Effect of Anisotropic Scattering on MOX fuel Analysis

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The effect of anisotropic scattering on neutronic performances is investigated for MOX fuel analysis not only in the fuel cell but also in one-dimensional core geometry. It is found that the effect of anisotropic scattering for UO_2 fuel is small, but it is large for MOX fuel. To treat the high order anisotropic scattering, the treatment up to P_3 scattering is enough for the MOX fuel analysis.

1. Introduction.

The conventional method treats the effect of anisotropic scattering by the transport correction, but this method is inadequate for MOX fuel cell [1]. So the high order anisotropic scattering is considered for MOX fuel cell and numerical results are obtained. Furthermore, to treat the effect of anisotropic scattering on core characteristics, we investigate the effect in one-dimensional core geometry.

2. Calculation model.

The effective macroscopic cross section was obtained by SRAC95 [2] based on JENDL-3.2 [3]. For the cell calculation, we used the MARIKO [1] code (method of characteristics) and both MOX and UO_2 fuel cells are investigated: the cell pitch is 1.26cm, the fuel inner diameter is 0.403cm and the cladding outer diameter is 0.475cm. To change the moderator to fuel volume ratio, the cell pitch was changed. For one-dimensional core geometry calculation, we used the TWOTRAN-II [4] and calculated the core characteristics of MOX fuel: the width of core region is 80cm or 300cm, and the core is consisted of several fuel, cladding and moderator regions and the each region has been chosen close to the real cylindrical cell preserving the volumes, the thickness of the reflector varies from 0cm to 30cm and the boundary condition is vacuum.

3. Calculation Results and Discussions.

a. Effect of moderator subdivision

We divided the moderator region up to 120. The effect of moderator subdivision on k_∞

is presented on Table 1. In the case of no moderator subdivision, the average neutron current is zero, so the effect of P_1 scattering becomes zero. By increasing the moderator subdivision, the effect of P_1 scattering for MOX fuel cell varies up to about -0.16%, although the effect of transport correction varies from about +0.19% to +0.17%. The total effect (of replacing the transport corrected cross section with P_1 scattering) varies from about -0.19% to -0.33%. Figure 1 shows the difference of neutron spectrum for MOX fuel cell in the moderator region between transport correction (or the P_1 scattering case) and the P_0 scattering case in the case of 4 regions subdivision. The transport correction has soft neutron spectrum compared to the P_0 scattering case, so the effect of transport correction has positive sign; +0.19%. On the other hand, the P_1 scattering case has hard neutron spectrum compared to the P_0 scattering case, so the effect of P_1 scattering has negative sign; -0.12%.

b. Effect of high order anisotropic scattering

The effect of high order anisotropic scattering on k_∞ is presented on Table 2. The effect of high order anisotropic scattering is smaller than that of P_1 scattering; the effect of treatment up to P_5 scattering for MOX fuel cell is about -0.23%, but the effect of P_1 scattering is about -0.16%. The effect of treatment up to P_3 scattering is about -0.22%, it is enough to treat the anisotropic scattering. The effect of anisotropic scattering for UO_2 fuel cell is small; the effect of treatment up to P_5 scattering is about -0.03%.

c. Effect of moderator to fuel volume (Vm/Vf) ratio

The effect of Vm/Vf ratio on k_∞ is presented on Table 3. In the case of Vm/Vf ratio of 1.7, the effect (of replacing the transport corrected cross section with P_5 scattering) is about -0.39%. In the case of Vm/Vf ratio of 1.0, the effect is not changed; about -0.36%. In the case of Vm/Vf ratio of 3.0, the effect decreases to about -0.26%. This is because the effect of transport correction decreases with large Vm/Vf ratio (soft neutron spectrum); the effect is +0.22% with Vm/Vf ratio of 1.0, the effect is +0.17% with that of 1.7, the effect is +0.06% with that of 3.0. Figure 2 shows the macroscopic transport and total cross section for MOX fuel cell in fuel and moderator regions. The difference of macroscopic cross section between transport and total cross section decreases with the decrease of energy, so the effect of transport correction decreases with the softening of neutron spectrum.

d. Effect of anisotropic scattering in 1-D core geometry

Table 4 shows the effect of anisotropic scattering on k_{eff} in 1-D core geometry for MOX fuel. The effect depends on the core width; the effect is about -2.55% for core width of

80cm, but is about -0.56% for that of 300cm, this is because the outside of the reflector is vacuum and the neutron current for core width of 80cm is larger than that of 300cm; Figure 3 shows that the neutron current for core width of 300cm is quite different from that of 80cm.

4. Conclusion.

The effect of anisotropic scattering for MOX fuel cell is about -0.39%. The effect of high order anisotropic scattering is small and the treatment up to P_3 scattering is enough for MOX fuel analysis. The large Vm/Vf ratio decreases the effect of anisotropic scattering. It is concluded that the effect of anisotropic scattering is small for UO_2 fuel, but it is large for MOX fuel, so the transport correction is inadequate for MOX fuel.

References

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[3] Shibata, K., *et al.*: "Japanese Evaluated Nuclear Data Library, Version-3.2" ---JENDL-3.2---, JAERI-1319 (1990).
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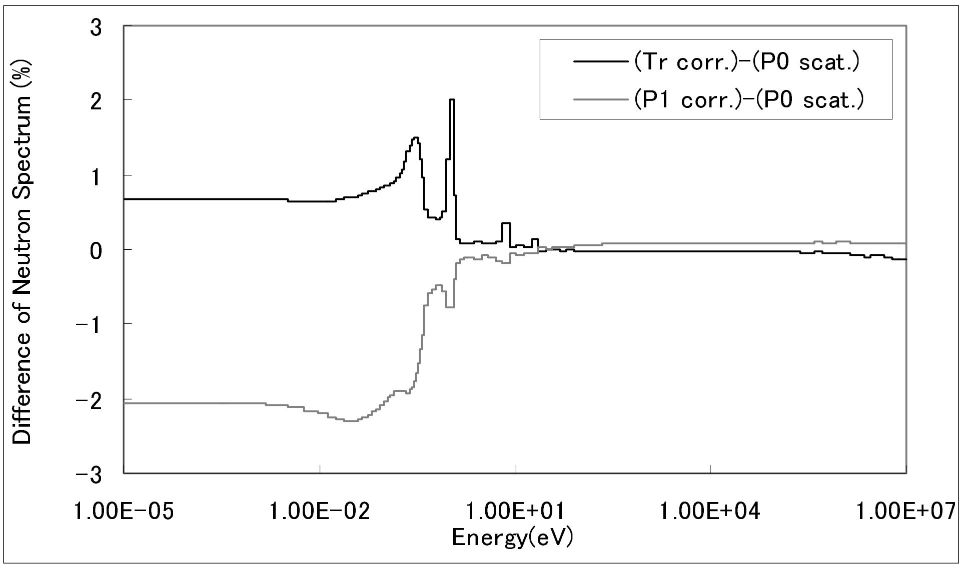

Figure 1 Difference of Neutron Spectrum for MOX Fuel Cell in Moderator Region

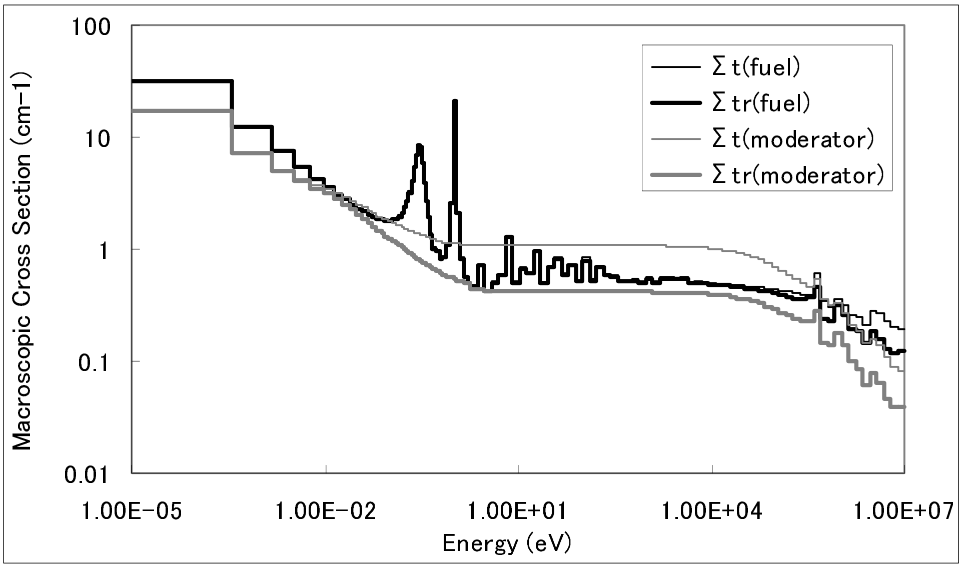

Figure 2 Macroscopic Cross Section for MOX Fuel

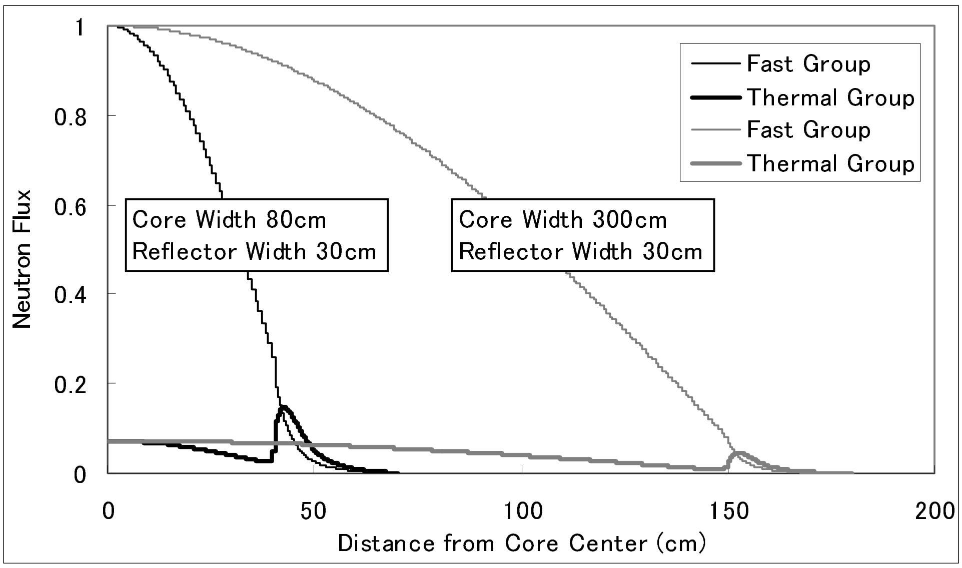

Figure 3 Neutron Flux Distribution for MOX Fuel

Table 1 Effect of moderator subdivision on k_∞

No subdivision.

	k_∞	Δk_∞		
	P_0 scattering	Transport correction*	P_1 scattering*	$\Delta k_{P1}-\Delta k_{tr}$**
MOX	1.19598	+0.191	+0.000	-0.191
UO_2	1.36798	+0.046	+0.000	-0.046

4 regions.

	k_∞	Δk_∞		
	P_0 scattering	Transport correction	P_1 scattering	$\Delta k_{P1}-\Delta k_{tr}$
MOX	1.19598	+0.191	-0.118	-0.309
UO_2	1.36798	+0.047	-0.011	-0.058

8 regions.

	k_∞	Δk_∞		
	P_0 scattering	Transport correction	P_1 scattering	$\Delta k_{P1}-\Delta k_{tr}$
MOX	1.19604	+0.177	-0.136	-0.313
UO_2	1.36762	+0.048	-0.008	-0.056

120 regions.

	k_∞	Δk_∞		
	P_0 scattering	Transport correction	P_1 scattering	$\Delta k_{P1}-\Delta k_{tr}$
MOX	1.19607	+0.165	-0.163	-0.328
UO_2	1.36721	+0.051	-0.004	-0.055

* Relative difference of k_∞ from P_0 scattering case.

** Difference of k_∞ for P_1 scattering and transport correction.

Table 2 Effect of high order scattering on k_∞

Vm/Vf=1.7

	k_∞	Δk_∞						
	P_0	Tr corr.*,+	P_1**,+	P_2**,+	P_3**,+	P_4**,+	P_5**,+	$\Delta k_{P5}-\Delta k_{tr}$++
MOX	1.19607	+0.165	-0.163	-0.209	-0.221	-0.221	-0.225	-0.390
UO_2	1.36721	+0.051	-0.004	-0.026	-0.030	-0.030	-0.030	-0.081

* Transport correction.

** Treatment up to P_n scattering.

+ Relative difference of k_∞ from P_0 scattering case.

++ Difference of k_∞ for P_5 scattering and transport correction.

Table 3 Effect of moderator to fuel volume ratio on k_∞

Vm/Vf=1.0

	k_∞	Δk_∞						
	P_0	Tr corr.$^{*,+}$	$P_1^{**,+}$	$P_2^{**,+}$	$P_3^{**,+}$	$P_4^{**,+}$	$P_5^{**,+}$	Δk_{P5}- Δk_{tr}^{++}
MOX	1.11465	+0.216	-0.109	-0.139	-0.143	-0.143	-0.146	-0.362
UO_2	1.25045	+0.100	-0.043	-0.070	-0.074	-0.074	-0.074	-0.174

Vm/Vf=3.0

	k_∞	Δk_∞						
	P_0	Tr corr.	P_1	P_2	P_3	P_4	P_5	Δk_{P5}- Δk_{tr}
MOX	1.28818	+0.062	-0.135	-0.179	-0.196	-0.196	-0.200	-0.262
UO_2	1.40320	+0.070	+0.100	+0.087	+0.083	+0.083	+0.083	+0.013

* Transport correction.

** Treatment up to P_n scattering.

+ Relative difference of k_∞ from P_0 scattering case.

++ Difference of k_∞ for P_5 scattering and transport correction.

Table 4 Effect of anisotropic scattering on k_{eff} in 1-D geometry

Core width: 80cm

	Thickness of Reflector	k_{eff}	Δk_{eff}		
		P_0 scattering	Tr corr.*	P_1 scattering*	Δk_{P1}- Δk_{tr} **
MOX	0cm	1.15171	-1.124	-2.548	-1.424
	10cm	1.16215	-0.882	-2.261	-1.379
	30cm	1.16242	-0.865	-2.235	-1.370

Core width: 300cm

	Thickness of Reflector	k_{eff}	Δk_{eff}		
		P_0 scattering	Tr corr.	P_1 scattering	Δk_{P1}- Δk_{tr}
MOX	0cm	1.19878	-0.193	-0.559	-0.366
	10cm	1.19909	-0.185	-0.552	-0.367
	30cm	1.19909	-0.183	-0.551	-0.368

Core width: ∞

	Thickness of Reflector	k_∞	Δk_∞		
MOX		P_0 scattering	Tr corr.	P_1 scattering	Δk_{P1}- Δk_{tr}
	0cm	1.20305	-0.091	-0.357	-0.266

* Relative difference of k_∞ from P_0 scattering case.

** Difference of k_∞ for P_1 scattering and transport correction.