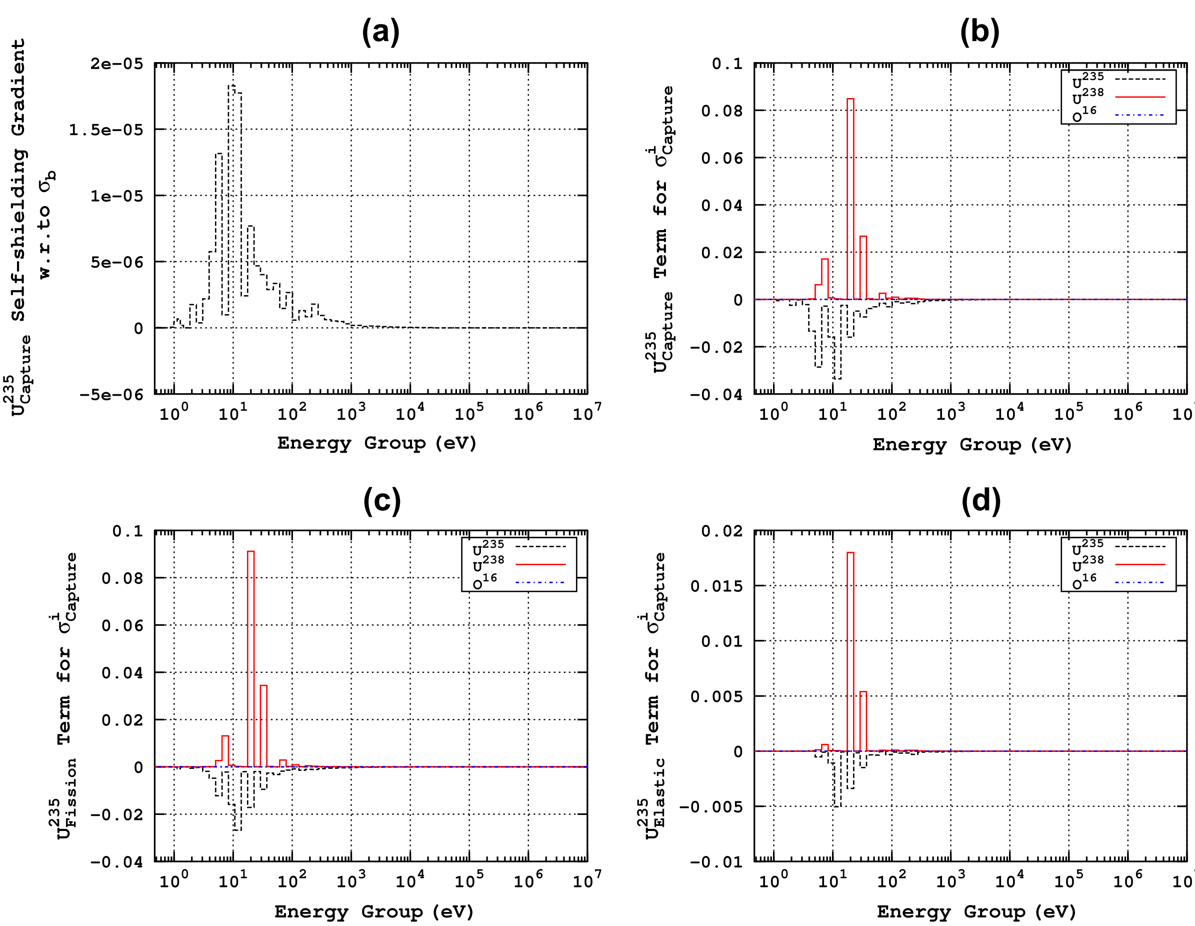

Fig. 1. U^{235} *TERM* due to $\sigma^i_{capture}$ perturbations.