Migration of Fission Products in a Tri-Isotropic-Coated Fuel Particle

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1. Introduction

A tri-isotropic(TRISO)-coated fuel particle of a high temperature gas-cooled reactor (HTGR) generates power and fission products in its kernel during a reactor operation. Some part of the fission products generated migrates into a fuel element and then a coolant. The TRISO-coated particles are major source of fission products in a HTGR if there is no fuel contamination. It is necessary in the analysis of the fission product migration in a HTGR to evaluate quantitatively the release rate of the fission product from a TRISO particle. This study set up a numerical model calculating a fission product transport in a TRISO particle.

2. Modeling for Fission Product Transport

The TRISO-coated fuel particle consists of a fuel kernel, a buffer layer, and three coating layers as shown in Fig. 1. The coating layers are an inner pyrocarbon (IPyC) layer, a silicon carbide (SiC) layer, and an outer pyrocarbon (OPyC) layer. The fission products are generated through a fission and a recoil in the kernel. They move to the inner surface of the IPyC layer through the buffer pore very fast. Some of the fission products penetrate the coating layers.

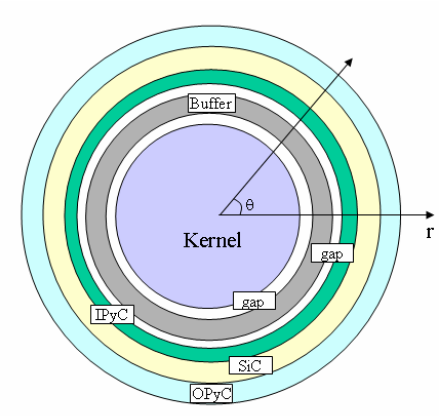

Fig. 1. A TRISO-coated fuel particle.

The major transport mechanism of the fission products within the TRISO particle is a diffusion and a trapping. The trapping process, however, is not considered in this study because it is very complicated. The diffusion process can be described by the following Fickian diffusion equation [1].

$$\frac{\partial C^{(i)}(r,t)}{\partial t} = B^{(i)}(r,t) - \lambda C^{(i)}(r,t) + \frac{1}{r^2}\frac{\partial}{\partial r}\left[r^2 D^{(i)}(r,t)\frac{\partial C^{(i)}(r,t)}{\partial r}\right], \quad (1)$$

$$\left[-D^{(K)}\frac{\partial C^{(K)}}{\partial r}\right]_{r=0} = 0\ , \quad (2)$$

$$C^{(i)} = \phi_{i,i+1} C^{(i+1)}\ , \quad (3)$$

$$\left[-D^{(i)}\frac{\partial C^{(i)}}{\partial r}\right]_{r=r_i} = \left[-D^{(i+1)}\frac{\partial C^{(i+1)}}{\partial r}\right]_{r=r_i}\ , \quad (4)$$

$$C^{(i)}(r_O,t) = 0\ , \quad (5)$$

$$C^{(i)}(r,0) = 0\ , \quad (6)$$

where i = layer (K = kernel, B = buffer, I = IPyC, S = SiC, O = OPyC), C = concentration (μmol/cm^3), B = birth rate (μmol·s^{-1}·cm^{-3}), D = diffusion coefficient (cm^2/s) = D_0 exp(-E/(RT)), D_0 = pre-exponent factor of a diffusion coefficient (cm^2/s), E = activation energy (J/mol), R = gas constant (8.314 J/(mol·K)), T = temperature (K), λ = decay constant (s^{-1}), r = radial coordinate (cm), t = time (s) , ϕ = partition factor. The initial concentration is zero over the entire region. The concentration at the particle surface is always zero because the fission products diffuse through the pore of a fuel element very fast.

A finite difference method was used to solve Eqs. (1) to (6) [2]. Each layer was divided into $N^{(i)}$ intervals, respectively. It is assumed that the diffusion coefficient and birth rate is dependent on the time only within each interval.

3. Estimation of a Fission Product through a Pebble

The data for calculating the Sr^{90} release from a TRISO-coated particle is shown in Table 1 [3]. The birth rate was assumed to be constant throughout the kernel and was zero in the buffer and coating layers. A large number was chosen as the value of the diffusion coefficient in the buffer in order to express a rapid diffusive transport. Temperature was assumed to be constant throughout the particle for a simple calculation.

Fig. 2 shows the concentration evolution of Sr^{90} in a coated particle at 1290 °C. The concentration is flat in

the fuel region, which is due to a uniform source distribution. The concentration increases with time. Fig. 3 displays the release of Sr^{90} from the particle surface at 900, 1000, and 1290 °C. The release amount also increases with the temperature.

Table I. Data for calculating Sr^{90} migration

Data		Values
B (μmol/(cm^3·s))		7.8×10^{-9}
D_0 (cm^2/s)	UO_2	32
	Buffer	1
	PyC	2.3×10^{-2}
	SiC	1.2×10^{-5}
E (J/mol)	UO_2	488000
	Buffer	0.
	PyC	197000
	SiC	205000
ϕ	UO_2 - buffer	1
	Buffer-IPyC	1
	IPyC-SiC	2
	SiC-OPyC	1

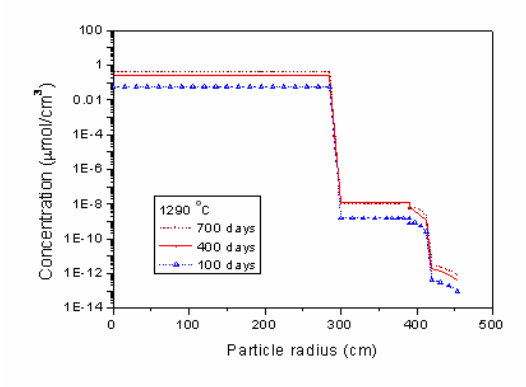

Fig. 2 Sr^{90} concentration evolution in a coated particle at 1290 °C

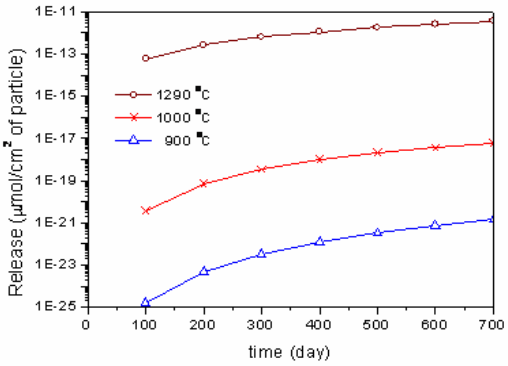

Fig. 3 Sr^{90} release from a coated particle

4. Conclusion

A computer program using a finite difference method was developed to estimate the transport of fission products through a TRISO-coated fuel particle. The program described the effects of the time and temperature on the release of Sr^{90} very well. The developed numerical scheme can be applied to the source term estimation for the analysis of a fission product migration in a HTGR fuel element.

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