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Sub-Fine Lattice Stochastic Modeling of Randomly Distributed Particle Fuels with Variability in Packing Fraction

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1. Introduction

In VHTR or HTGR designs, coated particle fuels are randomly dispersed within pebbles or fuel compacts. The reported explicit modeling of the double heterogeneity introduced by the coated particle fuels includes coarse lattice models [1, 2], fine lattice models [3, 4], random sequential addition (RSA) models [5], and so on. In this paper, we provide a sub-fine lattice stochastic (Sub-FLS) model for analysis of the randomly packed coated fuel particles.

2. Methods

In this section the important characteristics of the Sub-FLS modeling are described.

2.1 Sub-Fine Lattice

One of the main differences between the original fine lattice and the new sub-fine lattice in this paper is the lattice size. We defined the simple cube fine lattice in Ref. 3 as one cube that circumscribes a single fuel particle, namely, the edge length of the fine lattice is $2R$ (2 times of the particle radius). Instead, we use $2R/\sqrt{3}$ as the spacing in sub-fine lattice to guarantee that each lattice can contain only one particle center point.

2.2 Random Placement of Particle Center Point

Another major improvement over FLS is the random placement scheme of particle center point within the sub-fine lattice, which is similar to the fast RSA method recently proposed in Ref. 6. This scheme adds more randomness to fuel particle distributions.

Furthermore, only two neighboring lattices need be checked for overlapping in each direction and thus Sub-FLS modeling reduces the overlapping checking burden drastically compared to basic RSA method.

2.3 Packing Fraction Variability (PFV) Sampling Method

The lattice probability sampling (LPS) concept as introduced in Ref. 4 is modified in this Sub-FLS modeling to reflect the variability in packing fraction realized in manufactured pebbles or compacts. The number of fuel particles in a pebble or compact may be off from the required one but the statistical average should approach the nominal packing fraction.

Differently from the equal probability in Ref. 4, we imbed the LPS concept in Sub-FLS modeling by treating the packing fraction as a mean value with a given variance (which would in practice represent the manufacturing quality). Therefore, the number of particles will be sampled following the Gaussian normal distribution with corresponding mean and variance in particle numbers. These sampled particle numbers are then placed in the above sub-fine lattice system as in Section 2.2 for MCNP runs.

2.4 Calculational Flow

The calculational flow is shown in Figure 1.

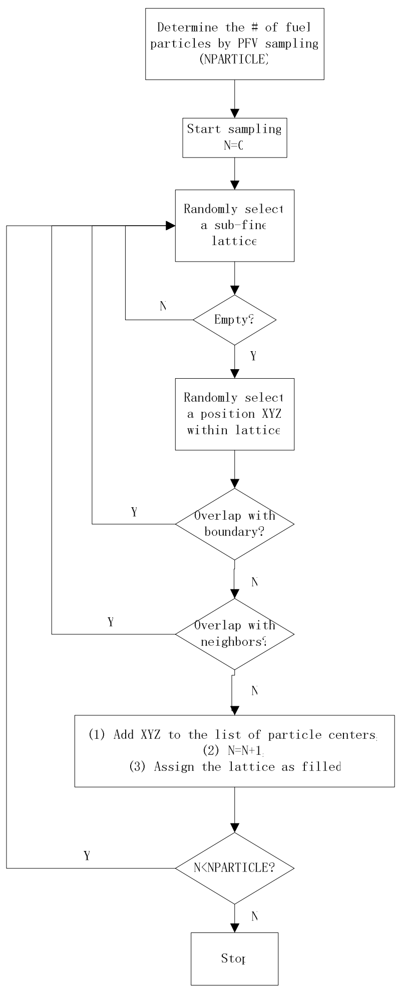

Figure 1. Calculational flow of Sub-FLS modeling

3. Numerical Results

The Sub-FLS model was tested on the same cube problem as described in Ref. 4. The criticality results are compared with other models in Table 1.

Table 1. Criticality Results of Cube Problem [a,b]

Models	$k_\infty \pm \sigma$	Δk_∞
FLS	1.57268 ± 0.00022	104pcm
Sub-FLS [c]	1.57168 ± 0.00019	4pcm
RSA	1.57195 ± 0.00023	31pcm
Metropolis	1.57164 ± 0.00022	(reference)

[a] 300 skip cycles and 1000 active cycles with 1000 histories per cycle

[b] mean value of multiple (12) realizations

[c] without PFV, 125 fuel particles in each realization

Figure 2 shows the number of particles sampled from the normal distribution of the packing fraction with mean of 0.04917 and variance of 0.0000015 (standard deviation of 0.00124). Table 2 and Figure 3 contain the results of k_∞ from MCNP criticality calculations with and without packing fraction variability (PFV).

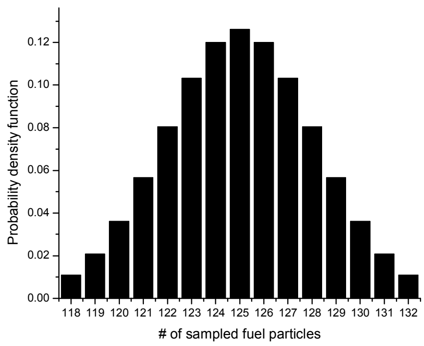

Figure 2. Distribution of # of sampled fuel particles

Table 2. Sub-FLS Results of Cube Problem [a]

# of realizations	Criticality results	
	Without PFV	With PFV imbedded
12	1.57168 ± 0.00019	1.57434 ± 0.00173
24	1.57164 ± 0.00016	1.57297 ± 0.00144
36	1.57172 ± 0.00015	1.57223 ± 0.00113

[a] 300 skip cycles and 1000 active cycles with 1000 histories per cycle

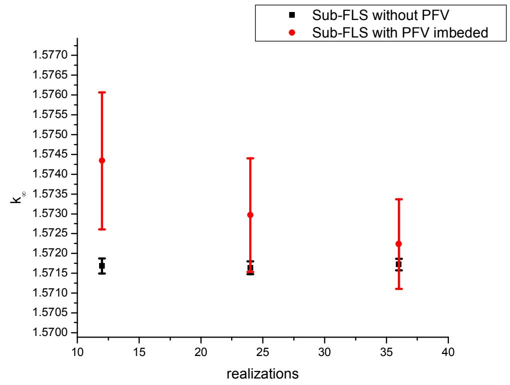

Figure 3. Comparison of Sub-FLS results

4. Conclusions

The sub-fine lattice stochastic (Sub-FLS) model was proposed and tested. This Sub-FLS model could be used conveniently to analyze the randomly packed coated fuel particles. Compared to the usual fixed lattice method, the Sub-FLS modeling allows more realistic stochastic distribution of fuel particles and thus results in more accurate criticality calculation. Compared to the basic RSA method, the Sub-FLS requires much simpler and efficient overlapping checking procedure.

The packing fraction variability (PFV) concept was introduced and successfully implemented into Sub-FLS model. By sampling the number of fuel particles following the Gaussian normal distribution of the packing fraction with corresponding mean and variance, PFV can reflect the fuel manufacturing quality.

ACKNOWLEDGEMENT

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