Depletion Analysis of Spatial Self-shielding Effect for Double Heterogeneous Region Near Burnable Poison

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Introduction

- Double Heterogeneity (DH) Effect for a VHTR Fuel Compact in DeCART2D
  - ✓ Option 1 : Spatial self-shielding effect is considered by Sanchez & Pomraning Method, which needs pre-generated self-shielded MG XS library.
  - ✓ Option 2 : Spatial & energy self-shielding effect is treated by Pin-based point-wise Slowing-down Method for DH (PSM-DH) in the resonance energy region.
- Effective Homogenized Cross Section Method proposed for non-resonant spatial self-shielding effect
  - ✓ T. Y. Han, H. C. Lee, Treatment of Non-resonant Spatial Self-shielding Effect of Double Heterogeneous Region, Nuclear Engineering and Technology, available online, (2022).
  - ✓ Developed based on a spherical unit cell model with explicit coated layers and a matrix layer, which is consistent MOC calculation region with PSM-DH for the DH resonance treatment.

Purpose

- The depletion analysis of the effective homogenized cross section method is examined using VHTR mini block problem with burnable poison and the change of the spatial self-shielding effect with the depletion is investigated.

Review of Effective Homogenized Cross Section Method

- Effective Homogenized Cross Section for a homogenized compact

$$\tilde{\Sigma}\bar{\phi}V = \sum_i \Sigma_i \phi_i V_i$$

i : sub-region index for matrix and particle layers,
$\tilde{\Sigma}$: effective homogenized total macroscopic cross section,
$\bar{\phi}$: homogenized flux for a compact,
V : volume of a compact,
Σ_i : total macroscopic cross section at sub-region i,
ϕ_i : flux at sub-region i,
V_i : volume of sub-region i.

- Self-shielding Factor for Compact

$$f_i = \frac{\tilde{\Sigma}}{p_i \Sigma_i} \frac{P_i}{\sum_i P_i}$$

P_i : first collision probability at sub-region i.

- Transmission Probability for Homogenized Compact

$$T = \int_0^{2R_c} t(l) f(l) dl = \int_0^{2R_c} e^{-\tilde{\Sigma} l} \frac{l}{2R_c^2} dl$$

$t(l)$: transmission prob. in a chord, l.
$f(l)$: prob. Density function for the chord, l.

- Effective Cross Section for Compact

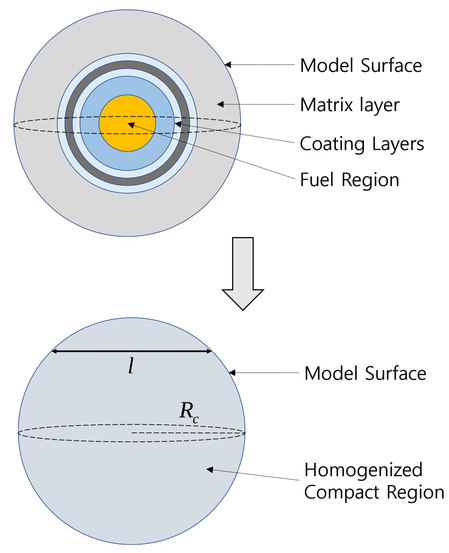
$$\tilde{\Sigma} \cong \frac{1}{2R_c}\left(1 - \frac{5}{\sqrt[3]{3}\hat{T}} + \frac{\hat{T}}{\sqrt[3]{9}}\right)$$

$$\hat{T} = \sqrt[3]{27 - 54T + 2\sqrt{3}\sqrt{92 - 243T + 243T^2}}$$

- Relation of transmission probability and collision probability.

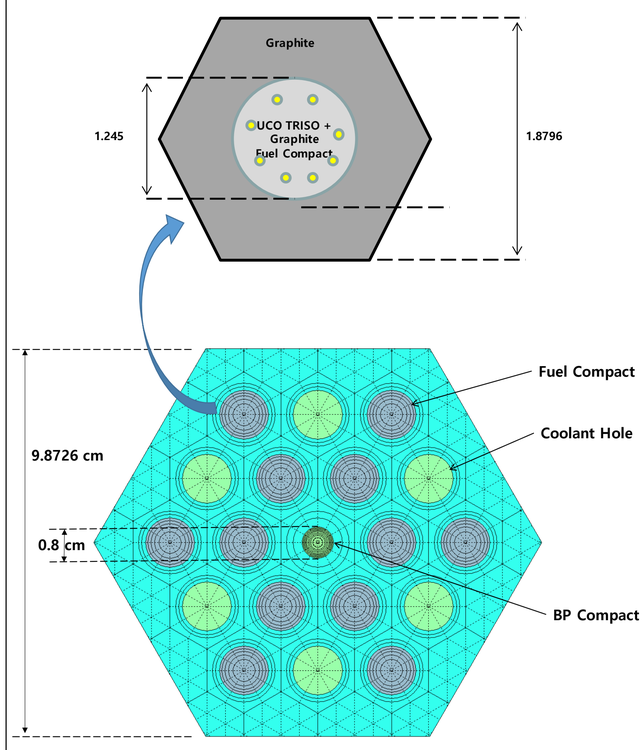
$$T = 1 - \sum_i P_i$$

$$P_i = \bar{l} p_i \Sigma_i \left(1 - \sum_j P_{ij}\right)$$



Result and Discussion

Mini Fuel Block Problem with Burnable Poison based on MHTGR-350



Burnup (Days)	TEMP=1200K, PF=35%					
	McCARD (M) (σ≈14 pcm)	DeCART with Hom.[1](H)	DeCART with Ehom.[2](E)	Diff. (H-M) (pcm)	Diff. (E-M) (pcm)	DH Effect[3]
0	1.14800	1.15250	1.14755	450	-45	-374
25	1.13260	1.13659	1.13179	399	-81	-374
50	1.14043	1.14377	1.13922	333	-121	-349
100	1.15520	1.15808	1.15399	288	-121	-306
150	1.16715	1.16997	1.16630	282	-85	-269
200	1.17722	1.17953	1.17627	231	-95	-235
250	1.18503	1.18714	1.18430	211	-73	-202
300	1.19145	1.19310	1.19069	165	-76	-170
350	1.19610	1.19763	1.19565	153	-45	-138
400	1.20010	1.20089	1.19933	79	-77	-109
450	1.20250	1.20299	1.20183	49	-67	-80
500	1.20387	1.20402	1.20324	15	-63	-54
625	1.20272	1.20244	1.20245	-28	-27	0
750	1.19603	1.19571	1.19626	-32	23	38
875	1.18548	1.18484	1.18569	-64	21	60
1000	1.17100	1.17077	1.17170	-23	70	68
1125	1.15419	1.15433	1.15517	14	98	63
1250	1.13581	1.13620	1.13678	39	97	45
1375	1.11604	1.11685	1.11704	81	100	15
1500	1.09544	1.09662	1.09627	118	83	-29

[1] Volume weighted homogenization for thermal energy range
[2] Effective homogenization method for thermal energy range
[3] $\frac{1}{k_H} - \frac{1}{k_E}$

- DH effect in the thermal range are not small (about 370 pcm) in the initial burnup step and decreases with depletion.
- DH effect is negligible over 500 days considering the DH effect in the resonance range (about 4500 pcm).
- The DH effect of fuel compact near BP is originated from the change of the thermal utilization caused by the self-shielding effect in the thermal range.
- The method can accurately reflect the DH effect in the thermal energy range for the depletion problem.
- The effect for fuel block with BP must be taken into consideration

Conclusions

- The depletion analysis of the recently proposed effective homogenized cross section method was examined using VHTR mini block problems with burnable poison and the change of the spatial self-shielding effect with the depletion was investigated.
- The calculations revealed that the DH effect in the thermal range are not negligible in the initial burnup step and decreases with depletion.
- The results shows that the effect is small when the BP effect disappear.