Validation of Sensitivity Coefficients Considering Indirect Effect

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1. Introduction

In order to evaluate the quantitative effect on neutronic properties caused by the change of cross sections, sensitivity coefficients are very powerful parameters. Sensitivity coefficients show the breakdown of the effect in nuclide, reaction type and energy range or group.

SAINT-II[1] (Sensitivity Analysis code based on INtegral Transport theory) was developed in Osaka University to calculate the sensitivity coefficients of cell parameters based on collision probability method. It is able to treat the strong heterogeneity of cell structures accurately. But sensitivity coefficients calculated by SAINT-II haven't included the "indirect effect". Only the "direct effect" is evaluated in SAINT-II. Where, "direct effect" shows the sensitivity coefficients caused by the change of effective cross section for one target nuclide, and "indirect effect" shows the sensitivity coefficients caused by the change in effective cross section of other nuclide through the change in background cross section[2]. And "direct effect" shows the conventional sensitivity coefficients calculated by the generalized perturbation theory.

Therefore the system which calculates not only the direct portion of sensitivity coefficients (D-SC) but also the indirect portion of sensitivity coefficients (I-SC) was developed and the applicability of D-SC was assessed by quantifying I-SC in this study.

2. Sensitivity analysis

In this section, some of the new definitions used to sensitivity analysis are described.

D-SC is defined as the change in k_{eff} relative to the change in a certain nuclide cross section, considering the change in neutron flux but not the change in other nuclide cross section,

$$(S_{k,\sigma_x^i})_{direct} = \frac{\partial k}{k} \bigg/ \frac{\partial \sigma_x^i}{\sigma_x^i} = \frac{\sigma_x^i}{k}\frac{\partial k}{\partial \sigma_x^i}, \quad (1)$$

where "k" is multiplication factor, σ_x^i is the cross section for reaction "x" of a certain nuclide "i".

On the other hand, I-SC is defined as the change in k_{eff} relative to the change in other nuclide cross section, caused by the change in the background cross section through the change in cross section of nuclide "i". Therefore I-SC for the cross section of nuclide "i" and reaction type "x" can be evaluated by the following Eq. (2);

$$\begin{aligned}(S_{k,\sigma_x^i})_{indirect} &= \sum_j \sum_y \frac{\sigma_y^j}{k}\frac{\partial k}{\partial \sigma_y^j} \times \frac{\sigma_x^i}{\sigma_y^j}\frac{\partial \sigma_y^j}{\partial \sigma_x^i} \\ &= \sum_j \sum_y S_{k,\sigma_y^j} S_{\sigma_y^j,\sigma_x^i}\end{aligned}, \quad (2)$$

where the first fraction shows the conventional sensitivity coefficients of nuclide "j" and reaction type "y", and the second fraction shows the sensitivity coefficient for the cross section of nuclide "j" and reaction type "y" relative to the change in cross section of nuclide "i" and reaction type "x". I-SC for the cross section of nuclide "i" and reaction type "x" is evaluated by summing up for reaction type and nuclide.

The total sensitivity coefficients (T-SC) are calculated as the sum of D-SC and I-SC,

$$\begin{aligned}(S_{k,\sigma_x^i})_{total} &= \frac{\sigma_x^i}{k}\frac{dk}{d\sigma_x^i} \\ &= (S_{k,\sigma_x^i})_{direct} + (S_{k,\sigma_x^i})_{indirect} \\ &= S_{k,\sigma_x^i} + \sum_j \sum_y S_{k,\sigma_y^j} S_{\sigma_y^j,\sigma_x^i}\end{aligned}. \quad (3)$$

3. Calculations and Results

3.1 Calculation Approach

SRAC2006[3] was used to obtain the group-wise cross sections for JENDL-3.3[4]. The group-wise cross sections were used in SAINT-II to obtain D-SC. I-SC and T-SC were calculated by using the self-shielding factor been built in cross section library set. All calculations were performed in 107 energy groups. The target system in this paper is the enrichment of ^{235}U is 3.0wt% for the UO_2 cell and calculated in the infinite homogeneous mixture. The results are limited for the multiplication factor as the target neutronic property.

3.2 Results

Here we will show two typical results. One is the sensitivity coefficients of ^{238}U capture cross section and ^{235}U elastic cross section for the multiplication factor.

3.2.1 ^{238}U capture cross section

T-SC and D-SC of ^{238}U capture cross section are shown in Fig. 1. The reason why the difference between T-SC and D-SC is small is as follows. At first, I-SC caused by ^{235}U has negative and positive portion caused by the capture and fission, respectively, and this bring a cancellation as I-SC. This is shown in Fig. 2. Secondary, the number density of ^{235}U is two orders of magnitude smaller than that of ^{238}U, and this causes the small change in self-shielding effect of ^{235}U by changing the cross section of ^{238}U. This brings that the magnitude of I-SC is much smaller than that of D-SC.

This result shows that D-SC which is used as conventional sensitivity coefficient is adequate as T-SC, in this case.

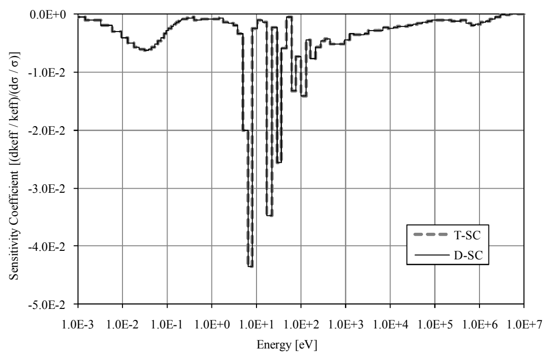

Fig. 1 T-SC and D-SC of ^{238}U capture cross section

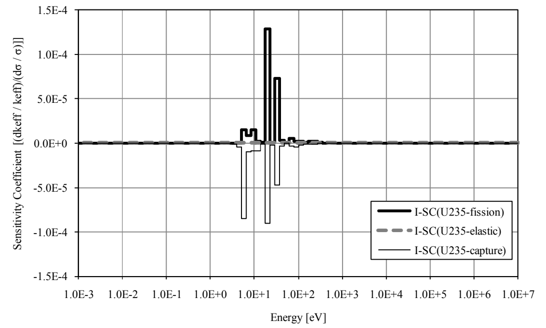

Fig. 2 The breakdown of I-SC by ^{235}U

3.2.2 ^{235}U elastic scattering cross section

Figure 3 shows another result; T-SC and D-SC of ^{235}U elastic scattering cross section. The difference between T-SC and D-SC is large especially in the following energy ranges; 6.48eV~8.32eV, 17.6eV~22.6eV and 29.0eV~37.3eV. The reason why the difference is large is as follows. In those energy ranges, ^{238}U resonance capture cross section peaks exist and D-SC of ^{235}U elastic is positive because ^{235}U elastic scattering reaction escapes ^{238}U resonance capture. The magnitude of I-SC of ^{238}U capture cross section is large compared to D-SC of ^{235}U because there is no cancelation of I-SC for ^{238}U and the number density of ^{238}U is two orders of magnitude larger than that of ^{235}U.

This result shows that the D-SC is not always adequate as T-SC in the case where the magnitude of sensitivity coefficients is not so large.

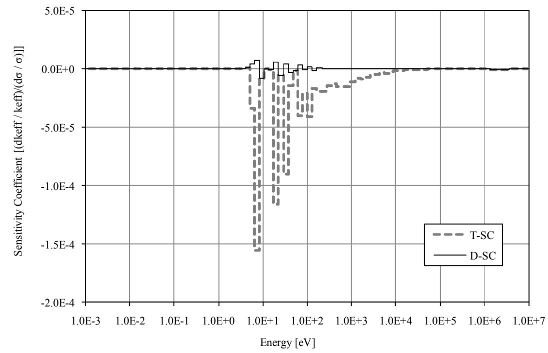

Fig. 3 T-SC and D-SC of ^{235}U elastic cross section

4. Conclusion

In this study, the system which calculates not only D-SC but also I-SC was developed and D-SC was assessed by quantifying I-SC. It is found that D-SC is adequate in case that D-SC is large such as ^{238}U capture cross section, however D-SC is not always adequate in the cases where D-SC is not so large.

The calculation for MOX fueled cell is under investigation and is planned to present the results at the conference.

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