Progressive Improvement of nTRACER Solutions for OPR1000 with Better Cross Section Treatments

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1. Introduction

At Seoul National University, nTRACER [1] is being developed as a direct whole core calculation code for which more research is being performed these days than the conventional two-step codes. nTRACER can model the core very precisely. It involves the planar-wise MOC-based CMFD formulation for sub-pin level calculations and the sub-group method for resonance self-shielding treatment. There have been several changes in nTRACER since its first version. The macro level grid method (MLG) was introduced to reduce the calculation burden of the subgroup fix source problems (SGFSP) [2]. Additionally, resonance interference factor (RIF) table method was adopted to treat the resonance interference effect [3]. Also, the spectral SPH method has been applied to consider the angular flux dependency of multigroup cross sections [4]. The purpose of this paper is to examine the fidelity of the updated nTRACER solutions for YGN Unit 3, which is the first OPR1000, by progressively improving the cross section treatments in nTRACER. The McCARD [5] solutions are sued as the references

2. YGN3 Models and Results

YGN Unit 3 has 177 assemblies which are in the 17x17 lattice. In all the calculations in this work, space/bottom grids and cutbacks are included. In Sections 2.1 and 2.2, 'Previous nTRACER' indicates the version before applying MLG, RIF table and spectral SPH and 'Updated nTRACER' indicates after applying these improvements. The calculation results of nTRACER are compared with those of McCARD for a HZP 2D quarter core and HZP Cycle 1 3D quarter core. In nTRACER the 47-group cross section library generated from ENDF/B-VII.0 is used. The ray tracing parameters are as follow: 16 azimuthal and 4 polar angles, and the ray spacing of 0.05cm. The anisotropic scattering treatment in MOC is done by transport corrected P_0 option and by the P_2 option. All the reference solutions from McCARD were calculated with 100,000 neutron particles and 500 inactive and 1500 active cycles.

2.1. HZP 2D Core Calculations

The *k*-eff and power distribution error are shown in Table 1. The results show that updated nTRACER agrees well with McCARD. The reactivity error is reduced about 100 pcm for both scattering orders. The relative error in radial power distribution is also improved as to its maximum and RMS error. The RMS error is reduced from 1.27% to 0.33% in P_0 case and 1.55% to 0.54% in P_2 case. As shown in Fig. 1 and Fig. 2, the power tilt behaviors of the radial power error distributions are improved in the updated nTRACER results when compared with the previous results.

Table 1. nTRACER, McCARD HZP 2D core *k*-eff and power distribution error comparison.

Scattering Order	nTRACER Version	*k*-eff	$\Delta\rho$ pcm	Radial Max. Rel. error [%]	Radial RMS error [%]
McCARD(reference)		1.00244			
P_0	Previous	1.00447	202	2.22	1.27
	Updated	1.00348	103	0.59	0.33
P_2	Previous	1.00509	263	2.44	1.55
	Updated	1.00400	155	1.12	0.54

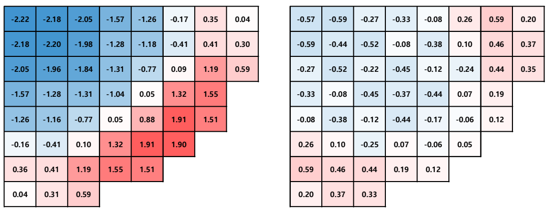

Fig. 1. Relative difference in radial power distribution of the 2D core in the P_0 calculation, previous nTRACER(left) and updated nTRACER(right).

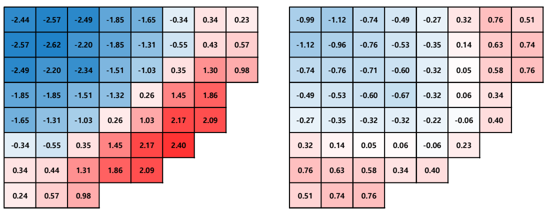

Fig. 2. Relative difference in radial power distribution of the 2D core in the P_2 calculation, previous nTRACER(left) and updated nTRACER(right)

2.2. Cycle 1 3D HZP Core Calculations

The *k*-eff results and the power distribution error for the 3D cases are shown in Table 2. The reactivity difference is reduced about 150 pcm in P_0 and 250 pcm in P_2. It shows that the nTRACER results agree well with the McCARD results. The RMS error in radial power distribution is reduced from 2.12% to 0.91% in P_0 case and from 1.53% to 1.18% in P_2 case. As shown in Fig. 3 and Fig. 4, the power tilt behavior decreases in updated nTRACER which is similar to 2D case.

Table 2. nTRACER, McCARD HZP 3D core *k*-eff and power distribution error comparison

Scattering Order	nTRACER Version	*k*-eff	Δρ pcm	Radial Max. Rel. error [%]	Radial RMS error [%]
McCARD(reference)		0.99835			
P_0	Previous	1.00079	244	4.47	2.12
	Updated	0.99934	99	1.80	0.91
P_2	Previous	1.00237	402	3.26	1.53
	Updated	0.99992	157	2.39	1.18

Fig. 3. Relative difference in radial power distribution of 3D core in the P_0 calculation, previous nTRACER(left) and updated nTRACER(right).

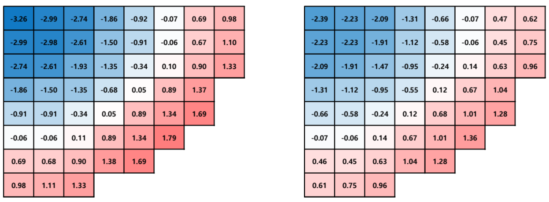

Fig. 4. Relative difference in radial power distribution of 3D core in the P_2 calculation, previous nTRACER(left) and updated nTRACER(right).

2.3. Effect of Weighting Spectrum used in Generation of Shroud Multigroup Cross Section

nTRACER library contains specially treated cross sections for the nuclides frequently used in shroud. In the nTRACER library, the multigroup cross sections of the nuclides in the reactor are generated from the ultrafine group spectra of a representative fuel pin. Therefore, the shroud nuclides usually have the same multigroup cross sections generated using ultrafine spectra in cladding. However, for the reason that the shroud spectra are significantly different from those in active volume in reactor, MG cross sections weighted with the spectra of the shroud were added for the shroud nuclides.

Fig.5 shows the ultrafine spectra in the cladding and the shroud region generated with CENTRM and McCARD, respectively. Both the flux spectra are normalized to make the total fission source unity. The flux spectra show the different shapes which make different multigroup cross section especially over 100 eV as shown in Fig.6. The solid lines here are the macroscopic cross sections weighted with shroud spectra and the dotted lines are the error of them from weighting spectra. Therefore, nTRACER should use the multigroup cross section which is obtained with shroud spectra.

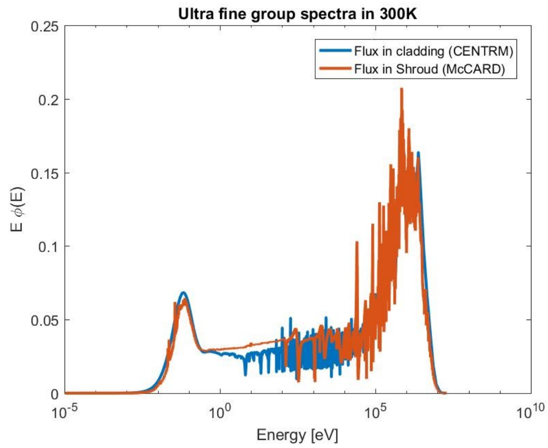

Fig. 5. Comparison of cladding and shroud ultrafine spectra

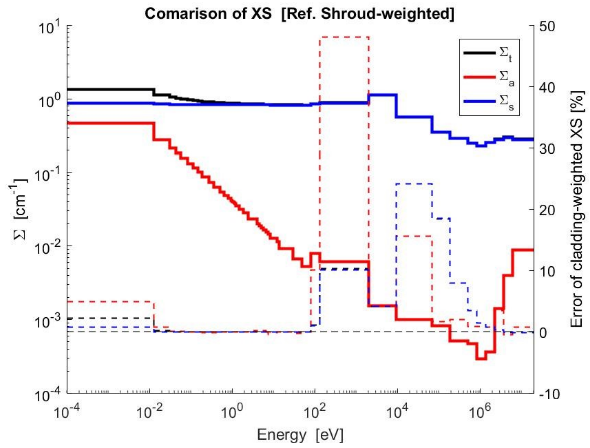

Fig. 6. Comparison of cladding and shroud cross section. Solid: multigroup XS, dotted: error

The results which are indicated as 'updated nTRACER' at 2.1 and 2.2, the cross sections generated with cladding spectra are used for shroud material. The following part are the calculation results of nTRACER using cross section generated with shroud spectra for shroud material in 2D and 3D core cases. The 'Shroud' in XS type in Table 3 and Table 4 indicates the XS generated with the spectra from shroud and 'Cladding' indicates that generated with the spectra from cladding.

In Table 3, it is shown that in 2D core case the reactivity difference is reduced about 20 pcm. The RMS error in radial power distribution is reduced from 0.33% to 0.27% in P_0 case and from 0.54% to 0.23% in P_2 case. The power tilt is also improved in both cases.

Table 3. nTRACER, McCARD HZP 2D core *k*-eff and power distribution error comparison.

Scattering Order	XS type for the shroud	*k*-eff	$\Delta\rho$ pcm	Radial Max. Rel. error [%]	Radial RMS error [%]
McCARD(reference)		1.00244			
P_0	Cladding	1.00348	103	0.59	0.33
	Shroud	1.00330	86	0.41	0.27
P_2	Cladding	1.00400	155	1.12	0.54
	Shroud	1.00384	139	0.59	0.23

Fig. 7. Relative difference in radial power distribution of 2D core in the P_0 calculation, cladding (left) and shroud (right).

Fig. 8. Relative difference in radial power distribution of 2D core in the P_2 calculation, cladding (left) and shroud (right).

In Table 4, it is shown that in 3D core case the reactivity difference is reduced about 20 pcm. The RMS error in radial power distribution is reduced from 0.91% to 0.65% in P_0 case and from 1.18% to 0.87% in P_2 case.

Table 4. nTRACER, McCARD HZP 3D core *k*-eff and power distribution error comparison.

Scattering Order	XS type for the shroud	*k*-eff	$\Delta\rho$ pcm	Radial Max. Rel. error [%]	Radial RMS error [%]
McCARD(reference)		0.99835			
P_0	Cladding	0.99934	99	1.80	0.91
	Shroud	0.99916	81	1.02	0.65
P_2	Cladding	0.99992	157	2.39	1.18
	Shroud	0.99975	140	1.67	0.87

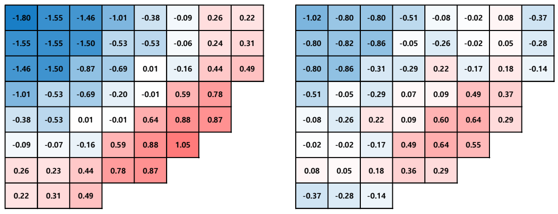

Fig. 9. Relative difference in radial power distribution of 3D core in the P_0 calculation, cladding (left) and shroud (right).

Fig. 9. Relative difference in radial power distribution of 3D core in the P_2 calculation, cladding (left) and shroud (right).

3. Conclusion

The YGN Unit 3 is calculated with updated nTRACER direct whole core and the results are compared with McCARD MC code. In HZP 2D core case, the reactivity difference between nTRACER and McCARD is reduced about 100 pcm and it agreed well, 103 pcm in P_0 and 155 pcm in P_2 anisotropic scattering. In HZP Cycle 1 3D core case, nTRACER also agree well with McCARD, 99 pcm in P_0 case and 157 pcm in P_2 case. The RMS error in radial power distribution were reduced and the power tilt of nTRACER is improved as well. Due to the cross section change in the shroud region, the power distribution error could be reduced evidently in both 2D and 3D cases.

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