Validation of Sensitivity Analysis Code APSTRACT for Fast Reactor Design

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1. Introduction

A sensitivity analysis code APSTRACT (Analyzer of Perturbation and Sensitivity with TRAnsport Calculation) has been developed as an essential step of fast reactor development in Republic of Korea[1]. Validated and comprehensive sensitivity processing tool with conjunction with nuclear data covariances may serve as a powerful utility to obtain the uncertainty, due to the data, in calculated quantities of applied interest [2]. Further application of generalized method of least squares combined with experimental measurements may improve used cross section evaluation in order to achieve better calculation results and smallest possible uncertainties. Validation of sensitivity coefficients generation procedure is in a frame of a calculation bias estimation and cross section adjustment process fundamental and highly requested necessity and should be carried out carefully.

2. Calculation methods

Computational route to determine sensitivity coefficients by APSTRACT code is based on 150 group MATXS and ISOTX format data library from ENDF/B-VII. The KALIMER-150 equilibrium core flux was used as a weighting function in NJOY library processing [3] and the self-shielding calculation was performed by TRANSX [4]. Flux solver TWODANT, transport code included in the modular DANTSYS [5], was chosen to determine angular forward and adjoint fluxes . For validation purposes, 238 group sensitivity data sets were also independently generated by SCALE6.1.1 system where stochastic Monte Carlo KENO6 module was used as a neutron solver and sensitivity coefficients were carried out by TSUNAMI-3D module. As a reference ERANOS 33 groups results coming from CEA (*Commissariata l'energie atomique et aux énergies alternatives - France*) and PSI (*Paul Scherrer Institute - Switzerland*) published on the WPEC Subgroup 33 web page were plotted in the final results comparison. In order to make an extensive validation four modified R-Z benchmark problems defined by Subgroup 33 were investigated, namely: Joyo, ZPPR9, ZPR6-7 (standard configuration) and ZPR6-7 (High ^{240}Pu content)[6]. The calculated sensitivity coefficients in the 150 and 238 group structure were condensed to 33 energy group format which is suitable for comparison with the reference Subgroup 33 data.

3. APSTRACT techniques and capabilities

Sensitivity analysis code APSTRACT is based on standard perturbation theory which is based on steady state Boltzmann transport equations. After some modifications and taking into account the perturbed transport operators further derivation leads to the common expression of the multiplication factor first order sensitivity.

$$S_k = \frac{\frac{dk}{k}}{\frac{d\sigma_{r,n,x,g}}{\sigma_{r,n,x,g}}} = -k \frac{\left\langle \Psi^*, \left(A - \frac{F}{k} \right)_{r,n,x,g} \Psi \right\rangle}{\langle \Psi^*, F\Psi \rangle} \quad (1)$$

The A and F stand for the Boltzmann transport and production operators, Ψ and Ψ^* represent angular forward and adjoint fluxes, k is the multiplication factor and $\sigma_{r,n,x,g}$ symbolizes a microscopic cross section in position r, for nuclide n, reaction x and energy group g respectively.

4. Results

TWODANT deterministic flux calculations were performed with Sn-8 and P-3 Legendre order of scattering configuration. KENO6 stochastic flux calculations were run with 10,000 histories/generation for forward calculation and 100,000 histories/generation for adjoint calculation until the computational statistic reached sufficient accuracy. Afterwards both fluxes were directly used in TSUNAMI-3D module. The comparisons of sensitivity profiles for chosen reactions and for most important isotopes are presented below. The sensitivity profiles of individual benchmark cases were in a good accordance, therefore the results from JOYO and ZPR6-7 investigation are presented only which can been seen in Tab.1.

Tab. 1. Comparison of total sensitivity of U^{238} capture

$S^{U238}_{capture}$	ZPR6-7	ZPR6-7 High Pu	ZPPR9	JOYO
APSTRACT 33g	-2.43E-01	-2.42E-01	-2.63E-01	-1.36E-01
APSTRACT 150g	-2.49E-01	-3.16E-01	-2.72E-01	-1.31E-01
SCALE	-2.46E-01	-2.37E-01	-2.64E-03	-1.27E-01
PSI-ERANOS	-2.44E-01	-2.38E-01	-2.66E-01	-1.28E-01
CEA-ERANOS	-2.44E-01	-2.37E-01	-2.65E-01	-1.27E-01

In each figure two APSTRACT profiles can be seen where in the first case the neutron flux and sensitivities were calculated in 150 group structure and then condensed to 33 group structure. In the second case the neutron flux based on 150 group calculation was used in TRANSX code in order to process 33g group cross section libraries which were afterwards used to determine 33 group sensitivity coefficients.

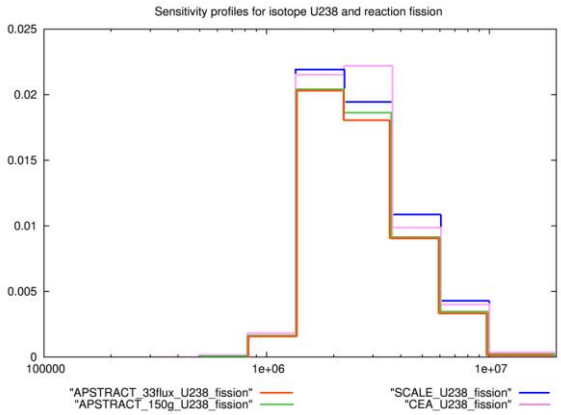

Fig. 1. Sensitivity profile of U^{238}fission in JOYO case

In the figures 1 and 3 it can be seen the sensitivity profiles of fission and capture reactions for isotope U^{238}. Except for one group in 33 group APSTRACT results shown in figure 3, all sensitivity profiles have very similar shapes and same order of magnitude.

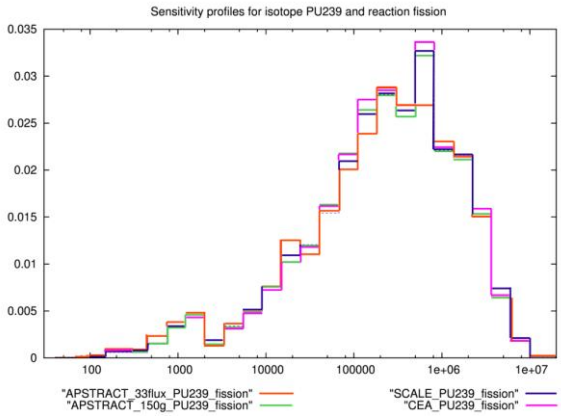

Fig. 2. Sensitivity profile of Pu^{238} fission in JOYO case

Figure 2 presents very good agreement between all profiles for the fission reaction of isotope Pu^{239}. Higher discrepancy can be observed in the sodium capture sensitivity profile for ZPR6-7, demonstrated in Figure 4. In the part with highest energies, in case of both APSTRACT results, the sensitivity goes rapidly to zero. However, SCALE and PSI results reached noticeable values. This behavior may be connected to the different sets of used cross section data.

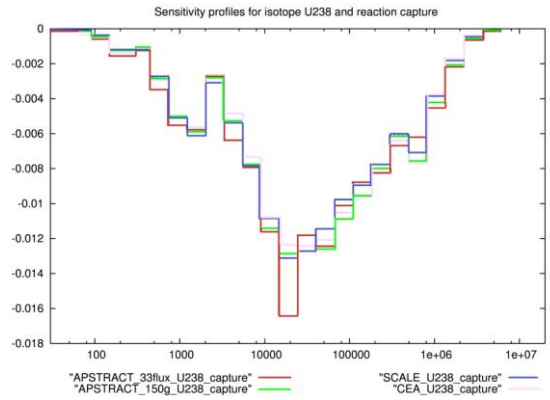

Fig. 3. Sensitivity profile of U^{238} capture in JOYO case

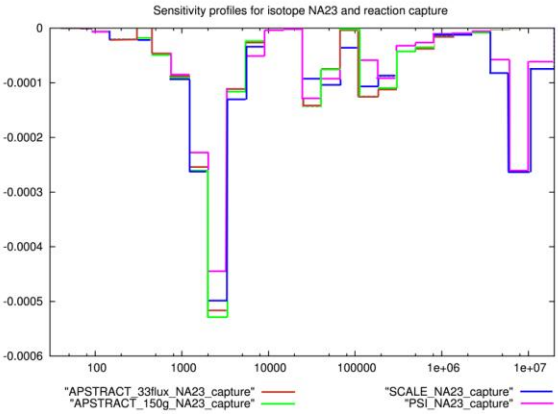

Fig. 4. Sensitivity profile of Na^{23} capture in ZPR6-7 case

5. Conclusion

A sensitivity analysis code APSTRACT has been developed within framework of cross section uncertainty and adjustment as a part of Korean Sodium Fast Reactor Program. Due to this reason the sensitivity validation process plays a significant part of the development. This paper presents the APSTRACT ability to provide comparable sensitivity coefficient profiles with well-known codes used worldwide. Therefore, after finalization of development it can serve as a part of unique and powerful tool in the future design studies.

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