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Fission Product Releases from a Two-region UCO Kernel of an HTR Coated Fuel Particle

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1. Introduction

UCO is one of kernel materials of a coated fuel particle of a high temperature reactor (HTR). The UCO kernel is a mixed UO_2 and UC_x for a reduced CO pressure. The image analyses of UCO kernels show that the fabricated UCO kernels have an inner mixed oxide and carbide region and an outer UO_2 rind region [1,2]. The different thermal conductivities of oxide and carbide and the different diffusivities of fission products in oxide and carbide affect the behaviors of fission product releases (FPRs) from the UCO kernel. This study examines the behaviors of FPRs from a UCO kernel with two distinct regions.

2. Characteristics of a UCO kernel

Fig.1 shows a segmented UCO kernel [2]. It consists of an inner mixed UO_2 and UC_x region and an outer UO_2 shell.

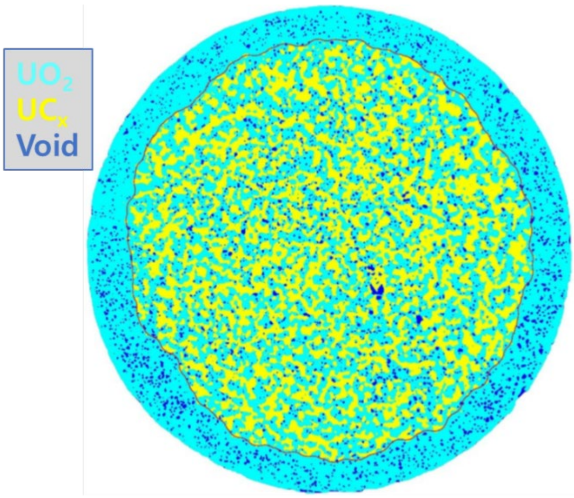

Fig. 1. A segmented UCO kernel.

Ref. [3] provides a thermal conductivity correlation for UO_2. The thermal conductivity calculated using the correlation is shown in Fig. 2. Due to the lack of relevant UCO data, the thermal conductivity correlation of UO_2 is assumed valid for UCO. The diffusivity of a fission product in a kernel can be expressed by the following Arrhenius-type equation:

$$D = \sum_i D_{0,i} e^{-\frac{Q_i}{RT}} , \qquad (1)$$

where D is the diffusivity (m^2/s), D_0 is the pre-exponential factor (m^2/s), Q is the activation energy (J/mol), R is the gas constant (8.314 J/mol K)), T is the temperature (K). Table I presents the pre-exponential factor and activation energy related to the diffusivity of Ag, Cs, Sr, Kr in UO_2 [4].

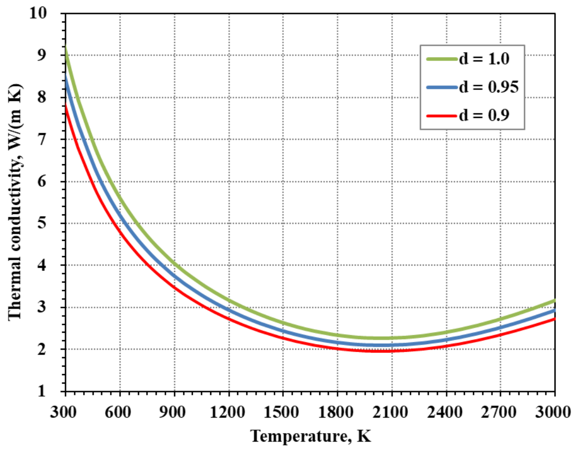

Fig. 2. UCO thermal conductivities according to a fractional density (d).

Table I: Diffusivity Parameters of Fission Products in UO_2

Fission product	$D_{0,1}$ m^2/s	Q_1 J/mol	$D_{0,2}$ m^2/s	Q_2 J/mol	Note
Ag	6.70×10^{-9}	165000			
Cs	5.60×10^{-8}	209000	5.20×10^{-4}	362000	
Sr	2.20×10^{-3}	488000			
I, Xe, Kr	1.30×10^{-12}	126000			[a] NOC
	8.80×10^{-15}	54000	6.00×10^{-1}	480000	[b] AC

[a] Normal operation condition
[b] Accident condition

3. Calculation of FPRs

The considered fission products are silver, cesium, strontium, and krypton. A UCO kernel diameter is 425 μm. The considered thicknesses of an outer UO_2 shell of a UCO kernel are 5, 10, 15 μm. No retention of fission products in UC_x was assumed. The diffusivity of a fission product in the inner mixed region of a UCO kernel becomes:

$$D_{UO_2+UC_x} = \frac{1}{\frac{f}{D_{UO_2}} + \frac{1-f}{D_\infty}} , \qquad (2)$$

where f is the fraction of UO_2 phase and D_∞ is the very big diffusivity (usually 1×10^{-6} m^2/s). This study assumes that the fraction of UO_2 phase is 0.65 and the temperature at a kernel surface is 1000 ℃. The COPA code [5] calculates the FPRs.

4. Calculation Results

Fig. 3. shows the temperature distribution in a kernel. The assumption that UO_2 and UCO have the same thermal conductivity produced the same temperature distribution. Figs. 4 to 7 show the concentration distributions of ^{110m}Ag, ^{137}Cs, ^{90}Sr, ^{85}Kr in a kernel. The concentrations increase with rind thickness. They drop sharply at the interfaces between a UO_2 and UC_x region and an outer UO_2 rind. Figs. 8 to 11 show the fractional releases of ^{110m}Ag, ^{137}Cs, ^{90}Sr, ^{85}Kr from a kernel. The fractional releases decrease with rind thickness. According to Eq. (2), the diffusion of fission products in the UO_2 and UC_x phase is greater than one in UO_2 phase. The diffusion is delayed in the outer UO_2 rind. Strontium has the greatest retention effect due to the UO_2 rind

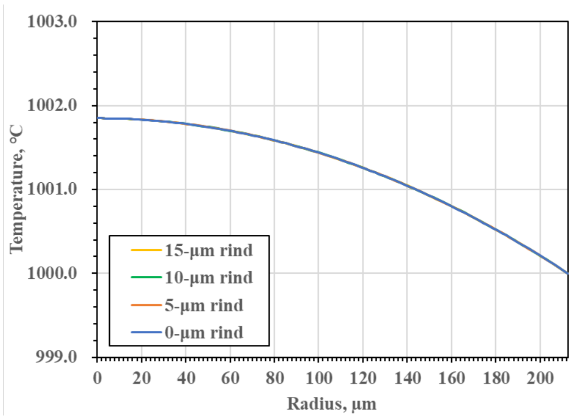

Fig. 3. Temperature distribution in a kernel.

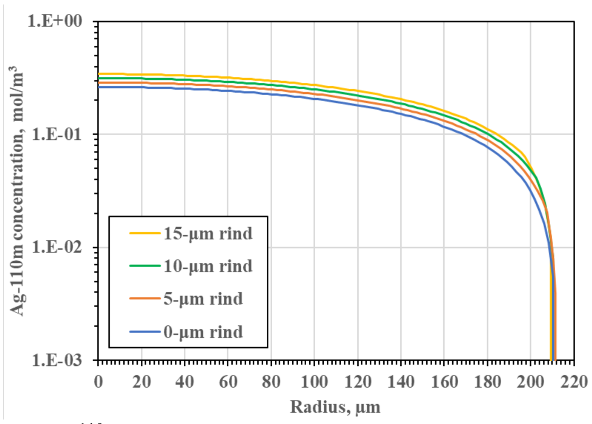

Fig. 4. ^{110m}Ag concentration distribution in a kernel.

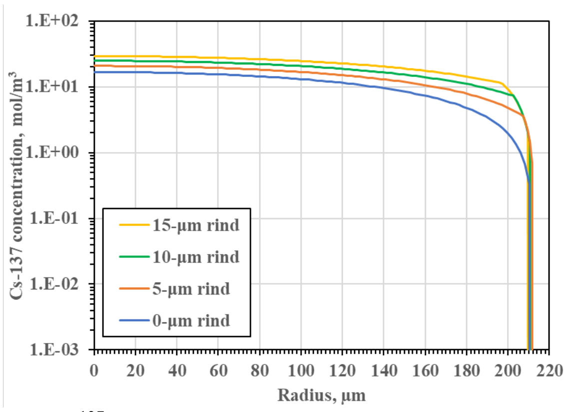

Fig. 5. ^{137}Cs concentration distribution in a kernel.

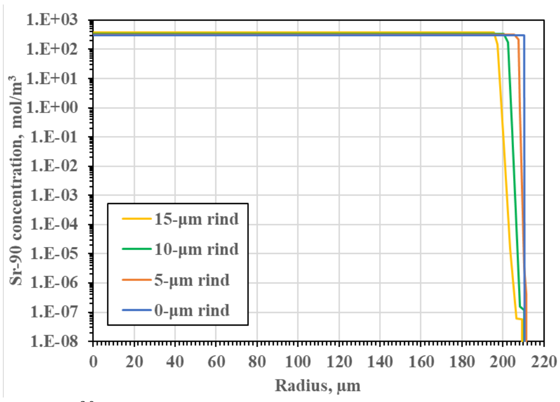

Fig. 6. ^{90}Sr concentration distribution in a kernel.

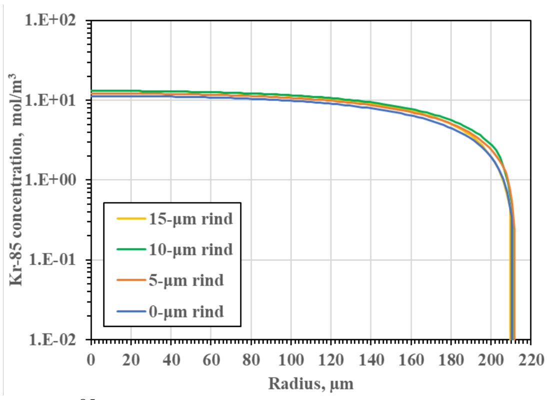

Fig. 7. ^{85}Kr concentration distribution in a kernel.

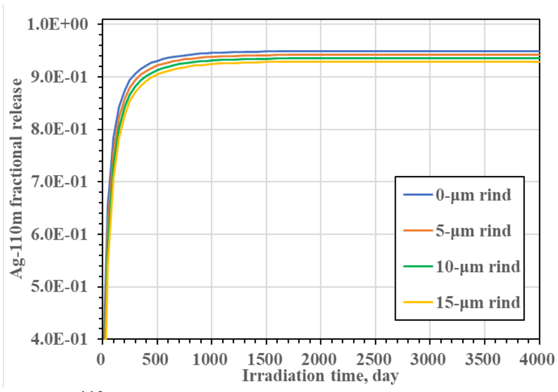

Fig. 8. ^{110m}Ag fractional release from a kernel.

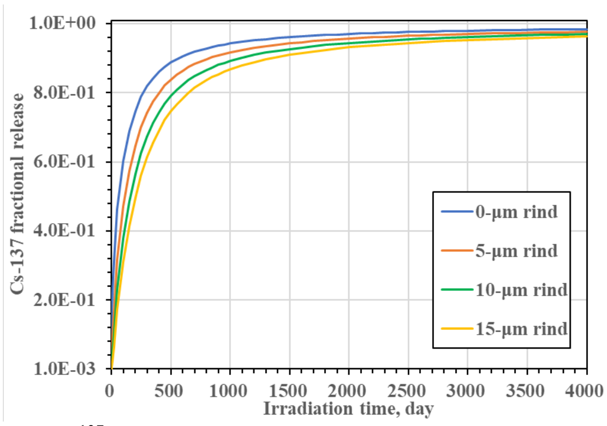

Fig. 9. ^{137}Cs fractional release from a kernel.

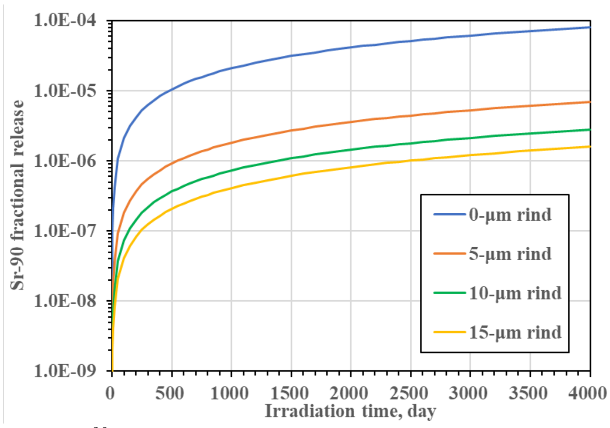

Fig. 10. ^{90}Sr fractional release from a kernel.

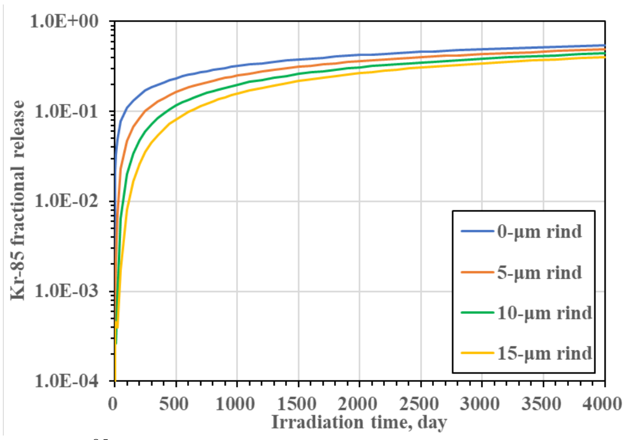

Fig. 11. ^{85}Kr fractional release from a kernel.

5. Summary

The release behaviors of ^{110m}Ag, ^{137}Cs, ^{90}Sr, ^{85}Kr from a two-region UCO kernel having an inner mixed oxide and carbide and an outer UO_2 rind have been examined. The concentrations increase with rind thickness and they drop sharply at the interfaces between the two regions. The fractional releases decrease with rind thickness. The diffusion slows down in the outer UO_2 rind. Strontium has the greatest retention effect due to the UO_2 rind

ACKNOWLEDGEMENTS

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