ATCROSS - Cross Section Adjustment Tool for Fast Reactor Design

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1. Introduction

In order to develop the competitive design of fast reactor core in Republic of Korea, the conventional cross section adjustment method is considered as a promising tool to improve prediction accuracy of the target core parameters. The new computational code ATCROSS was developed in KAERI, and will serve as an effective computational system in the future SFR design process. In addition, the determination of cross section uncertainty propagation on evaluated result was implemented into the code, so the potential impact of inaccurate quantities in evaluated nuclear data such as microscopic cross sections can be determined and quantified. Correlations as well as uncertainties contained in nuclear data can have a significant impact on the overall uncertainty in the calculated response; thus, it is important to include covariances as well as variances in the uncertainty analysis.

2. ATCROSS techniques, methods and capabilities

The main principle of the conventional cross section adjustment method (CA) is that adjustments are applied to the evaluated cross section data as much as possible within their error limits and taking into account correlations, in such a way, that a better agreement between calculated results and measured integral data is obtained. An important precondition for the cross section adjustment method is that the linear relation always exists between variations of an integral data R (responses for the each experiment) and differential data T (cross section set):

$$\delta R = S.\delta T\,, \tag{1}$$

where the symbol S denotes the cross section sensitivity coefficients. Assuming that the cross-section set has a Gaussian distribution, and by using Bayesian theorem (basic derivations are described elsewhere [1] in detail) the posterior cross-section set of (CA) method T' is derived as:

$$T' = T_0 + MS^T\left[SMS^T + V_e + V_m\right]^{-1}\left[R_e - R_c(T_0)\right], \tag{2}$$

where M stands for the prior covariance matrix and $V_e + V_m$ are the variances with respect to the experiment and the analysis (calculation) method respectively. The subscripts "e/c" represent if the response was experimentally measured or if it was calculated. Posterior covariance matrix satisfies the equation:

$$M' = M - MS^T\left[SMS^T + (V_e + V_m)\right]^{-1}. \tag{3}$$

If we consider the cross-section error and the method error independently, the adjustment response becomes:

$$Var(R(T')) = SM'S^T + V_m\,. \tag{4}$$

As a result, adjusted cross section data, adjusted responses and variations for the target and the integral experiments are obtained. In addition, the uncertainty ΔR on the target integral parameter can be evaluated by the well-known sandwich formula:

$$\Delta R^2 = S_R M S_R^T\,, \tag{5}$$

where the impact of the individual reactions and energy groups can be evaluated separately. The diagonal elements of the resulting matrix (5) represent the relative variance values for each of the system under consideration, and the off-diagonal elements are the relative covariances between given experiments. In order to evaluate the individual contribution to the uncertainty associated to a single cross section σ_{lmn} (isotope l, reaction r, and energy group n), ΔR_{lmn} is derived as:

$$\Delta R_{lrn} = \sqrt{S_{lrn}^2 m_{lrn} + \Sigma_k^{Ncorr} Corr_k S_{lrn} m_{lrn} S_k m_k}\,, \tag{6}$$

where m are the elements of covariance matrix and k is the index for all $Ncorr$ (i.e. the total number of other cross sections that are correlated to current one).

3. Calculation specifications

In order to demonstrate the capabilities of ATCROSS code, the sensitivity profiles for the specific experiments defined by Subgroup 33 web page [2] were used. All of these sensitivity profiles were calculated by CEA (*Commissariat l'energie atomique et aux énergies alternatives - France*) in 33 energy group format suitable for the fast reactor calculations. The covariance data (JENDL-4.0) were prepared by NJOY99.396 code. The list of integral experiments, the associated response values and standard deviations are shown in the Tab. 1.

Table I: The list of experiments and associated data

No.	Experiment	R_e	σ_{Re}	R_c
1.	Flattop	1.00000	0.00300	0.99801
2.	Jezebel	1.00000	0.00200	0.99814

3.	Jezebel Pu240	1.00000	0.00200	1.00256
4.	Joyo	1.00105	0.00180	1.00022
5.	ZPPR9	1.00077	0.00117	1.00072
6.	ZPR6-7	1.00051	0.00230	1.00322
7.	ZPP6-7 Pu240	1.00080	0.00220	1.00301
8.	Flattop F28/F25	0.17990	0.01100	0.17805
9.	Flattop F37/F25	0.85610	0.01400	0.84316
10.	Jezebel F28/F25	0.21330	0.01100	0.21275
11.	Jezebel F37/F25	0.98350	0.01400	0.96872
12.	Jezebel F49/F25	1.46090	0.00900	1.44056
13.	ZPPR9 C28/F25	0.12960	0.01900	0.13003
14.	ZPPR9 F49/F25	0.92250	0.02000	0.90073

The first seven responses correspond to the multiplication factor and the rest to the measured spectral indexes. For the target core, ZPR6-7 Pu240 experiment was used with the calculated response equal to 1.00301. The real measured value of effective multiplication coefficient reach the value 1.0008.

4. Results

In this section the results of the adjustment are presented and briefly discussed. Due to the limited space, results are mainly introduced in the graphical form. The prior and posterior C/E responses with their variances are shown in the next figure.

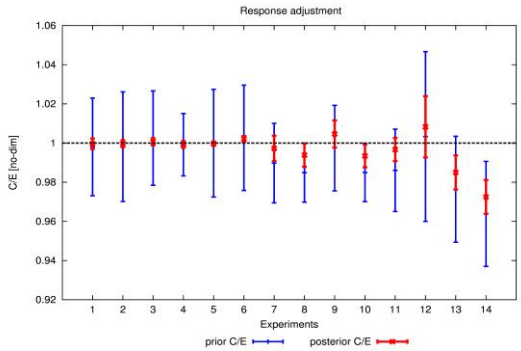

Fig. 1. The prior and posterior C/E responses.

As it is clearly shown in the Fig. 1, posterior responses are pushed much closer to the reality and their variances were significantly decreased as well. In the case of experiments number 13 and 14, the original data were greatly biased, and therefore the CA method was not able to reach the correct value within one standard deviation. These results imply that these experiments suffer from some kind of inaccuracy and should be carefully revised in the future. The target core response was also pushed closer to the reality when the new response value reaches 1.00193. The next Fig. 2 gives information about the size of uncertainty coming from the cross section data in each of the investigated experiments and shows the similarity between each sensitivity profile and the target core described by the correlation factor.

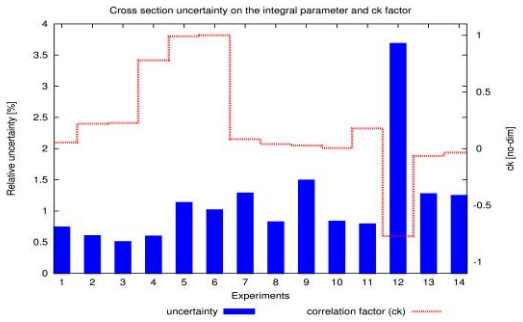

Fig. 2. The cross section uncertainty on the integral parameter.

The highest uncertainty coming from the cross section data is observed in experiment No. 12. The almost perfect match of sensitivity profiles between target and the experiment was achieved in No. 6. The target uncertainty analysis shows that the two highest contributors to the overall uncertainty are ^{238}U capture and inelastic reactions which was also confirmed by the highest reaction-reaction.

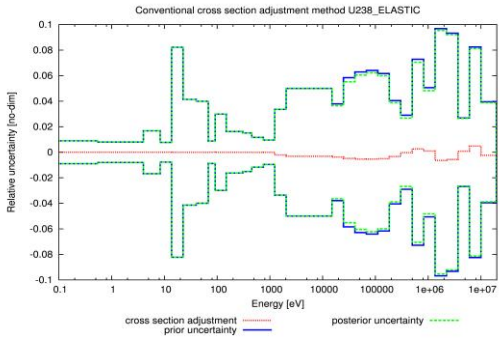

Fig. 3. The adjustment trend for isotope ^{238}U - reaction elastic.

In the Fig. 3 it can be seen that adjustments were also applied to elastic reaction of ^{238}U mainly in the fast energy range.

3. Conclusions

This paper introduces the new code ATCROSS and briefly presents its abilities to improve prediction accuracy of the target core parameters. In conjunction with the cross section uncertainty analysis module, it can play a significant role in the future fast reactor development in Republic of Korea.

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