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Application of the RPT Method to Diluted Kernel TRISO Fuel

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INTRODUCTION

The Reactivity-equivalent Physical Transformation (RPT) method.[1,2,3] has been developed to handle the double-heterogeneity of TRISO fuels used in HTGRs. In the RPT method, the original double-heterogeneous problem is transformed to a conventional single-heterogeneous one: fuel particles are dispersed in a smaller fuel zone with a higher packing fraction and a smaller surface area, and then the new fuel region is simply smeared. (See Fig. 1) The fuel radius (RPT radius) is determined such that the neutron multiplication factor is equivalent to the reference value. By using the RPT method, a complex double-heterogeneous problem can be easily analyzed with the well-matured conventional methodologies. The RPT method has been shown to work very accurately for conventional TRISO fuels with a concentrated fuel kernel. In this paper, the RPT method is applied to an unusual TRISO fuel with a diluted kernel.[4]

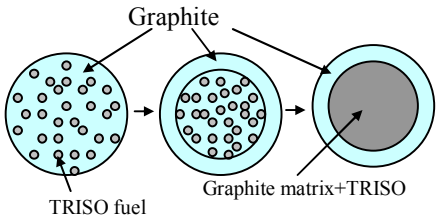

Fig. 1. The RPT concept.

TRISO WITH A DILUTED KERNEL

A diluted kernel was originally developed for a plutonium TRISO fuel. Figure 2 depicts the concept of a carbon-diluted kernel.

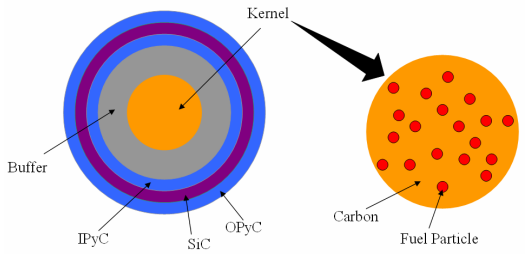

Fig. 2. TRISO with a diluted kernel.

In a diluted kernel, very small fuel particles (10~40μm diameter) are dispersed in a carbon matrix with a small volume fraction. Compared with a concentrated kernel, a diluted kernel has a one more heterogeneity. Therefore, it is very difficult to analyze TRISO with a diluted kernel by using conventional methods.

In this paper, an LWR $TRUO_2$ fuel is used as the fuel particles and the following specific design parameters are used: diameter of fuel particles=30μm, volume fraction of fuel particles in kernel=20%, kernel diameter=300μm, density of carbon matrix=1.70g/cm^3. The coating thicknesses are as follows: buffer=100μm, inner PyC=35μm, SiC=35μm, outer PyC=40μm.

As a model problem, a hexagonal unit cell of a prismatic HTGR is considered, which is shown in Fig. 3.

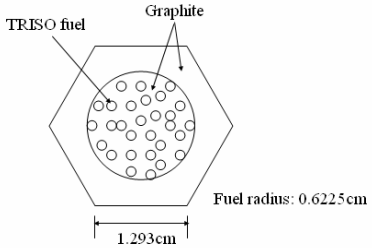

Fig. 3. Configuration of a unit cell problem.

The fuel packing fraction of TRISO particles is 35% and a helium gap of 0.0125 is also modeled between fuel compact and graphite block. It is assumed that all the materials are at a constant temperature of 1200°K. All neutronic calculations are performed with the continuous energy Monte Carlo code MCCARD[5].

DETERMINATION OF THE RPT RADIUS

Taking into account the randomness of both TRISO and fuel particles, the reference k-infinity value of the original problem was calculated by MCCARD and it is 1.03947±0.00020. Figure 4 shows the reactivity as a function of the effective fuel radius. An effective fuel radius of 0.6225cm corresponds to a simple VWH (volume-weighted homogenization) since it is the radius of the fuel compact. As shown in Fig. 4, the double-heterogeneity of the problem is very large, ~7144pcm. It is observed that the reactivity shows a linear relationship with the effective fuel radius, which was observed in conventional concentrated kernels, too. The linear relationship makes it very easy to determine the RPT

radius. The RPT radius is found to be 0.3928cm corresponding to a new packing fraction of 88.2%.

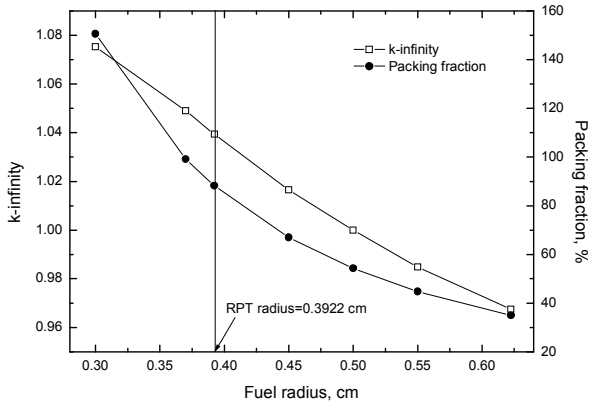

Fig. 4. Reactivity vs. effective fuel radius.

Figure 5 show the sensitivity of the RPT radius to the material temperature. The RPT radius for 1200°K was applied to other temperatures. One can see that the RPT radius is very insensitive to the temperature and the agreement is extremely good over the temperature range of 300~1500°K. In Fig. 5, the standard deviation of k-infinity is less than 0.00020. Similar behaviors were also observed in TRISO fuels with a concentrated kernel.

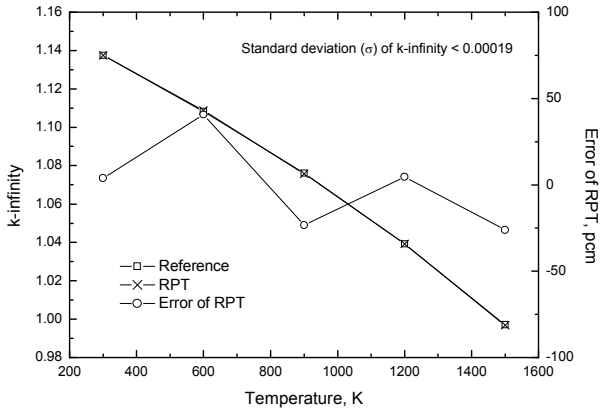

Fig. 5. Impact of temperature on the RPT radius.

DEPLETION ANALYSIS

Monte Carlo depletion calculations were performed to check the validity of the RPT model during fuel irradiation. For the reference model, each TRISO particle was independently modeled in the depletion analysis. In the case of the RPT model, the RPT radius for the fresh condition is applied to all burnup conditions. Figure 6 shows the results.

It is clearly seen that the RPT model provides very accurate solutions over the whole fuel burnup range, while the VHW model shows huge errors. Error of the RPT model is within 100pcm even up to a burnup of 700 GWD/tHM. The scattered behavior of the error is due to stochastic features of the Monte Carlo solution.

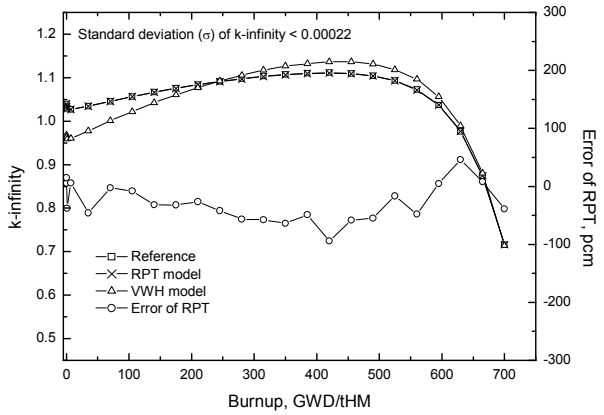

Fig. 6. Accuracy of RPT model during fuel irradiation.

CONCLUSIONS

The RPT method has been applied to a multiple-heterogeneous TRISO fuel with a carbon-diluted kernel. The RPT radius can be determined easily since the reactivity changes linearly with the effective fuel radius. The RPT radius is extremely insensitive to the fuel temperature and it can be used over a wide range of fuel temperature. In addition, an RPT model determined at zero-burnup condition can be utilized during fuel irradiation up to a very high burnup with a very good accuracy.

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