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HTGR Unit Fuel Pebble k-infinity Results Using Chord Length Sampling

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NOTICE

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INTRODUCTION

There is considerable interest in transport models that will permit the simulation of neutral particle transport through stochastic mixtures. Chord length sampling techniques that simulate particle transport through binary stochastic mixtures consisting of spheres randomly arranged in a matrix have been implemented in several Monte Carlo Codes [1-3]. Though the use of these methods is growing, the accuracy and efficiency of these methods has not yet been thoroughly demonstrated for an application of particular interest – a high temperature gas reactor fuel pebble element.

This paper presents comparison results of k-infinity calculations performed on a LEUPRO-1 pebble cell. Results are generated using a chord length sampling method implemented in a test version of MCNP [3]. This Limited Chord Length Sampling (LCLS) method eliminates the need to model the details of the micro-heterogeneity of the pebble. Results are also computed for an explicit pebble model where the TRISO fuel particles within the pebble are randomly distributed. Finally, the heterogeneous matrix region of the pebble cell is homogenized based simply on volume fractions. These three results are compared to results reported by Johnson et al [4], and duplicated here, using a cubic lattice representation of the TRISO fuel particles. Figures of Merit for the four k-infinity calculations are compared to judge relative efficiencies.

DESCRIPTION OF WORK

LEUPRO-1 Fuel Pebble Model

The model is the LEUPRO-1 pebble spherical unit cell described and analyzed by Johnson et al [4]. This unit cell was originally presented as a numerical benchmark for code/method intercomparisons. The material compositions for this pebble cell are well described in [4] and will not be represented here.

The pebble unit cell model has three concentric spherical shells. The outermost shell has an outer radius of 3.7959 cm with a diffuse (white) outer boundary condition. The outermost shell is homogenized coolant and graphite that represents the fuel ball surroundings. The next region has an outer radius of 3.0 cm and is comprised of graphite. The innermost region has an outer radius of 2.5 cm. This region is a graphite matrix containing 9394 UO_2 fuel kernels that are spheres of radius 0.04577 cm. Each fuel kernel possesses its own microstructure of 5 concentric spherical shells. The MCNP model created by Johnson et al treats the matrix region of the fuel pebble as a 3-D array of cubic cells 0.091 cm on a side. Each cubic cell contains a fuel kernel at its center.

Explicit Model

An explicit model of the LEUPRO-1 pebble cell was created to obtain another benchmark to compare against LCLS results. The true statistical distribution of fuel kernels was unknown and the random distribution of kernels in the matrix was created by the Random Sequential Addition method [5]. Fuel kernels were not permitted to overlap the matrix boundary or each other.

LCLS Model

The LCLS model contains only the 3 shell regions, with no detail of the matrix heterogeneity. Transport through the matrix is handled by randomly sampling surface crossings with fuel kernels. The LCLS model assumes that the pdf of chords between fuel kernels has the exponential form

$$p(\lambda) = \frac{1}{\bar{\lambda}} \cdot \exp(-\frac{\lambda}{\bar{\lambda}}) \ , \qquad (1)$$

where $\bar{\lambda}$ is the average chord length in the matrix material. Based on a method described in [3], $\bar{\lambda}$ was determined empirically for this model to be 0.9154 cm.

RESULTS

Table I shows the k_∞ results for the four cases. Also shown are the Figure of Merit Ratios for each case. The Figure of Merit ratio for a given case is defined as the FOM for that case divided by the FOM for the explicit case.

TABLE I. Summary of Results.

Model	k_∞ *	FOM Ratio **
Explicit	1.7261 (6)	1
Lattice [4]	1.7226 (27!)	***
Lattice	1.7233 (6)	15.1
Chord Length Sampling	1.7256 (6)	43.6
Homogenized	1.6363 (7)	57.9

* 1 standard deviation uncertainty on last digit in parentheses
** Figures of Merit are relative to explicit case
*** Figure of Merit not reported
! Confidence Interval on uncertainty not given

The lattice model of [4] was recreated to verify the model information, and both lattice results are in close agreement. The model with a homogenized matrix region underpredicts k-effective by 8%. This result is consistent with a similar comparison made by Gurevich [2] and illustrates how badly simple homogenization works for this model.

The explicit case and the LCLS case agree within statistics, but both are greater than the Lattice benchmark by approximately 0.003. Both models simplify the true kernel distribution, and it may be that the true k-effective is bounded by the lattice model and the explicit model. Since both models are acknowledged as approximations, if the difference between them is considered acceptable, then the LCLS method may be attractive due to its simplicity and speed advantage over the lattice model.

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